N O T I C E

Remotely Piloted Vehicle: Application of the GRASP Analysis Method

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GENERAL RELIABILITY ANALYSIS SIMULATION PROGRAM

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SUMMARY

This is a consolidation of the preliminary work done in the application of a General Reliability Analysis Simulation Program (GRASP) for the Lockheed Remotely Piloted Vehicle (RPV) system, being developed for the United States Army.

The model simulates the field operation of the RPV system. By using individual component reliabilities, the overall reliability of the RPV system is determined. The results of the simulations are given in operational days. The model represented is only a basis from which more detailed work could progress.

The RPV system in this model is based on preliminary specifications and estimated values. The scope of this report demonstrates the use of GRASP from basic system definition, to model input, and to model verification.

INTRODUCTION

This report is a consolidation of the preliminary work done in the application of a General Reliability Analysis Simulation Program (GRASP) for the Lockheed Remotely Piloted Vehicle (RPV) system, being developed for the United States Army.

This paper demonstrates the process used to create the RPV model, to change the model into the RPV data set, to validate the RPV model/data set, and the steps necessary to interpret the output. The results of the GRASP simulation are expressed in successful operational days. A successful operational day is defined as the completion of three 3-hr mission flights in a 12-hr period. Each simulation begins with five new air vehicles and all ground equipment in operational status.

The conclusion of the report emphasizes the versatility of using GRASP, and the status of the RPV data sets.

ABBREVAITIONS

ADT   air data terminal (part of MICNS communications package)
AF   air frame
ARA   air reference assembly
AV   air vehicle
AVIM air vehicle intermediate maintenance
AVO   air vehicle operator
AVOC air vehicle operator console
AVUM air vehicle unit maintenance
EPS   electrical power system
FCEP flight control electronics package
FLT   flight
GCS   ground control station
GCSIU GCS interfacing unit
GEN   generator
GRASP generalized reliability analysis simulation program
GSE   ground support equipment
IR   infrared (landing system)
LA   launcher assembly
LMSC Lockheed Missiles and Space Company
LRU   line-replaceable units
MAIM main GCS computer
MC   mission commander
MCO   mission commander operator
MCOC mission commander operator console
MICNS modular integrated control navigation system
MP   mission payload
MPC   mission payload operator console
MPO   mission payload operator
MPS   mission payload subsystem
MS   maintenance shelter
MTBF mean time before failure
NAV   navigation
NPV   navigation display unit
PROP propulsion assembly
REC   recovery subsystem
RGT   remote ground terminal
RPV   remotely piloted vehicle
TTF   time to fail
TTR   time to repair

GRASP II COMPUTER PROGRAM REVIEW

GRASP II (Version II) is a Fortran-based computer program which can simulate a reliability-based system operation consisting of time and cost. GRASP is a method by which a system can be represented by certain parameters and logical relationships, and be shown graphically as a network diagram presenting the reliability configuration of that system.

In order for a model to be developed, certain building blocks must be understood. GRASP network diagramming is based on two basic elements: nodes and arcs. Nodes are events in the system, such as a failure of a component, end of a repair, or completion of any other type of activity. Nodes are denoted by circles in which N1 is the number of pulses needed to release the node the first time and N2 is the number of pulses needed to release the node at subsequent times. Arcs, or branches, represent time-consuming activities, such as time-to-fail (TTF), time-to-repair (TTR), or any event precedence relationship in the system. Event precedence relationships have no duration, that is, they occur instantaneously. (See figure 1 for examples of nodes and arcs.)

This is a basic look at the GRASP network diagram. Further information can be obtained from the GRASP Users Manual, and it is recommended that the reader review and become familiar with GRASP if a more detailed discussion is required.
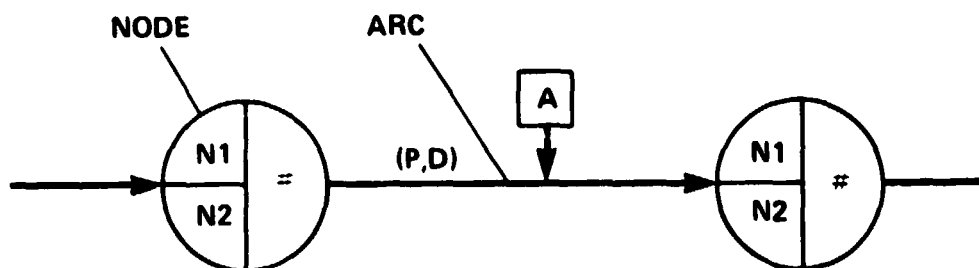

Figure 1.- Arc and node diagram.

COMPOSITION OF THE LOCKHEED RPV SYSTEM

The Lockheed RPV system consists of several components. These components divide the RPV system into key factors from which a network model can be made. In the following discussion, the overall mission function is first explained and then the individual components are described as they relate to the system.

The RPV system, as addressed in this report, is a combination of hardware and mission function. The hardware consists of mobile ground units used to support the air vehicles (AV) and the five AV's used for mission function.

The mission function consists of spotting and designating targets. The steps in this process include the prelaunch check (making sure all systems are working); the climb-out; the outbound flight; the mission stage where targets are found and identified; the inbound flight, which is similar to the outbound flight; and the recovery of the AV. The mission occurs between the outbound and inbound flight segments.

The hardware consists of seven mobile ground units:

1. Launcher truck
2. GCS (Ground Control Station)
3. Recovery truck
4. MS (Maintenance Shelter)
5. Crane truck (truck carries two AV's)
6. AV truck (truck carries three AV's)
7. Pickup truck

Trailers for transporting the Remote Ground Terminal (RGT) and two generators are also required.

The GCS controls the AV while the AV is in flight. It can also perform the checkout during prelaunch and monitor tests during a mission flight. The MS (Maintenance Shelter) is a field workshop for repairing the AV's, GCS, RGT, generators, launcher, and recovery truck.

The following description of the RPV system provides a working knowledge of the basic system characteristics as they relate to this report; it is public information, having been published in Aviation Week and Space Technology (vol. 112, no. 2, Jan. 7, 1980, pp. 54-63).

The major areas of reliability concern are between stages C to F (fig. 2), where C to D to E is system checkout, E to F is AV flight and mission operations, and F to "or" is the recovery of the AV. Although factors of emplacement leading up to state C can be modeled, a limit must be placed on the size of the RPV system being modeled by GRASP; therefore, the system of emplacement has been disregarded.

An objective of the model analysis is to simulate the operational limits of a fielded RPV unit, that is, how many days can the system operate (successfully) from a fresh start, where a successful day is defined as three successful mission flights being performed within a 12-hr period. Thus the RPV system baseline model revolves around prelaunch and flight of the AV's.

The day begins with an AV on the launcher ready for its prelaunch check. If it is determined that the AV fails the prelaunch check, the prelaunch is aborted. The model will start a removal (time 15 min) of the bad AV from the launcher and replace it (in 15 min) with a good AV from the ready-pool. If

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Figure 2.- Functional baseline.
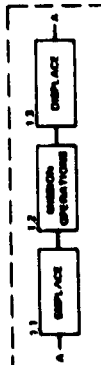
the GCS or any other ground equipment fails and causes the launch to be aborted, the model aborts and waits until the failed component is fixed. Upon repair the model begins a new prelaunch check.

The GRASP model cannot detect multiple failures at a single time. For example, if the GCS and a generator fail at the same time, the GRASP selects the one that was coded in first into the program and selects that particular one as the failed component. In any case, this is not a problem because the failure rates are low to start with.

Using the above example, another assumption, based on low failure rates, is that if the GCS and generator fail at the same time, they go into repair at the same time. The modeled RPV system has only one Maintenance Shelter (MS) and multiple repairs are handled on a sequential priority basis.

The key functional paths used in the model are diagrammed in figure 3, which shows how the AV's are used in the system.
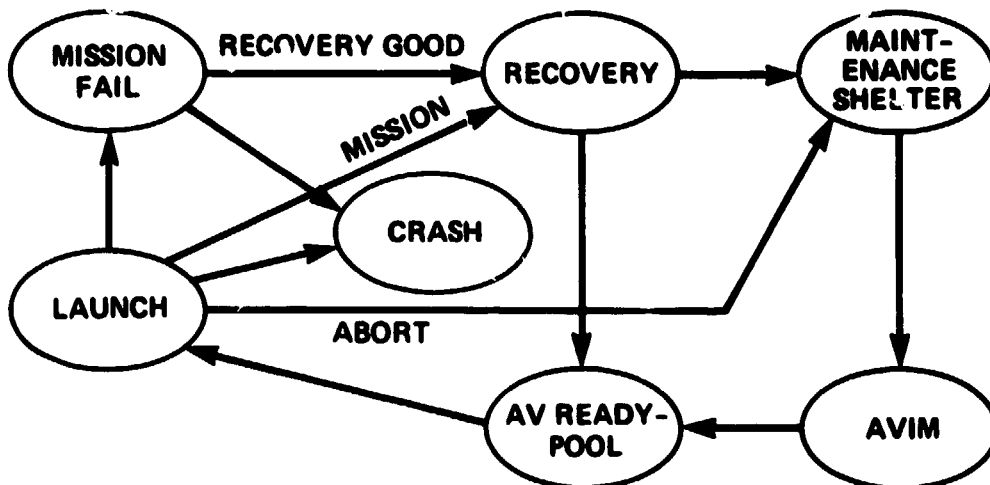

Figure 3.- Functional paths.

After being provided with some initial assumptions, a meeting was held wherein more refined assumptions were incorporated into the model. Those assumptions are listed below:

1. If GCS main computer fails during a mission, the mission is aborted and inbound and recovery paths are set up. Note that the recovery operates at lower values.

2. The laser is needed for the mission and is only used during the outbound flight for position updating.

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3. The recovery stage of the mission flight can be successful with IR or MPS recovery systems. Note that only MPS is used when IR is down.

4. If a subsystem goes down, it goes into repair without delay. (Example: AV, GCS, RGT, GSE, LA, Recovery.) The probability of more than one subsystem being down at the same time is low.

5. Launcher and Recovery hardware will only fail in an active state.

6. GSE refers explicitly to power generators. Note that the remote ground terminal has its own generators.

7. Of the three different maintenance systems, each exhibits its own characteristics for isolation of problems.

A chart was made up showing the reactions of the possible failed components during possible events. This provided a framework upon which the complete RPV system was composed into functional elements. A GRASP network diagram is constructed from table 1. This topic will be discussed in the next section.

BUILDING OF THE GRASP NETWORK

In the previous section the RPV system was broken down into functional elements. The idea was to represent these functional elements as nodes (events) and arcs (timed activities). The key hardware elements are the AV, GCS, RGT trailer, generators, launcher assembly truck, and recovery truck.

For the reliability model and GRASP network model, the AV will be represented by seven subsystems.

1. MP: mission payload
2. FCEP: flight control electronic package and flight sensor package
3. ARA: air reference assembly
4. ADT: air data terminal
5. EPS: electrical power system
6. AF: airframe
7. PROP: propulsion assembly

Certain assumptions that pertain to the AV are described next. It was assumed that failure during prelaunch of any of the AV subsystems (1 through 7) would cause the launch to be aborted. This is then followed by removal of the failed AV (15 min) and its replacement on the launcher with a good AV from the ready-pool.

