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AIRCRAFT RELIABILITY AND MAINTAINABILITY SIMULATION (ARMS)

By

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September 1971

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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13. ABSTRACT
This report describes the intermediate logic flow diagrams for a computerized simulation model of U. S. Army aircraft operations. The primary objective of the model is to provide a tool for timely and realistic evaluation of system reliability and maintainability. Also, an objective of the model is the calculation of the operational availability of the aircraft being simulated. The acronym ARMS (Aircraft Reliability and Maintainability Simulation) is given to the model developed in this report. The logic flows are structured to be consistent, where feasible, with the Navy's current VALUE IV (Validated Aircraft Logistics Utilization Evaluation) model. Consistency with VALUE IV is desired so that its programming may be utilized directly, to the maximum possible extent, when the ARMS program is written. It is recommended that the Army proceed with the programming and implementation of ARMS as soon as practicable.

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This report, which was prepared by Ultrasystems, Inc., under the terms of Contract DAAJ02-71-C-0007, describes a methodology for the dynamic evaluation of reliability and maintainability characteristics of conceptual as well as operational Army aircraft.

The methodology and simulation modeling described provides an intermediate flow diagram suitable for model programming guidance.

The conclusions and recommendation contained herein are concurred in by this Directorate. This concurrence does not imply that the recommendation will be implemented.

Project Engineer for this Contract was Mr. Howard M. Bratt, Reliability and Maintainability Division.

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Final Report

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SUMMARY

This report describes the intermediate logic flow diagrams for a computerized simulation model of U. S. Army aircraft operations The primary objective of the model is to provide a tool for timely and realistic evaluation of system reliability and maintainability. Also, an objective of the model is the calculation of the operational availability of the aircraft being simulated. The acronym ARMS (Aircraft Reliability and Maintainability Simulation) is given to the model developed in this report. The logic flows are structured to be consistent, where feasible, with the Navy's current VALUE IV (Validated Aircraft Logistics Utilization Evaluation) model. Consistency with VALUE IV is desired so that its programming may be utilized directly, to the maximum possible extent, when the ARMS program is written. It is recommended that the Army proceed with the programming and implementation of ARMS as soon as practicable.

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1.0 INTRODUCTION

1.1 General

This report describes the work accomplished for the definition and description of a computer simulation model for the evaluation of reliability and maintainability concepts. The developed simulation model, for the purpose of this report, is given the acronym ARMS (Aircraft Reliability and Maintainability Simulati n).

The objective of this effort was to study and modify the VALUE IV (Validated Aircraft Logistics Utilization Evaluation) computer simulation model developed by the Naval Air Development Center (NADC), Johnsville, Pennsylvania,[1] and to determine the feasibility of using the resultant modification for evaluating conceptual as well as operational Army aircraft.

The description of the model is presented as an intermediate logic flow diagram. The logic flow is presented in sufficient detail for computer programmers to develop a program listing; programming the model for the computer was beyond the scope of this contract. The model presented herein was developed from the following information sources:

- US Army Technical Manuals (TMs)
- US Army Directives/Regulations
- Discussions with Eustis Directorate, USAAMRDL personnel
- Discussions with RAND Corporation simulation personnel
- Defense Documentation Center (DDC) Literary Search
- Review of Operating Simulations
- NADC's VALUE IV model
- Discussions with NADC personnel

1.2 Simulation Application

The real value of a simulation model is the visibility it provides at the total system level. Changes in R&M concepts are evaluated relative to their effect on availability, NORS (Not Operationally Ready Supply), NORM (Not Operationally Ready Maintenance), scheduled and unscheduled maintenance manhours per flight hour, and other pertinent statistics. This type of system-level analysis greatly reduces the probability of overlooking a significant interface of the proposed change of function.

Simulation runs can provide data in support of numerous investigation areas and can be used, for example, to pretest new approaches, or to obtain data for analyses of trade-offs between proposed alternatives.

Some specific examples for the application of the ARMS model are as follows:

- Evaluate aircraft availability with respect to change in failure rates, repair time, or maintenance support concepts.

- Investigate the effectiveness of inspection procedures and overhaul time limits and predict the effects of such changes as increased Built-In Test Equipment (BITE).

- Evaluate the effects of changes in reliability and maintainability with regard to total operations, including a valuable input to cost effectiveness studies.

1.3 Scope of the Model

The logic flow developed in this study is sufficiently general to permit any Army aircraft to be simulated. The modular simulation approach will allow flexibility in adapting the model to the specific analysis required.