The AV subsystems were also modeled allowing for failure of the MP (mission payload) package during flight. This failure would result in the return of the AV with the proper sequencing time. Also, upon recovery of the AV with the failed MP, a reduced reliability of recovery occurs. Sequencing

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TABLE 1.- FAILURE MODES FOR SUBSYSTEMS

Failure	Action					
	Prelaunch	Launch climb-out	Outbound	Mission	Inbound	Resources
Two of three consoles[a]	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
One of three consoles[a]	Repair recycle	Recovery	Inbound/ recovery	Inbound/ recovery	Recovery	No effect
Navigation display unit[a]	Repair recycle	Recovery	Inbound/ recovery	Inbound/ recovery	No effect	No effect
Main computer[a]	Repair recycle	Recovery	Inbound/ recovery	Inbound/ recovery	No effect	Recovery degraded mode
GCS I/U[a]	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
Launcher hardware	Repair recycle	No effect	No effect	No effect	No effect	No effect
Recovery hardware	No effect	No effect	No effect	No effect	No effect	AV lost
GSE	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
RGT[a]	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
MPS/TV	Repair recycle	Recovery	Inbound/ recovery	Inbound/ recovery	No effect	IR only
Laser	Repair recycle	Recovery	Inbound/ recovery	Inbound/ recovery	No effect	No effect
FCEP	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
ARA	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
Propulsion	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
ADT	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
IR	Repair recycle	No effect	No effect	No effect	No effect	MPS landing

[a]10-min delay to determine if equipment cannot be placed back into operational status.

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time refers to the time needed for the return of an AV in the event of a failure. If the AV is on climb-out or outbound and a failure occurs, then the AV is returned. The time that the model has used to get the AV to the climb-out or outbound is assumed small. If the MP fails on the mission phase, then the model starts an inbound flight upon detection of the failure. Thus the 25-min period for the inbound flight is not negligible as was the case in the failure of the MP during climb-out or outbound flight.

The modeling of the other hardware elements is not as complicated as that of the MP. The AV subsystems are grouped together. As stated before, if any of these subsystems fail during the prelaunch, the launch is then aborted and AV replacement procedures are started. If the other items fail during flight (excluding MP) then the model will crash the AV at the time of failure and begin the launch of a new AV.

Upon successful launch of the AV, another AV from the AV ready-pool is placed on the launcher. This process is done so that if the AV in the air fails and crashes, then the AV on the launcher is ready for its prelaunch checkout.

During the mission flight the AV is continually checked as two separate systems: (1) the mission payload, and (2) items 2 through 7 above (p. 7). If any of these systems fail, the model will properly select the path for that failure to be recognized.

The GCS has 10 major subsystems for its model. Of these 10, only 6 are necessary for proper modeling: the three consoles, the GCS Interface Unit (IU), the navigation display, and the main computer.

The omission of the communications equipment is justified because there is adequate redundancy in that system and because the communications network does not directly affect the critical operation of either the RPV or AV.

The AVO (air vehicle operator) console, MPO (mission payload operator) console, and the MCO (mission commander operator) console are assumed to operate in a somewhat redundant fashion. That is, if one console fails then the AV can still be controlled (to a limited extent) and return of the AV is initiated. If two consoles fail, control of the AV cannot be maintained and the AV is lost. There is a 10-min timer that sets the limits for repair of the GCS and reestablishment of communications with the AV. These 10-min timers are not only for the consoles but also for other GCS subsystems in the model.

Of the six components used to model the GCS there are only two failures that result in loss of the AV: a two-console failure (as stated before) and loss of the GCS interface unit computer.

If a model component fails and is not sent immediately to repair, a repair facility is designated for that component. (Note that this is based on low failure rates.) For the GCS model, GRASP generates only one set of failure data at the start of the simulation. When a GCS subsystem fails,

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GRASP generates a new mean time between failure (MTBF) for that particular subsystem only, unlike the AV model in which a new set is derived for each flight at prelaunch.

If the GCS does go down and an AV is lost, the model waits until the GCS is back up (arc 141-142 value #31) before starting a prelaunch check (node 6 to start prelaunch at node 2). Node 6 monitors the status of the GCS from node 152. When node 6 releases then it is known that an AV is on the launcher and that the GCS is ready to do a prelaunch.

VERIFICATION PROCESS

As with any program, experience in debugging is an essential element when input errors or logic errors surface. Both errors are difficult to correct, but finding the logic errors seems to be more challenging. GRASP has an option that is very useful in finding these logic errors. It is called the trace option, as specified on the first input card. The trace option gives the user a printout of the step-by-step pulse actions that occur in the model.

After the model has been diagrammed, it must then be incoded in the proper order for input into the GRASP program. The best process for checking the input is a node-by-node, arc-by-arc review. This process is most effectively done by two persons: one to read the node from the network diagram and the other to check it off on the computer printout. This process checks for input errors that may have occurred.

Next, the trace option is employed to analyze the output and validate the pathway of the pulse. In validating the model, errors surface easily and can be identified quickly. In one example, the trace option located a misplaced arc, which was causing a pulse to split in two. After locating the problem, it was soon corrected. The trace option, furthermore, follows the logic pattern of the model, thus providing an easy way to check for logic errors.

SAMPLE INTERPRETATION

A total of 14 different model-system configurations were addressed, each evaluated on a nodal-observation basis. The frequency of a node's occurrence was recorded on a cumulative basis. Other information was provided such as minimum time of occurrence, maximum time of occurrence, and standard deviation. For our particular model, only the number of observations was important. Other features could be incorporated, but because of the simplistic nature of the model they were omitted. Thus the number of observations could be converted into the number of days the RPV system is operational. A sample run follows, which serves to demonstrate the method of interpretation.

Node	Number of observations
5	27
182	23
299	50

Number of observations (node 5) = 27
Number of simulations   = 100
                    27/100 = 27%

Nodes 5 and 182 show a system-failure situation, with the nodes indicating the cause or source of failure. Node 5 was observed 27 times in 100 simulations, indicating a 27-percent occurrence due to depletion of available air vehicles. Node 182 was observed 23 times, indicating a 23-percent occurrence due to incomplete 3-hr missions in the 12-hr periods. Node 299 (indicating successful missions) was observed 50 times in 100 simulations, showing 10 successful operational days without failure of the RPV system.

RECOMMENDATIONS

The system model discussed in this paper is only a base from which more detailed work could progress. Significant improvements might include:

1. Adding cost to the model. Although not specified in this report, additional cost requirements and values could be assigned after preliminary research.

2. Varying the mission time. This model uses a maximum time of 3 hr (plus 5 min prelaunch) to perform a mission scenario. A routine could be designed to vary the mission time between 1 hr and 3 hr.

3. Modeling the subsystems past the line-replaceable units (LRU's) to the board level or part level. This would provide far greater accuracy in the function and operation of the system.

4. Finding the average number of operational days. This model now determines the number of operational days until three successful flights cannot be completed within 12 hr. The model could be altered to determine, for example, that in 100 days, 80 are operational (i.e., producing successful missions) and 20 are failures.

At the conclusion of this project, additional features were requested from Lockheed, but there was no time to implement them. However, Lockheed suggested changing the failure rate for the AV subsystem so that a percentage of the failures would cause the AV to crash. Figure 4 shows the present failure monitor features of the AV subsystem, and figure 5 shows the effects of changing the features to accommodate a percentage of failures.

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The RPV system in this model is based on specifications and estimated values, and the reader should bear in mind that corrections of data values or modifications may be necessary as time goes on. It should also be noted that the status of the model presented in this report is by no means indicative of the operational status of the RPV system under development at LMSC.
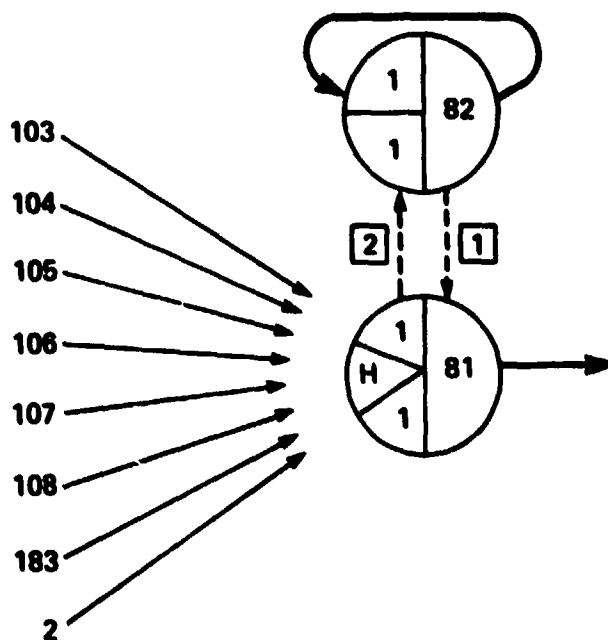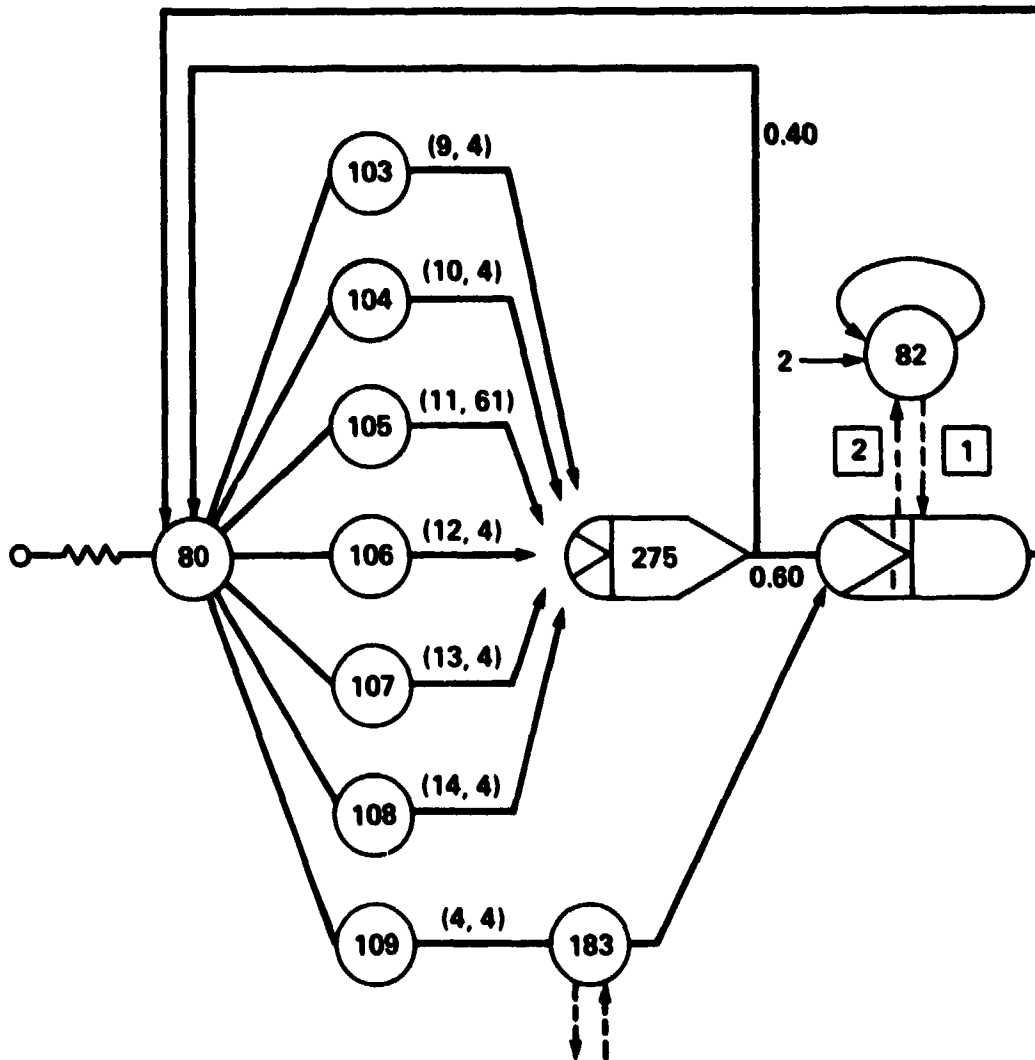

Figure 4.- Current AV subsystem.

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Figure 5.- Proposed modifications to AV subsystems.

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APPENDIX A

NODE DIAGRAMS

The node diagrams are a pictorial analysis of the GRASP-RPV model. The mainline model consists of figures 6-9. Figures 10-13 show other system and support equipment.

Figure 6.- Prelaunch, climbout.
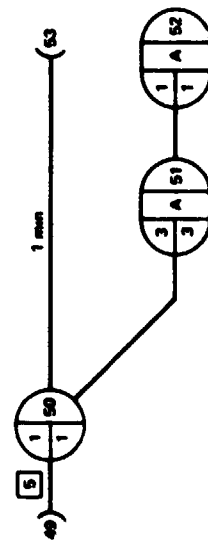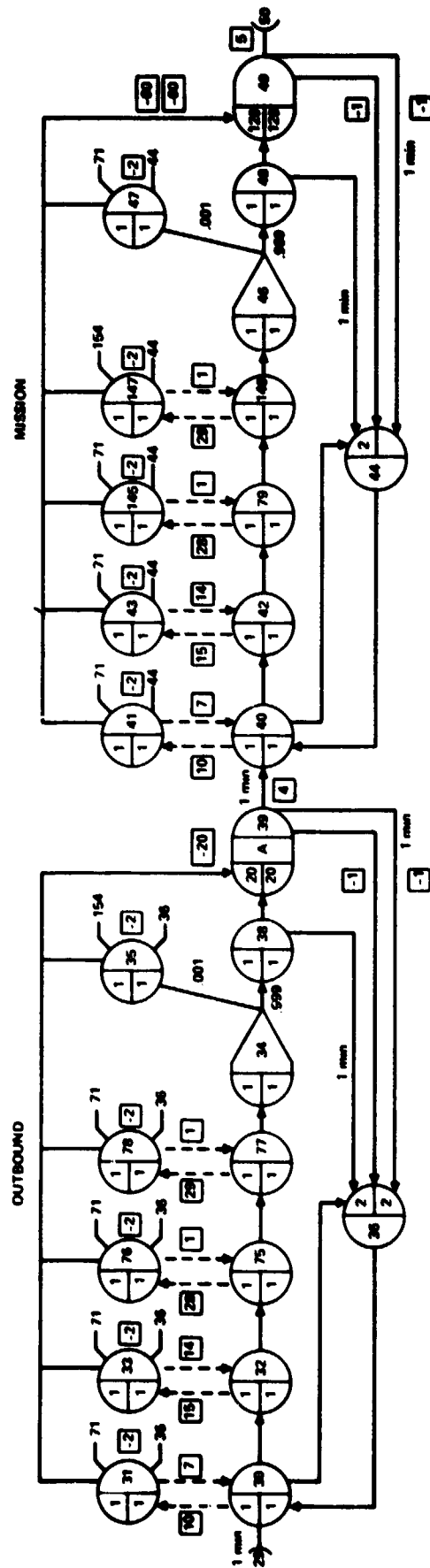
Figure 7.- Outbound, mission.
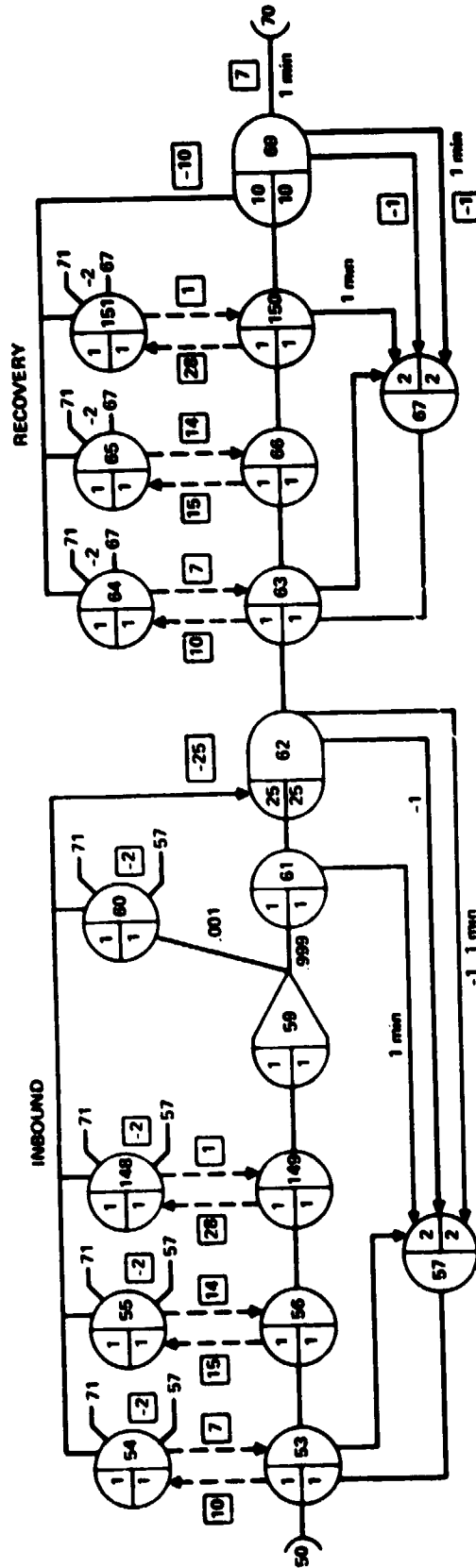
Figure 8.- Inbound, recovery.

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Figure 9.- Recovery, timer.

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Figure 10.- AV subsystem, ground equipment.
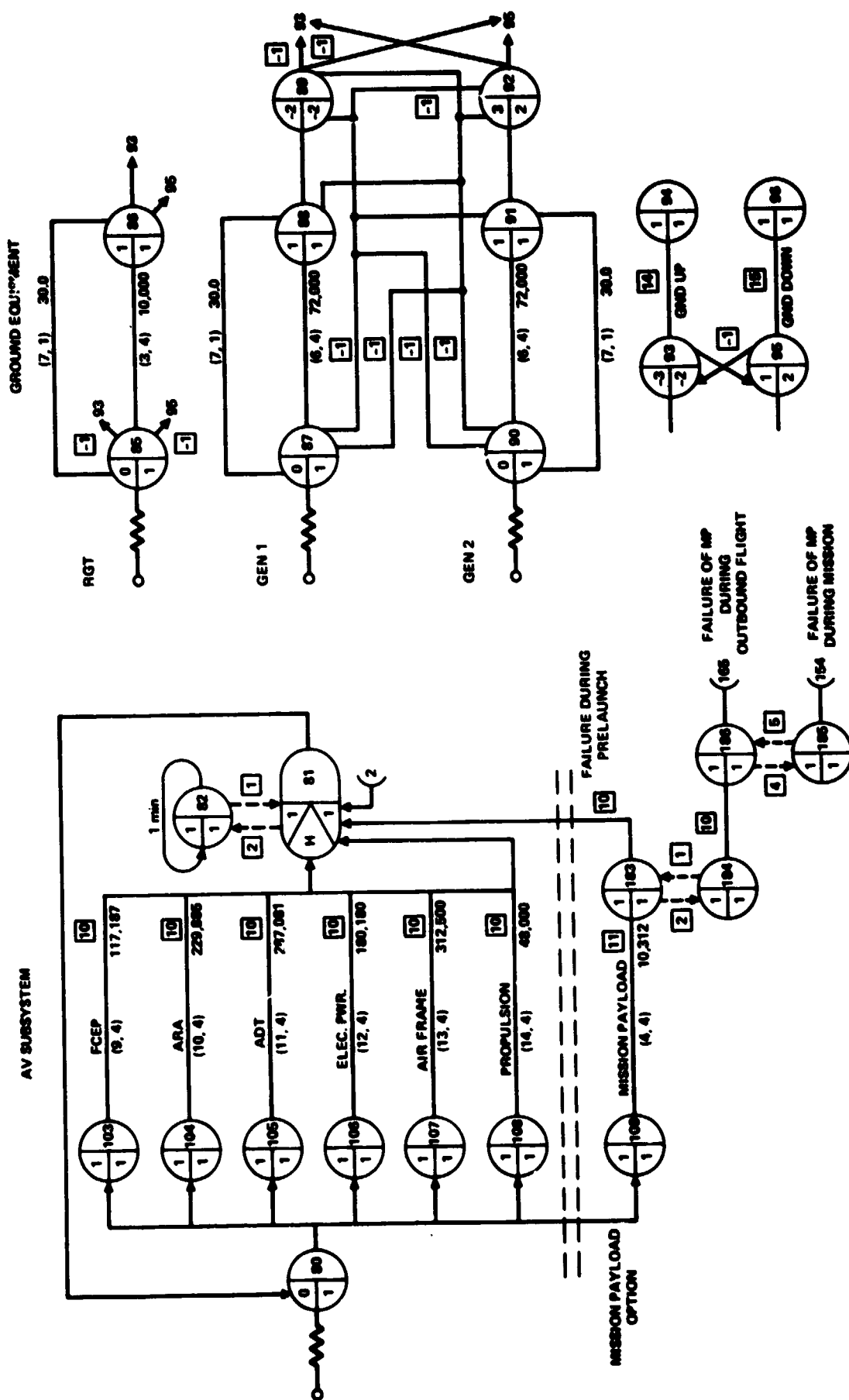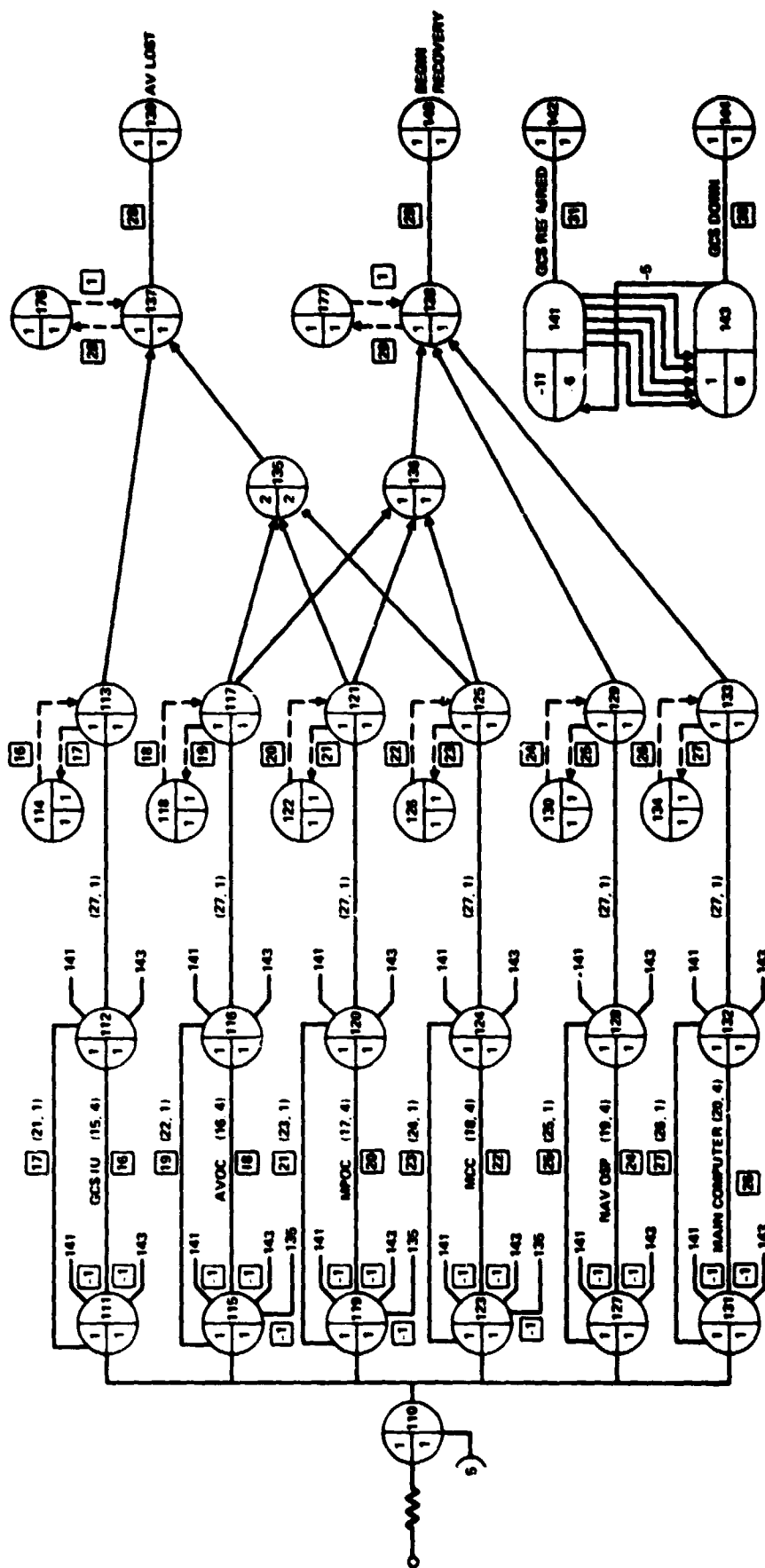
Figure 11.- GCS subsystem, ground equipment.