1.4 Computer Requirements

The logic flow developed in this report is not restricted to any individual concept of programming or to any specific computer language. The computer requirements needed to support ARMS are, therefore, not rigidly defined with regard to type, size or speed of the computer. The size of the operation being simulated is sufficiently large that use of one of the major computer simulation languages is required for cost effective operation.

2.0 ARMS/VALUE IV LOGIC FLOW

2.1 Areas of Comparison

The Navy carrier-based air operation has many functional similarities to the Army field operations. Some of the more important likenesses are as follows:

1. The Navy's organization is based on the aircraft wing, which is made up of three aircraft squadrons. The Army battalion is made up of one or more (usually three) aviation companies.

2. The Navy has a system of operational inspections which very closely approaches the Army's daily, preflight, turnaround, aircrew run-up, and postflight.

3. The Navy's maintenance force is functionally organized in a structure that is nearly identical to the Army organization.

4. The Navy and Army both use a specialty code and skill level designation for maintenance personnel.

5. Both services use an alert and standby aircraft procedure in support of flight operations.

2.2 Areas of Difference

The major difference between the Army and Navy operations philosophies lies in the area of scheduled inspection and preventive maintenance. The Navy controls the scheduled inspection cycle by calendar time, while the Army inspection cycle is based on cumulative flying time on the aircraft, except in the case of the daily inspection, which is performed each day if the aircraft has flown that day or at least once every 72 hours if the aircraft is capable of being flown but has not flown. The Navy calendar inspection does not require VALUE IV to maintain a record of total flying time by aircraft, while in ARMS this must be done.

There are some differences in the maintenance manpower policies and operational scheduling which result quite naturally from the basic difference in operational environment. A carrier operation at sea must consider different periods of operation and missions than, say, a jungle-based helicopter company.

2.3 ARMS and VALUE IV Flow Structure

The VALUE IV program hierarchy is as follows:

1. Program (Total VALUE IV Model)

2. Routine

3. Subroutine

4. Loop

The routines within ARMS were named in a manner that permits maximum ease of correlation with the VALUE IV counterparts. The flow structures for both models are shown in Figure 1.

It should be noted that even though the routines and subroutines in ARMS cover the same general area of operation as VALUE IV, there are no loop designations in ARMS.

The following paragraphs in this section are devoted to a discussion of the ARMS model. The paragraphs are titled in accordance with the ARMS flow structure. Flow diagrams are presented for the most detailed level available; i.e., if a routine is made up of two or more subroutines, only the subroutines are presented. At the beginning of each paragraph, the applicable ARMS flow diagram and the closest VALUE IV counterparts are referenced.

2.4 ARMS Logic Flow

2.4.1 Aircraft Complement Routine

The purpose of this routine is to identify the mission to be undertaken in the simulation. It also selects and distributes the required aircraft in an organizational structure defined by the input data. The VALUE IV model has the capacity to simulate up to three wings which include three squadrons each. This compares to a capacity of three battalions of three companies each for ARMS. Any portion of either model can be exercised in a given run. It should be noted, however, that the computer memory load and quantity of input data required increase greatly as the number of types of aircraft being simulated is increased. For example, an aviation company is assumed to have two aircraft in the inventory: a heavy lift helicopter and a tactical support helicopter. The reliability, maintenance, supply support, and mission data all must be entered for both aircraft. Once these statistics are in the computer memory, very little increase in program size is needed to increase the number of aircraft of each type or even the number of companies simulated. If, however, a third type of aircraft, e.g., attack helicopter, is added to the inventory, an entire new set of aircraft and mission statistics must be input and the size of the memory required is increased significantly.

The complement of aircraft is divided into two classes: those which are "up" or capable of being flown and those which are "down" or not available for flight. This routine controls the "up" aircraft, which are further divided into the Ready Pool and Alert/Standby Pool.

2.4.1.1 Ready Pool Subroutine

See Figure 2 in regard to ARMS as well as Figure 4 in regard to

VALUE IV. After the initialization of the complement, all aircraft which are available to respond to a mission call are stored in this subroutine. As the aircraft come into the Ready Pool, the priority counters are set for prelaunch status. At the end of daily operations, all "up" aircraft are returned and the complement is scanned for aircraft requiring daily inspection because 72 hours has elapsed since its last daily or because it was flown during the day's operation and the daily has not been performed.