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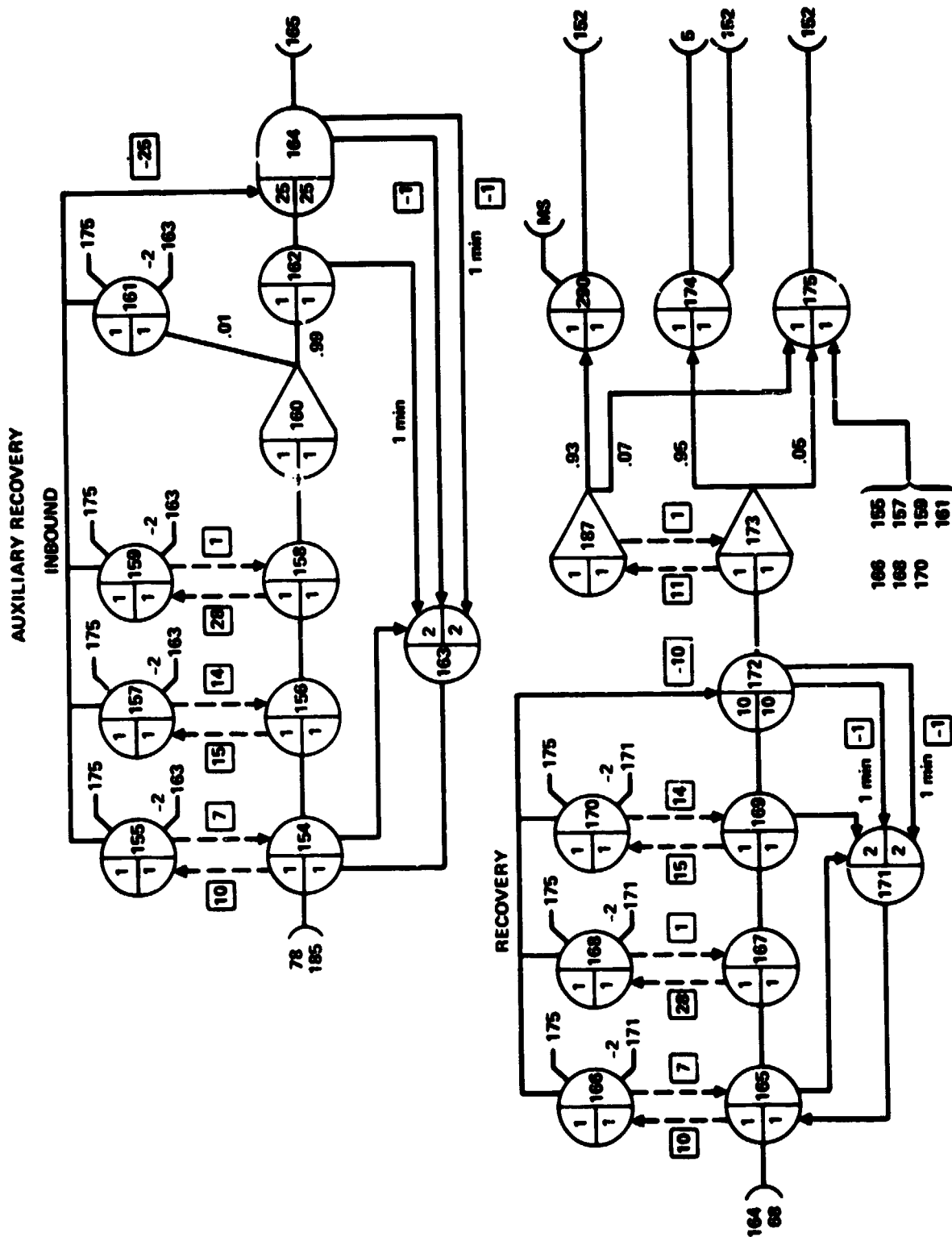
Figure 12.– Auxiliary recovery.

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Figure 13. Maintenance shelter plans 1, 2, 3.

APPENDIX B

NODE-ARC DESCRIPTIONS

This section describes the meanings for the nodes and arcs in the node diagrams. The section is categorized by node number with the description of the arcs following.

PRELAUNCH, CLIMBOUT (Figure 6)

Node	Significance
2	Indicates start of simulation, start of preflight/prelaunch check
	Arc 2-11: begins prelaunch check
	Arc 2-81: checks the AV for starting new distribution
3	Indicates abort required due to AV failure
	Arc 3-10: issues abort
	Arc 3-5: removes inoperative AV from launcher within a 15-min period
	Distribution 1, parameter 8
4	Indicates new AV from pool placed on launcher
	Arc 4-6: requires 15-min replacement period
	Distribution 1, parameter 8
	Arc 4-5: removes one AV from ready-pool
5	Indicates number of AV's used: N1 = 5, N2 = 5 (N2 indicates all AV's used; simulation over)
6	Indicates simultaneous readiness of GCS and of AV on launcher
	Arc 6-2: both GCS and AV ready for prelaunch check
7	Indicates prelaunch check stopped due to ground component failure (GEN & RGT); 15 performed but not 14
	Arc 7-178: ground equipment working
8	Indicates ground equipment not working; waiting for repair (14) from arc 93-94
	Arc 8-8: pulse cycling on 1-min
	Distribution 1, parameter 1; wait for repair
178	Indicates whether prelaunch was aborted due to GCS failure
	Arc 178-9: GCS backup
179	Indicates GCS still down in repair
	Arc 179-179: 1-min check — when GCS repaired, pulse transfers back to arc 178-9

9   Indicates junction (receiver node); ready to begin prelaunch
Arc 9-10:   updater arc to count aborts
Arc 9-2:   repairs finished, start prelaunch again

10   Indicates number of aborts during prelaunch due to AV, GCS, or
GND (nodes 12, 14, 26 respectively); aborts due to no-engine
start (node 19); and during a failed launcher (node 21)

11   Indicates prelaunch check of AV systems; if AV not working a
10 from 103-9 occurs, thus replacing 11 by 12

12   Indicates AV not working, 10 occurred in AV subsystem 103-9
Arc 12-15: update 1-min back counter (-2)
Arc 12-17: update 5-min front counter (-5)
Arc 12-6:   shows GCS still functioning
Arc 12-3:   starts removal and replacement of AV

13   Indicates whether ground equipment (GENs and RGT) is working —
if not, 15 occurs from arc 95-96, output of node 13 is
replaced by node 14
Arc 13-16: ground equipment working, continue prelaunch check

14   Indicates ground equipment failure (caused by 15 from arc 95-96),
stops prelaunch for repairs
Arc 14-17: update 5-min front counter (-5)
Arc 14-15: update 1-min back counter (-2)
Arc 14-7:   removal pulse to node 7, where node 7/8 releases
            pulse when ground equipment is repaired

16   Indicates whether GCS is working — if not, 30 from arc 143-144
replaces output of 16 with output of 26
Arc 16-17: indicates GCS working, updates node 17 and
            decreases 5 to 4, then 4 to 3, etc. (This
            is how 5 min are counted. If prelaunch time
            is changed to 10 min, then replace N1 and N2 of
            node 17 with 10)

Arc 16-15: 1-min loop back occurring 5 times results in
            5 min for prelaunch node 15 at 1 (due to 11);
            at 0, node releases and prelaunch starts again

26   Indicates GCS failure (caused by 30 from arc 143-144); pre-
launch stopped for repairs which puts node 26 with 16
Arc 26-17: update 5-min front counter (-5)
Arc 26-15: update 1-min back counter (-2)
Arc 26-7:   GCS failure, waits at 7 until GCS repaired
            (actually, 7 moves to 178, but model waits
            at 179, continues check until GCS is ready)

Node	Significance

15   Indicates reset of 1-min counter if prelaunch aborted by 12,
14, 26, or 17 (when released)
Arc 15-11: start prelaunch again

17   Indicates the number of 1-min checks that have been made (if
prelaunch becomes 10 min, change N1 and N2 to 10)
Arc 17-18: prelaunch acceptable, attempt to start engine
Arc 17-15: update 1-min counter to stop

Indicates another prelaunch check — if another item needs to be
checked during prelaunch, follow same format; arc 13-16 includes
possibility for failure as represented by dotted lines, and must
have repair status like GCS 31 . Also,

1) Update 17 with -5
2) Update 15 with -2
3) Divert to 7 to create failure similar to GCS
4) Place operating up and down between Arc 7-178

18   Indicates engine start, a probablistic node in that the engine
may or may not work
Arc 18-20: the probability of the engine working .999 defined on arc
Arc 18-19: the probability of the engine not working .001 defined
              on arc

19   Indicates engine did not start, AV failed on launcher
Arc 19-3: start abort and replacement of AV

20   Indicates engine working, the command is given for the launch of AV
Arc 20-21: launcher failed .001, needs 15-min to repair
Arc 20-22: launcher worked, AV in air, .999, mission flight has begun

21   Indicates launcher failed but has been fixed now due to the 15 min
along arc 20-21
Arc 21-9: count as abort so that another prelaunch can begin

22   Indicates launcher worked, AV in air and mission flight has begun
Arc 22-4: start the 15 min needed to prepare another AV on the
            launcher
Arc 22-23: 1-min time no signal, just sending pulse to climbout

23   Indicates AV is up and working (similar to prelaunch node 11)
Arc 23-24: AV has failed somewhere
Arc 23-25: Update arc for the 5-min climbout
Arc 23-27: AV OK, continue to check other components

Node	Significance

24 Indicates AV failure, AV will crash or an MP failed and will be taken up in 154
Arc 24-29: update 5-min counter (-5)
Arc 24-25: update 1-min counter (-2)
Arc 24-71: failure of mission flight

25 (see 36)
Arc 25-23

27 Indicates ground equipment system check
Arc 27-28: failure
Arc 27-37: ground equipment OK, continue

28 Indicates ground equipment failure
Arc 28-29: update 5-min counter (-5)
Arc 28-25: update 1-min counter (-2)
Arc 28-71: failure of mission flight, AV lost

29 Indicates the number of 1-min checks that have been made; if necessary to change climbout to 10 min, changes N1 and N2 of mode 29 to 10.
Arc 29-30: climbout OK, all systems good for 5 min
Arc 29-25: updates 1-min counter (node 25) to stop

37 Indicates loss of AV control through GCS passing arcs 137 to 139, resulting in the loss of an AV
Arc 37-45: if via arc 137-139, GCS down
Arc 37-58: GCS OK, continue

45 Indicates GCS failure to the point at which control of an AV cannot be maintained, 28 occurs where flight is stopped, AV lost
Arc 45-37: resets node back upon starting a prelaunch
Arc 45-29: updates 5-min counter (-5)
Arc 45-25: updates 1-min counter (-2)
Arc 45-71: stops flight and exits

58 Indicates whether GCS passed arc 138-140 which means GCS cannot perform a flight, but control of AV is still good enough to attempt a recovery
Arc 58-68: done by arc 138-140 GCS down/start recovery
Arc 58-29: update 5-min counter
Arc 58-25: ready to begin next 1-min check; distribution 1, parameter 1

68 Indicates GCS failure, but control of AV is still possible, then 29 occurs, then exit baseline model and recover
Arc 68-58: GCS OK, reset
Arc 68-29: update 5-min counter
Arc 68-25: update 1-min counter
Arc 68-165: start recovery part of flight

Node	Significance

30 Indicates beginning of outbound system check, starting with operation
of AV subsystems
Arc 30-31: AV subsystem failed, exit via ☐10
Arc 30-32: AV subsystems OK, continue
Arc 30-36: update 1-min counter to ready

OUTBOUND, MISSION (Figure 7)

31 Indicates AV subsystem failure; from 103 to 108 and 109 if MP is
included in dataset
Arc 31-30: flight over, reset
Arc 31-39: update 20-min counter
Arc 31-71: stop flight, mission flight failure due to AV subsystem
Arc 31-36: update 1-min counter to stop

32 Indicates ground-equipment system check
Arc 32-33: done by ☐15 showing failure
Arc 32-75: ground equipment OK, continue

33 Indicates ground equipment failure
Arc 33-32: ground equipment fixed via ☐14
Arc 33-39: update 20-min counter (-20)
Arc 33-71: mission flight failure, AV lost
Arc 33-36: update 1-min counter to stop

75 (see 37)
Arc 75-76: caused by arc 137-139, GCS down
Arc 75-77: GCS OK, continue

76 (see 45)
Arc 76-75: resets GCS back to working status upon prelaunch ☐1
Arc 76-71: stops flight and exits
Arc 76-36: updates 1-min counter to stop
Arc 76-39: updates 20-min counter (-20)

77 (see 58)
Arc 77-78: done by arc 138-140, GCS down/start recovery
Arc 77-34: GCS OK, continue

78 (see 68)
Arc 78-77: GCS OK, reset arc to prelaunch
Arc 78-39: update 20-min counter
Arc 78-36: update 1-min counter
Arc 78-154: start recovery part of flight

Node	Significance

34   Indicates environmental check for the possibility of being shot down
Arc 34-38:   AV survived .999 on arc
Arc 34-35:   AV shotdown .001 on arc

35   Indicates AV shot down-lost
Arc 35-39:   update 20-min counter (-20)
Arc 35-71:   mission flight failure, AV lost
Arc 35-36:   update 1-min counter to stop

38   Indicates AV survived/split node from probability node
Arc 38-36:   ready to begin next 1-min check; distribution 1, parameter 1
Arc 38-39:   update 20-min counter (1)

36   Indicates start of 1-min counter which sequences the checks
Arc 36-30:   start check again

39   Indicates the number of 1-min checks that have been made
Arc 39-40:   outbound flight good, continue 1 min ☐4 distribution 1, parameter 1
Arc 39-36:   stop 1-min counter, reset (-1)
Arc 39-36:   stop 1-min counter (-1, 1 min)

40   Indicates beginning of mission system check and check of AV subsystems
Arc 40-41:   AV subsystem failed, exit via ☐10
Arc 40-44:   update 1-min counter to ready
Arc 40-42:   AV subsystems OK, continue

41   Indicates AV subsystem failure; from 103 to 108 and 109 if MP included in dataset
Arc 41-40:   flight over, reset
Arc 41-49:   update 120-min counter (two-60's)
Arc 41-44:   update 1-min counter to stop
Arc 41-71:   mission flight failure

42   Indicates ground equipment system check
Arc 42-43:   done by ☐15 failure
Arc 42-79:   ground equipment OK, continue

43   Indicates ground equipment failure
Arc 43-42:   ground equipment fixed via ☐14
Arc 43-49:   update 120-min counter (two-60's)
Arc 43-44:   update 1-min counter to stop
Arc 43-71:   mission flight failure

44   Indicates start of 1-min counter which sequences the checks
Arc 44-40:   start check again

Node	Significance

79 (see 37)
Arc 79-145: caused by arc 137-139, GCS down
Arc 79-146: GCS OK, continue

145 (see 45)
Arc 145-79: resets node back upon starting a prelaunch
Arc 145-49: updates 120-min counter (two-60's)
Arc 145-71: stops mission and exits
Arc 145-44: updates 1-min counter (-2)

146 (see 58)
Arc 146-147: caused by arc 138-140, GCS down/start recovery
Arc 146-46: GCS OK, continue

147 (see 68)
Arc 147-146: GCS OK, reset
Arc 147-154: start inbound and recovery of AV
Arc 147-49: update 120-min counter
Arc 147-44: update 1-min counter

46 Indicates environmental check for the possibility of being shot down
Arc 46-47: AV shot down (.001 on arc)
Arc 46-48: AV survived (.999 on arc)

47 Indicates AV shot down — lost
Arc 47-49: update 20-min counter (-120)
Arc 47-71: mission flight failure, AV lost
Arc 47-44: update 1-min counter (-2) to stop

48 Indicates AV survived/split node from probability node
Arc 48-49: update 120-min counter (1)
Arc 48-44: ready to begin next 1 min

49 Indicates the number of 1-min checks made during the mission
Arc 49-50: mission good, continue with inbound 1 min [5]
distribution 1, parameter 1
Arc 49-49: stop 1-min counter reset (-1)
Arc 49-44: stop 1-min counter reset (-1, 1 min)

50 Indicates how many times the RPV passed the mission (statistics node)
Arc 50-53: send pulse on

51/52 Indicates the number of "sets of three" of completed missions
(both nodes do the same job)

INBOUND, RECOVERY (Figure 8)

Node	Significance

53   Indicates beginning of inbound systems check, starting with operation of AV subsystems
        Arc 53-54:   AV subsystem failed, exit via [10]
        Arc 53-56:   AV subsystem OK, continue
        Arc 53-57:   update 1-min counter

54   Indicates subsystem failure from 103 to 108 and 109 if MP is included in dataset
        Arc 54-53:   flight over, reset
        Arc 54-62:   update 25-min counter (-25)
        Arc 54-57:   update 1-min counter to stop
        Arc 54-71:   stop flight, mission flight failure due to AV subsystem

56   Indicates ground equipment system check
        Arc 56-55:   done by [15] failure
        Arc 56-148:   ground equipment OK, continue

55   Indicates equipment failure
        Arc 55-56:   ground equipment fixed via [14]
        Arc 55-62:   update 25-min counter (-25)
        Arc 55-57:   update 1-min counter to stop
        Arc 55-71:   mission flight failure, AV lost

148   Indicates loss of AV control through GCS passing arcs 137-139, resulting in the loss of an AV
        Arc 148-149: GCS down done by arc 137-139
        Arc 149-59:   GCS OK, continue

149   Indicates GCS failure to the point at which control of an AV cannot be maintained [28] occurs where flight is stopped, AV lost
        Arc 149-148: resets node back upon starting a prelaunch
        Arc 149-62:   updates 25-min counter (-25)
        Arc 149-57:   updates 1-min counter to stop
        Arc 149-71:   stops flight, AV lost, and exit

59   Indicates environmental check for the possibility of being shot down
        Arc 59-60:   AV shot down (.001 on arc)
        Arc 59-61:   AV survived (.999 on arc)

60   Indicates AV shot down, lost
        Arc 60-62:   update 25-min counter
        Arc 60-71:   mission flight failure, AV lost
        Arc 60-57:   update 1-min counter to stop

Node	Significance

61   Indicates AV survived/split node from probability node
Arc 61-62:   update 20-min counter
Arc 61-57:   ready to begin next 1-min check; distribution 1, parameter 1

57   Indicates start of 1-min counter which sequences the checks
Arc 57-53:   start check again

62   Indicates the number of 1-min checks that will be made. (If necessary, inbound can be changed, for example, from 25 to 30, simply by replacing N1 and N2 with 30 in node 62)
Arc 62-63:   inbound flight good, continue 1 min; distribution 1, parameter 1
Arc 62-57:   stop 1-min counter reset (-1)
Arc 62-57:   stop 1-min counter reset (-1, 1 min)

63   Indicates beginning of recovery, checking of AV subsystems
Arc 63-64:   AV subsystem failed, exit via [10]
Arc 63-66:   AV subsystem OK, continue
Arc 63-67:   update 1-min counter to ready

64   Indicates AV subsystem failure from 103 to 108 and 109 if MP included in dataset
Arc 64-63:   flight over, reset
Arc 64-69:   update 10-min recovery counter
Arc 64-67:   update 1-min recovery counter to stop
Arc 64-71:   mission flight failure

66   Indicates ground equipment system check
Arc 66-65:   done by [15] failure
Arc 66-150:   ground equipment OK, continue

65   Indicates ground equipment failure
Arc 65-66:   ground equipment fixed via [14]
Arc 65-71:   mission flight failure
Arc 65-69:   update 1C-min counter (-10)
Arc 65-67:   update 1-min counter to stop

151   Indicates GCS failure to the point at which control of AV cannot be maintained [28] occurs where flight is stopped, AV lost
Arc 151-150:   resets node back upon starting a prelaunch [1]
Arc 151-67:   updates 1-min counter to stop
Arc 151-69:   updates 10-min counter (-10)
Arc 151-71:   stops flight, AV lost, and exit

67   Indicates start of 1-min counter which sequences the checks
Arc 67-63:   starts check again

31

69   Indicates the number of 1-min checks during the recovery that have been made

       Arc 69-70:   recovery good (till net), continue with probability of net working
       Arc 69-69:   stop 1-min counter reset (-1)
       Arc 69-67:   stop 1-min counter reset (-1, 1 min)

70   Indicates the probability that recovery net works

       Arc 70-72:   net work good, AV recovered (.99)
       Arc 70-71:   net failed, AV lost (.01)

RECOVERY, TIMER (Figure 9)

71   Indicates mission flight failure; AV lost; however, if MP failed, then mission is not considered a failure

289   Indicates whether failure occurred in MP

       Arc 289-288: if failure in MP, hold
       Arc 289-152: failure not in MP; AV lost, reset

288   Indicates pulse stopped; MP failed but AV in recovery mode; pulse reestablished from subrecovery mode

       Arc 288-289: reset

72   Indicates mission flight successful; no problems disrupted the baseline program; mission counts as one good 3-hr sortie

       Arc 72-73:   update 3-sortie counter
       Arc 72-152:   update GCS available
       Arc 72-74:   put AV back in pool

73   Indicates the number of days in which three 3-hr sorties were completed successfully

       Arc 73-102:   [32]   stop 12-hr clock; three mission flights have been completed within the time period

74   Indicates AV replacement into pool

       Arc 74-5:   where 5 is pool, -1 to add to counter

152   Indicates GCS checked for readiness

       Arc 152-153: stop and hold until GCS is fixed
       Arc 152-6:   GCS available, start prelaunch again

153   Indicates system holding until GCS is ready

       Arc 153-152: GCS is ready, return
       Arc 152-152: 1-min loop. Checks status of GCS every 1 min (helps prevent infinite loops)

Node	Significance

101 Indicates start of 12-hr clock at beginning of simulation; if clock runs out before completion of three good sorties (Arc 73-102), simulation is terminated (end of daylight hrs)
Arc 101-102: 12 hr have passed

102 Indicates pulse received for completion of three mission flights or for completion of 12-hr period
Arc 102-180: three sorties completed first
Arc 102-181: 12 hrs have passed

180 Indicates three mission flights were completed, 12-hr clock starts again and records in N229
Arc 180-101: starts 12-hr clock for next day, model starts prelaunch automatically with Arc 152-6
Arc 180-299: decrease 299 by one

299 Indicates maximum of 10 successful days, then stops simulation run
Arc 299: sink node

181 Indicates three sorties were not completed within 12 hrs; 12 hr arrived at 102 first and diverted to 181
Arc 181-182: send pulse to stop simulation

182 Indicates 12 hrs over before three mission flights, collect statistics
Arc 182: sink node

AV SUBSYSTEM (Figure 10)

80 Indicates beginning of simulation; starts all components of AV
Arc 80-103: starts FCEP distribution
Arc 80-104: starts ARA distribution
Arc 80-105: starts ADT distribution
Arc 80-106: starts electric power distribution
Arc 80-107: starts airframe distribution
Arc 80-108: starts prop distribution
Arc 80-109: starts mission payload distribution

103 Indicates beginning of distribution for FCEP
Arc 103-81: distribution 4, parameter 9, number 10

104 Indicates beginning of distribution for ARA
Arc 104-81: distribution 4, parameter 10, number 10

105 Indicates beginning of distribution for ADT
Arc 105-81: distribution 4, parameter 11, number 10

Node	Significance

106   Indicates beginning of distribution for electric power
Arc 1C6-81:   distribution 4, parameter 12, number 10

107   Indicates beginning of distribution for the airframe
Arc 107-81:   distribution 4, parameter 13, number 10

108   Indicates beginning of distribution for the prop
Arc 108-81:   distribution 4, parameter 14, number 10

109   Indicates beginning of distribution for the MP
Arc 109-183:   distribution 4, parameter 4, number 11

183   Indicates failure of mission payload
Arc 183-81:   failure occurred in mission payload during prelaunch
         check
Arc 183-184:   node exchange done after prelaunch [2]

81   Indicates failure in an AV subsystem (from 103 to 108 and 183)
or distributions stop and restart; by 2 (the H denotes the halt
command specified in GRASP in which one pulse is received, and
the others are ignored)
Arc 81-82:   hold pulse until prelaunch is ready again
Arc 81-80:   start a new set of AV distribution for an AV on
         the launcher

82   Indicates pulse is postponed until prelaunch is ready
Arc 82-82:   return pulse
Arc 82-81:   return pulse to node 81 to start A

184   Indicates failure of mission payload after prelaunch before
mission return of AV
Arc 184-183:   reset node back before prelaunch
Arc 184-186:   failure occurred, start recovery

185   Indicates failure of mission payload during mission return of AV
via an inbound flight
Arc 185-186:   reset back with [5]
Arc 185-154:   send pulse to auxiliary recovery – inbound

186   Indicates failure of mission payload during climbout and outbound flight
Arc 186-165:   send pulse to auxiliary recovery
Arc 186-185:   divert pulse to auxiliary recovery on inbound if
         mission payload fails

Node	Significance

85   Indicates beginning of simulation
- Arc 85-86:   starts RGT failure distribution; distribution 4, parameter 3
- Arc 85-93:   updates ground equipment status
- Arc 85-95:   update ground equipment status

86   Indicates failure of RGT
- Arc 86-93:   update ground equipment status
- Arc 86-95:   update ground equipment status
- Arc 86-85:   repair of RGT; distribution 1, parameter 7

87   Indicates beginning of simulation
- Arc 87-88:   starts generator failure distribution; distribution 4, parameter 6
- Arc 87-89:   updates ground equipment status
- Arc 87-92:   updates ground equipment status

88   Indicates failure of generator 1
- Arc 88-87:   repair of generator 1; distribution 1, parameter 7
- Arc 88-89:   update ground equipment status
- Arc 88-92:   update ground equipment status

89   Indicates whether one of two generators is working
- Arc 89-93:   update arc
- Arc 89-95:   update arc
- Arc 89-92:   update arc

90   Indicates beginning of simulation
- Arc 90-91:   starts generator failure distribution
- Arc 90-89:   update ground equipment status
- Arc 90-92:   update ground equipment status

91   Indicates failure of generator 2
- Arc 91-90:   repair of generator 2; distribution 1, parameter 7
- Arc 91-92:   update ground equipment status
- Arc 91-89:   update ground equipment status

92   Indicates whether or not both generators are working
- Arc 92-95:   update arc
- Arc 92-93:   update arc
- Arc 92-89:   update arc

93   Indicates GCS status (update node)
- Arc 93-95:   update arc
- Arc 93-94:   arc for ground equipment status up   **14**

94   Indicates ground equipment working

35

Node	Significance

95   Indicates GCS status (update node)
Arc 95-93:   update arc
Arc 95-96:   arc for ground equipment status down **15**

96   Indicates ground equipment not working

GROUND CONTROL STATION (Figure 11)

110   Indicates beginning of GCS subsystem distributions
Arc 110-111:   starts the GCSIU distribution
Arc 110-115:   starts the AVOC console distribution
Arc 110-119:   starts the MP console distribution
Arc 110-123:   starts the MC console distribution
Arc 110-127:   starts the NDU distribution
Arc 110-131:   starts the main computer distribution
Arc 110-5:   subtracts one AV from the AV-ready pool when one
AV is on launcher at start of simulation — this
is easier than any other method

111   Indicates beginning of GCSIU distribution
Arc 111-112:   GCSIU parameter set 15, distribution 4
Arc 111-141:   updater arc for GCS up (141-142)
Arc 111-143:   updater arc for GCS down (143-144)

112   Indicates GCSIU failure
Arc 112-111:   start repair; parameter 21, distribution 1, number **17**
Arc 112-141:   updater arc for GCS repaired
Arc 112-143:   updater arc for GCS down
Arc 112-113:   timed check to see if GCSIU can be repaired before
fail is scheduled; distribution 1, parameter set 27

113   Indicates available time for on-site repair has passed and observed
vehicle must be scheduled for repair — GCSIU
Arc 113-114:   repair did not take place within check time schedule
failure
Arc 113-114:   divert pulse to stop **17**
Repair has taken place within the check time

114   Indicates pulse stopped, failure of GCSIU
Arc 114-113:   reset back **16**

115   Indicates beginning of AVOC distribution
Arc 115-116:   AVOC parameter set 16, distribution 4
Arc 115-141:   updater arc for GCS up (141-142)
Arc 115-143:   updater arc for GCS down (143-144)
Arc 115-135:   updater for two console failure

Node	Significance

116   **Indicates AVOC failure**
     Arc 116-115:   start repair parameter set 22, distribution 1
     Arc 116-141:   updater arc for GCS repaired
     Arc 116-142:   updater arc for GCS down
     Arc 116-117:   timed check to see if AVOC can be repaired before
                  failing; parameter set 27, distribution 1

117   Indicates available time for on-site repair has passed and
     observed vehicle must be scheduled for repair — AVOC
     Arc 117-135:   repair did not take place within check time;
                   schedule failure
     Arc 117-136:   repair did not take place within check time;
                   schedule failure
     Arc 117-118:   divert pulse to stop [19]

118   Indicates pulse stopped due to failure of AVOC
     Arc 118-117:   reset back [18]

119   Indicates beginning of MPC distribution
     Arc 119-120:   MPC parameter set 17, distribution 4
     Arc 119-141:   updater arc for GCS up (141-142)
     Arc 119-143:   updater arc for GCS down (143-144)
     Arc 119-135:   updater for two console failure

120   Indicates MPC failure
     Arc 120-119:   start repair parameter set 23, distribution 1
     Arc 120-141:   updater arc for GCS repaired
     Arc 120-142:   updater arc for GCS down
     Arc 120-121:   timed check to see if MPC can be repaired before
                   failing parameter set 27, distribution 1

121   Indicates available time for on-site repair has passed and observed
     vehicle must be scheduled for repair — MPC
     Arc 121-135:   repair did not take place within check time failure
                   scheduled
     Arc 121-136:   repair did not take place within check time failure
                   scheduled
     Arc 121-122:   divert pulse to stop [21]

122   Indicates pulse stopped for failure of MPC
     Arc 122-121:   reset back [20]

123   Indicates beginning of MCC distribution
     Arc 123-124:   MPC parameter set 18, distribution 4
     Arc 123-141:   updater arc for GCS up (141-142)
     Arc 123-143:   updater arc for GCS down (143-144)
     Arc 123-135:   updater for two console failures

124 Indicates MCC failure
    Arc 124-123: start repair parameter set 24, distribution 1
    Arc 124-141: updater arc for GCS repaired
    Arc 124-143: updater arc for GCS down
    Arc 124-125: timed check to see if MCC can be repaired before failing
                 parameter set 27, distribution 1

125 Indicates time over — MCC
    Arc 125-135: repair did not take place within check time
                 failure schedule
    Arc 125-136: repair did not take place within check time
                 failure schedule
    Arc 125-126: divert pulse to stop 23

126 Indicates pulse stopped for failure of MCC
    Arc 126-125: reset back 22

127 Indicates beginning of NDU distribution
    Arc 127-129: NDU parameter set 19, distribution 4
    Arc 127-141: updater arc for GCS up (141-142)
    Arc 127-143: updater arc for GCS down (143-144)

128 Indicates NDU failure
    Arc 128-127: start repair parameter set 25, distribution 1
    Arc 128-141: updater arc for GCS repaired
    Arc 128-143: updater arc for GCS down
    Arc 128-129: timed check to see if NDU can be repaired before
                 failing; parameter set 27, distribution 1

129 Indicates time over — NDU
    Arc 129-138: repair did not take place within check time
                 recovery scheduled
    Arc 129-130: divert pulse to stop 25

130 Indicates pulse stopped for NDU failure
    Arc 130-129: reset back 24

131 Indicates beginning of main computer distribution
    Arc 131-132: main computer parameter set 20, distribution 4
    Arc 131-141: updater arc for GCS up (141-142)
    Arc 131-143: updater arc for GCS down (143-144)

132 Indicates main computer failure
    Arc 132-131: start repair; parameter set 26, distribution 1
    Arc 132-141: updater arc for GCS repaired
    Arc 132-143: updater arc for GCS down
    Arc 132-133: timed check to see if main computer can be repaired
                 before failing; distribution 1, parameter set 27

Node	Significance

133 Indicates time over — main computer
Arc 133-138: repair did not take place within check time recovery scheduled
Arc 133-134: divert pulse to stop [27]

134 Indicates pulse stopped due to failure of main computer
Arc 134-133: reset back [26]

135* Indicates failure of two consoles
Arc 135-137: failure of GCS — if AV is in the air, it's lost

136* Indicates failure of one console
Arc 136-138: start recovery operations

137 Indicates GCS failure, loss of AV
Arc 137-139: failure of GCS scheduled a [28] for the main model
Arc 137-176: guard — protect from having two pulses issued along arc 137-139 for a mission flight

139 Indicates loss of AV

176 Indicates pulse stopped; only one pulse needed
Arc 176-137: reset by [1]

138 Indicates failure of GCS, AV returned for recovery
Arc 138-140: failure of GCS schedule a [29] for the main model

140 Indicates beginning of recovery

177 Indicates pulse stopped — only one pulse needed

141 Indicates GCS repaired
Arc 141-142: schedule [31] for main model
Arc 141-143: (5) GCS repaired, update

142 Indicates GCS repaired

143 Indicates GCS not working
Arc 143-144: GCS down, schedule [30] for main model
Arc 143-141: GCS down, update

144 Indicates GCS not working

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*The three-console model here should be redesigned so that three distributions (or as many as necessary) could be altered to indicate loss of AV control to the extent that (1) the mission would be aborted and the AV recovered or (2) recovery would be impossible and the AV lost.

AUXILIARY RECOVERY (Figure 12)

Node	Significance

154   Indicates beginning of auxiliary inbound system check, starting with all AV subsystems
Arc 154-155: AV subsystem failed, exit via ▢10
Arc 154-156: AV subsystem continue
Arc 154-163: update 1-min counter

155   Indicates AV subsystem failure from 103 to 108 and 109 if MP is included in dataset
Arc 155-154: flight over, reset
Arc 155-164: updater for 25-min counter
Arc 155-175: mission flight failure, AV lost
Arc 155-163: updater for 1-min counter

156   Indicates ground equipment system check
Arc 156-157: done ▢15 failure
Arc 156-158: ground equipment OK, continue

157   Indicates ground equipment failure
Arc 157-156: ground equipment fixed via ▢14
Arc 157-164: updater for 25-min counter
Arc 157-175: mission flight failure, AV lost
Arc 157-163: updater for 1-min counter

158   Indicates loss of AV control through arc 137-139, resulting in loss of AV
Arc 158-159: AV lost
Arc 137-139: GCS inoperative
Arc 158-160: GCS operating, continue mission

159   Indicates GCS failure to the point at which control of an AV cannot be maintained ▢28 occurs where flight is stopped and AV lost
Arc 159-158: reset node back upon starting a prelaunch
Arc 159-175: stops flight, AV lost, and exit
Arc 159-164: updates 25-min counter
Arc 159-163: updates 1-min counter

160   Indicates environmental check for the possibility of being shot down
Arc 160-162: AV survived (.999 on arc)
Arc 160-161: AV shot down (.001 on arc)

162   Indicates AV survived/split node from probability node
Arc 162-164: update 20-min counter
Arc 162-163: ready to begin next 1-min check; distribution 1, parameter set 1

Node	Significance

161   Indicates AV shot down — lost
Arc 161-164:   update 25-min counter
Arc 161-163:   update 1-min counter
Arc 161-175:   mission flight failure, AV lost

163   Indicates start of 1-min counter which sequences the checks
Arc 163-154:   start check again

164   Indicates the number of 1-min checks that have been made.
Arc 164-163:   stop 1-min counter, reset (-1)
Arc 164-163:   stop 1-min counter, reset (-1, 1 min)
Arc 164-165:   inbound flight good, continue

165   Indicates beginning of recovery, checking of AV subsystem
Arc 165-166:   AV subsystem failed, exit via 〔10〕
Arc 165-161:   update 1-min counter to ready
Arc 165-167:   AV subsystem OK, continue

166   Indicates AV subsystem failure from 103 to 108 and 109 if MP included in dataset
Arc 166-165:   flight over, reset
Arc 166-172:   update 10-min recovery counter
Arc 166-171:   update 1-min recovery counter to stop
Arc 166-175:   mission flight failure

167   Indicates GCS failure to the point at which control of an AV cannot be maintained 〔28〕 occurs
Arc 167-168:   resets node back upon starting a prelaunch 〔1〕
Arc 167-169:   GCS OK, continue

168   Indicates GCS failure, AV lost
Arc 168-172:   update 10-min recovery counter
Arc 168-171:   update 1-min counter
Arc 168-175:   mission flight failure, AV lost

169   Indicates ground equipment system check
Arc 169-170:   done by 〔15〕 failure
Arc 169-172:   ground equipment working, continue

170   Indicates ground equipment failure
Arc 170-169:   ground equipment fixed via 〔14〕
Arc 170-172:   update 10-min counter
Arc 170-171:   update 1-min counter to stop

171   Indicates start of 1-min counter which sequences the system checks
Arc 171-165:   starts check again

Node	Significance

172   Indicates the number of 1-min checks made during the recovery
       Arc 172-173:   recovery good (until net), continue with
                       probability of net
       Arc 172-171:   stop 1-min counter, rest (-1)
       Arc 172-171:   stop 1-min counter, reset (-1, 1 min)

173   Indicates probability that recovery net works
       Arc 173-174:   .95 recovery good
       Arc 173-175:   .05 recovery bad
       Arc 173-187:   node exchange (if MP is bad, probability is lower ⑪)

187   Indicates probability that recovery net works without MP for guidance
       Arc 187-190:   recovery good .93
       Arc 187-175:   recovery bad

290   Indicates recovery good, MP failed
       Arc 290:   MS send AV to MS to be repaired
       Arc 290-152:   start new mission flight

174   Indicates recovery good
       Arc 174-5:   AV OK, return to ready pool
       Arc 174-152:   start new mission flight

175   Indicates recovery unsuccessful, AV lost
       Arc 175-152:   start new mission flight

MS1 100% DIAGNOSTICS (Figure 13)

200   Indicates initialization of maintenance shelter 1
       Arc 200-201:   distribution 1, parameter set 27, installation time

201   Indicates test of test equipment
       Arc 201-103:   test good .99
       Arc 201-202:   test not good .01, keys in AVIM

202   AVIM

203   Indicates time for fault isolation to work
       Arc 203-204:   parameter set 27, distribution 1, fault isolation

204   Indicates probability of fault being detected
       Arc 204-206:   fault not detected .05
       Arc 204-205:   fault detected .95

205   Indicates probability of repairing the fault with an LRU
       Arc 205-202:   cannot be repaired at AVUM (.10)
       Arc 205-207:   repaired at AVUM .90

Node	Significance

206 Indicates that repair may need to take place in GSE, LA, REC, GCS, or RGT
Arc 206-210: transfer of pulse

207 Indicates time to replace LRU
Arc 207-209: distribution 1, parameter set 27

209 Indicates service check
Arc 209-210: service good .999
Arc 209-201: service not good, start again .001

210 Indicates service good, send AV back to AV ready pool
Arc 210-5:   AV to ready pool

MS2 70% CHARACTERISTICS (Figure 13)

220 Indicates initialization of maintenance shelter 2
Arc 220-221: distribution 1, parameter set 27

221 Indicates idle mode
Arc 221-222: transfer pulse

222 Indicates fault isolation time
Arc 222-223: distribution 1, parameter set 27

223 Indicates test confirmed from GCS
Arc 223-224: test not confirmed .05
Arc 223-226: test confirmed .95

224 Indicates check of testing arrangement
Arc 224-225: test arrangement good .95
Arc 224-221: test arrangement bad, start again

225 Send to AVIM

226 Indicates isolation to LRU
Arc 226-227: confirmed .90
Arc 226-225: not possible .10

227 Indicates AV sent to repair
Arc 227-228: repair time, distribution 1, parameter set 27

228 Indicates end of repair
Arc 228-229: send pulse for service check

Node	Significance

229   Indicates service check
      Arc 229-225: no good, send to AVIM .10
      Arc 229-230: service good .90

230   Indicates service good, send AV back to ready pool
      Arc 230-5:   AV to ready pool

MS3 CONTRACT SPECIFICATIONS (Figure 13)

3-188 Indicates installation time; distribution 1, parameter set 1

188   Indicates test for faults
      Arc 188-189: distribution 1, parameter set 7

189   Indicates probability of problem being fixed
      Arc 189-190: .10, sent to AVIM
      Arc 180-191: .90, send to repair

190   AVIM

191   Indicates repair time — send back to ready pool
      Arc 191-5:   parameter 8 $\boxed{-1}$, distribution 1

APPENDIX C

PARAMETER SET

This section describes the numbers used for the distributions. The distributions use a mean time for failure rate determination. Minimum and maximum time-rates are associated with distributions to provide a means for containment of times.

Distribution	Significance
1	Constant 1-min timer; used mostly for 1-min system checks in main program
2	Constant 720-min (12-hr) timer; used to time 1 day's activities Arc 101-102

3	Exponential distribution on RGT
	        10000.0 mean time in minutes
	            0.0 minimum time in minutes
	     99999999.0 maximum time in minutes
	            1.0 puts ERLANG-K into exponential

4	Mission payload
	         10,312 mean time in minutes
	            0.0 minimum time in minutes
	     99999999.0 maximum time in minutes
	            1.0 puts ERLANG-K into exponential

5	Old distribution — not used

6	Generators
	        720,000 mean time in minutes
	            0.0 minimum time in minutes
	     99999999.0 maximum time in minutes
	            1.0 puts ERLANG-K into exponential

7	Constant 30-min timer
8	Constant 15-min timer

9	FCEP
	      117,187.5 mean time in minutes
	            0.0 minimum time in minutes
	          190.0 maximum time in minutes
	            1.0 puts ERLANG-K into exponential

Distribution	Significance

10   ARA
         229885 mean time in minutes
           0.0 minimum time in minutes
         190.0 maximum time in minutes
           1.0 puts ERLANG-K into exponential

11   ADT
     287081.34 mean time in minutes
           0.0 minimum time in minutes
         190.0 maximum time in minutes
           1.0 puts ERLANG-K into exponential

12   Electrical power
     180180.18 mean time in minutes
           0.0 minimum time in minutes
         190.0 maximum time in minutes
           1.0 puts ERLANG-K into exponential

13   Air frame
     312500.00 mean time in minutes
           0.0 minimum time in minutes
         190.0 maximum time in minutes
           1.0 puts ERLANG-K into exponential

14   Propulsion assembly
       48000.0 mean time in minutes
           0.0 minimum time in minutes
         190.0 maximum time in minutes
           1.0 puts ERLANG-K into exponential

15   GCS IU
       48000.0 mean time in minutes
           0.0 minimum time in minutes
   99999999.0 maximum time in minutes
           1.0 puts ERLANG-K into exponential

16   AVO console
     22779.043 mean time in minutes
           0.0 minimum time in minutes
   99999999.0 maximum time in minutes
           1.0 puts ERLANG-K into exponential

17   MPO console
     63492.0635 mean time in minutes
           0.0 minimum time in minutes
   99999999.0 maximum time in minutes
           1.0 puts ERLANG-K into exponential

Distribution	Significance
18	MC console 57416.2679 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
19	NDU console 209790.210 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
20	GCS main computer 157480.0 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
21	GCS IU 15.00 constant repair time
22	AVO console 15.00 constant repair time
23	MPO console 15.00 constant repair time
24	MC console 15.00 constant repair time
25	NDU console 15.00 constant repair time
26	GCS main computer 15.00 constant repair time
27	Check time for GCS components 10.00 constant repair time

GCS/AIRCMS GDT λ=1350
ELECTRONICS ASSEMBLY λ=1327
FIBER OPTICS ASSEMBLY λ=8
BATTERY λ=8

GCS I.U. λ=1259
MODULES (11) λ=1190
POWER MODULE λ=159

DATA LOADER λ=50

COMPUTER S.P. UNIT λ=381
COMPUTER PROCESSORS λ=130
INTERFACE UNITS λ=171
MEMORY 2:32 kW λ=52
POWER SUPPLY λ=20
BOOTSTRAP TERMINATOR λ=8

NAVIGATION DPL. CONSOLE λ=285
NAV. DPL. UNIT λ=285

MISSION PL. FACILITY λ=200
TELEPRINTER λ=200

MC CONSOLE λ=1045
VIDEO MONITOR λ=345
VIDEO RECORDER λ=200
I/O MODULE BOARD λ=100
POWER MOD. ASSEMBLY λ=100
DISPLAY MODULE λ=100
COMM. PANEL ASY. λ=150
LIGHT PEN ASSEMBLY λ=50

MPO CONSOLE λ=945
VIDEO MONITOR λ=345
CPU MOD. BOARD λ=100
I/O MODULE BOARD λ=100
POWER MOD. ASSEMBLY λ=100
DISPLAY MODULE λ=100
COMM. PANEL ASY. λ=150
LIGHT PEN ASSEMBLY λ=50

AVO CONSOLE λ=2634
VIDEO MONITOR λ=345
GDT/MIU CTL. PANEL λ=1689
AVO DISPLAY MODULE BD λ=100
CPU MOD. ASSEMBLY λ=100
I/O MODULE ASSEMBLY λ=100
AVO POWER MODULE λ=100
COMM. PANEL ASSEMBLY λ=150
LIGHT PEN ASSEMBLY λ=50

COMM. RACK 2 λ=330
ANALOG SW. MODULE λ=130
COMM. PANEL ASSEMBLY λ=150
POWER SUPPLY λ=50

COMM. RACK 1 λ=1050
TRANSCEIVER λ=250
CRYPTO-LOGICAL SET λ=300
RADIO (VRC36) λ=500

Figure 14.- GCS reliability block diagram.
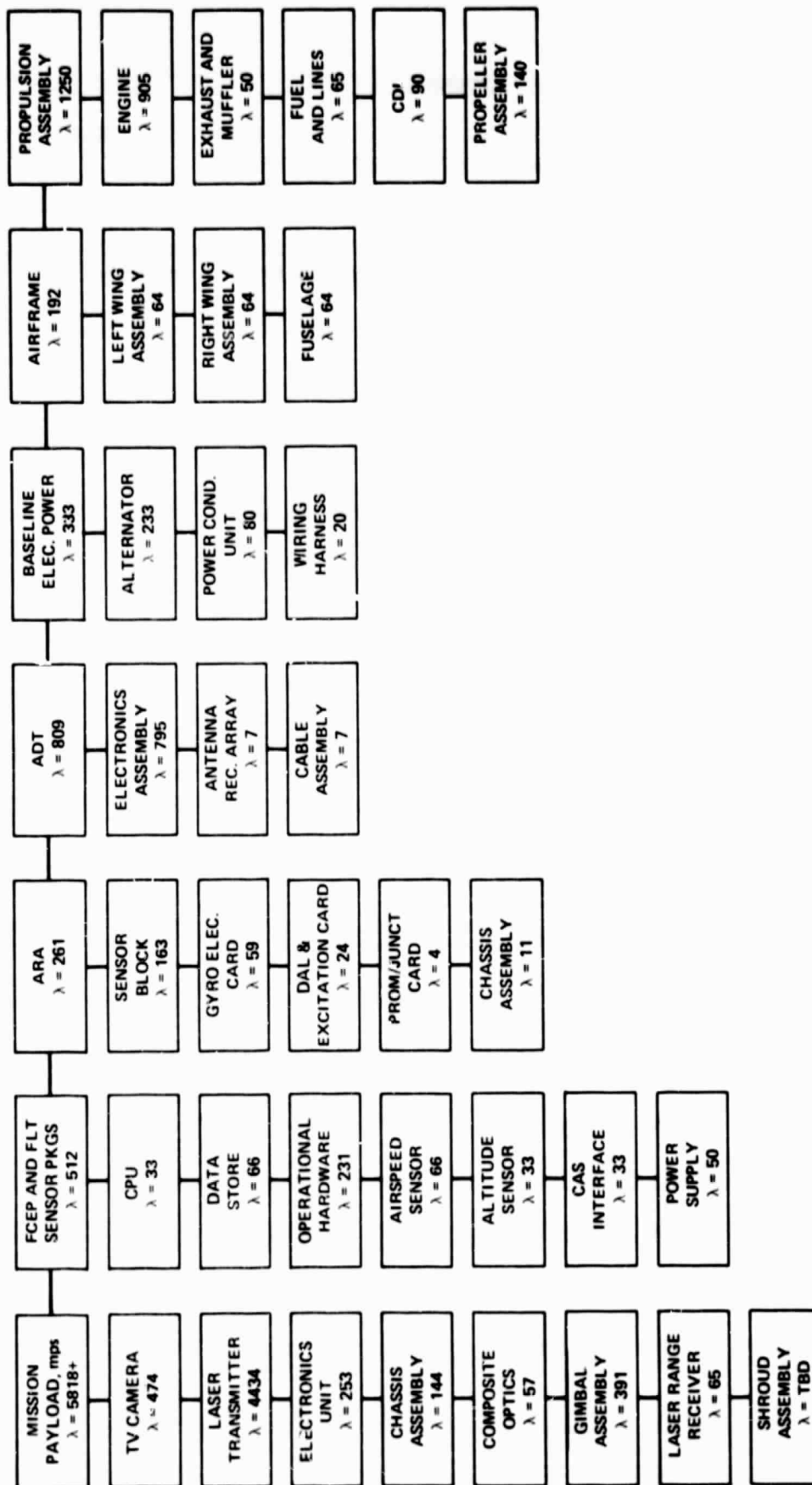
Figure 15.- RPV air vehicle subsystem reliability block diagram.

APPENDIX D

ACTIVITY NUMBERS

Activity numbers are assigned to denote different stages in the simulation. This section describes these stages and which arcs are used.

1	Prelaunch check is about to begin Arc ?-11
2	Prelaunch good/engine start and launch next Arc 17-18
4	AV has passed outbound ready to begin mission Arc 39-40
5	AV has passed mission, mission successful
7	AV has completed recovery approach, flight over
10	AV subsystem component failure
11	Mission payload failure
14	Ground equipment working
15	Ground equipment not working
16	Failure of GCS IU
17	Reapir of GCS IU
18	Failure of AVO console
19	Repair of AVO console
20	Failure of MPO console
21	Repair of MPO console
22	Failure of MC console
23	Repair of MC console
24	Failure of NAV DPL unit

25. Repair of NAV DPL unit

26. Failure of GCS main computer

27. Repair of GCS main computer

30. GCS not working

31. GCS repaired

28. GCS failure — AV lost

29. GCS failure — AV in recovery/inbound
(depends on AV location)

32. Successful day completed
3-3 hr sorties within 12 hours

33. Unsuccessful day

12-hr timer finished

ACTIVITY NUMBERS

```
 1 | 1, 11  ...
 2 | 31  ...
 4 | ...
 3 | ...
 7 | 2, 23  31  ...
   | 1, 12  23  24  ...
11 | ...
14 | ...
15 | ...
16 | ...
17 | ...
13 | ...
19 | ...
22 | ...
21 | ...
22 | ...
23 | ...
24 | ...
25 | ...
26 | ...
27 | ...
30 | ...
31 | ...
28 | ...
29 | ...
32 | ...
33 | ...
```

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APPENDIX E

DATA SET DESCRIPTIONS

The following table shows which data set contains the subelements that supplement the GRASP/Army RPV Simulation MAIN Program.

	MP	W/O MP	MS1	MS2	MS3	AV1M
RPV 11	X					
RPV 12		X				
RPV 13	X				X	
RPV 14		X			X	
RPV 15	X		X			
RPV 16		X	X			
RPV 17	X			X		
RPV 18		X		X		
RPV 19	X				X	X
RPV 20		X			X	X
RPV 21	X		X			X
RPV 22		X	X			X
RPV 23	X			X		X
RPV 24		X		X		X

APPENDIX F

DETERMINATION OF DISTRIBUTIONS

In this model, Lockheed uses the exponential distribution in all calculations. In the GRASP Program this is used as an ERLANG-1 (K = 1), because theoretically the exponential distribution is a particular case of the ERLANG distribution when K = 1. Thus for the exponential distribution it is:

$$\text{Mean (MTBF)} = \frac{1}{\lambda}$$

The λ's supplied by Lockheed represent the failure rates per million (10^6) hours. Therefore, the mean if computed is 1/original λ is expressed in millions of hours; and $1/\lambda \times 10^6$ is the mean expressed in hours; and $1/\lambda \times 10^6 \times 60$ is the mean expressed in minutes. This last case is used to determine the failure rates since the RPV system model operates in minutes.

GCS Subsystems

AVO Console

$\lambda = 2634$

$$\text{Mean} = \frac{1}{2634} \times 10^6 \times 60 = 22779.04 \text{ min}$$

which is Parameter Set No. 16

MPO Console

$\lambda = 945$

$$\text{Mean} = \frac{1}{945} \times 10^6 \times 60 = 63492.06 \text{ min}$$

which is Parameter Set No. 17

MC Console

$\lambda = 1045$

$$\text{Mean} = \frac{1}{1045} \times 10^6 \times 60 = 57416.27 \text{ min}$$

which is Parameter Set No. 18

53

Navigation DPL. Console

$\lambda = 286$

$$\text{Mean} = \frac{1}{286} \times 10^6 \times 60 = 209790.2 \text{ min}$$

which is Parameter Set No. 19

Computer Signal-Processing Unit

$\lambda = 381$

$$\text{Mean} = \frac{1}{381} \times 10^6 \times 60 = 157480 \text{ min}$$

which is Parameter Set No. 20

AV Subsystem

Mission Payload

$\lambda = 5818$

$$\text{Mean} = \frac{1}{5818} \times 10^6 \times 60 = 10312.82 \text{ min}$$

which is Parameter Set No. 4

FCEP and FLT Sensor Packages

$\lambda = 512$

$$\text{Mean} = \frac{1}{512} \times 10^6 \times 60 = 117187.5 \text{ min}$$

which is Parameter Set No. 9

ARA

$\lambda = 261$

$$\text{Mean} = \frac{1}{261} \times 10^6 \times 60 = 229885.06 \text{ min}$$

which is Parameter Set No. 10

ADT

$\lambda = 809$

$$\text{Mean} = \frac{1}{809} \times 10^6 \times 60 = 74165.64 \text{ min}$$

which is Parameter Set No. 11

Baseline Electrical Power

$\lambda = 333$

$$\text{Mean} = \frac{1}{333} \times 10^6 \times 60 = 180180.18 \text{ min}$$

which is Parameter Set No. 12

Air Frame

$\lambda = 192$

$$\text{Mean} = \frac{1}{192} \times 10^6 \times 60 = 312500 \text{ min}$$

which is Parameter Set No. 13

APPENDIX G

MAINTENANCE SHELTER CONCEPTS (Diagram 8)

In the GRASP Simulation Program three different types of maintenance systems were used to try to describe different types of diagnostic testing techniques.

Concept 1: Options for entire system checkout. Possibility of AV being sent to MS in need of repair.

Concept 2: Model from a LMSC document (LMSC-D732866). Purpose: to see if GRASP is a useful tool in making direct modeling adaptations.

Concept 3: A model resembling a similar contract requirement in which 90% of the AV's are repaired and returned to service