2.4.1.2 Alert/Standby Aircraft Subroutine

See Figure 3 in regard to ARMS as well as Figure 5 in regard to VALUE IV. The Alert/Standby aircraft are designated on a daily basis. As calls are received, other aircraft are selected for Alert/Standby status. The Alert or "Hot Spot" aircraft is replaced from the Standby aircraft once it has been called for a mission.

2.4.2 Mission Generator Routine

See Figure 6 in regard to ARMS as well as Figures 7 and 8 in regard to VALUE IV. This routine in ARMS is primarily concerned with establishing the daily flying requirements and issuing the mission call on schedule. The timing routine which controls the simulated daily clock is also controlled in this routine. The clock is established to advance in increments equal to one-tenth of an hour. At the end of the day's operation, the daily counts are stored and the counters are reset to begin the next day's operation. The clock with one-tenth of an hour divisions is compatible with current field operation procedures for recording elapsed time to perform actions.

The VALUE IV Mission Generator routine calls out the Standby or Alert aircraft when required and also changes mission requirements regarding mission length, number of aircraft required, etc. The control of Alert and Standby call in the ARMS program is handled in the Aircraft Operations routine. Even though these decisions exist at different points in the logic flows, a significant portion of the VALUE IV programming in these areas is expected to be directly applicable to ARMS.

The VALUE IV Flying Termination subroutine has no direct counterpart in ARMS. The Army operation differs significantly from the Navy carrier in this area. The carrier is "on station" and operating a flying schedule for a period of time and then returns to "port" and operates on a non-flying schedule. The Army has no comparable mode of operation. Hence, this portion of the VALUE IV program is deleted from ARMS.

2.4.3 Aircraft Operations Routine

This routine in ARMS compares to the Aircraft Mainline subroutine in the VALUE IV model. In both simulations, the sections are concerned with the flight operations sequence of preflight, flight and postflight. In spite of the similarities of coverage, it is in this area of operations that the greatest differences exist between ARMS and VALUE IV programming requirements. This is primarily due to the requirement in ARMS of logic to cover aircraft loss or emergency landings after takeoff. Neither of these problems is addressed in VALUE IV.

2.4.3.1 Mission Assignment and Summary Subroutine

See Figure 9 in regard to ARMS. There is no comparable flow for VALUE IV. This subroutine controls the daily clock counter for the entire Aircraft Operations routine. After the daily clock is started, mission calls are received from the mission generator, and it is this subroutine that scans the Ready Pool for aircraft to fill the mission call. If no aircraft are available in the Ready Pool, then the standby aircraft are called in accordance with the mission requirements. If there is more than one available aircraft in the Ready Pool, then a decision must be made regarding which aircraft to schedule for the mission. The VALUE IV program would simply reduce the Ready Pool by one count and assume that proper assignment of the mission would place an aircraft, with no regard to serial number designation, into the prelaunch activities. ARMS, however, must consider all available aircraft by tail number and their total individual flying time in such a manner that scheduled inspections and maintenance may be accomplished in an effective manner. This selection criterion is contained in the input data to the program. Once the selection has been made, the aircraft is sent to the Preparation and Preflight subroutine. The VALUE IV programming does not offer any base for building this portion of the ARMS decision logic.

2.4.3.2 Preparation and Preflight Subroutine

See Figure 10 in regard to ARMS as well as Figure 13 in regard to VALUE IV. Aircraft enter this subroutine after they have been selected for a mission. The regular scheduled mission aircraft will come from the mission assignment subroutine, but an aircraft may be designated for a mission while it is still in maintenance and come directly from Release and Reassembly, or it may enter this routine for a test hop via the Release and Reassembly subroutine following scheduled inspection. As the aircraft progresses through this routine, the tasks associated with configuration changes (e.g., remove seats and install litters) and servicing (e.g., fuel, oil, etc.) are completed. The preflight inspection tasks are performed to include ground crew walk-around and air crew engine run-up. The routine then follows the aircraft until takeoff or until completion of the time when ground abort can occur. Throughout this subroutine, when maintenance actions are discovered, they are immediately processed to determine the need for calling up a replacement aircraft from either the Alert/Standby or Ready Pool.

Throughout ARMS, aircraft are either "up" or "down" as described earlier in this report. It should be noted that even though noncritical maintenance actions ("up" squawks) are not considered as sufficient cause individually to ground an aircraft, when a number of these actions have been assessed against the same aircraft, a grounding condition can develop. The ARMS input data contains the maximum allowable number of noncritical maintenance actions which can occur prior to putting the aircraft in a "down" or grounded status. Once an aircraft has been put in a "down" status and sent to maintenance for corrective action, the possibility exists that after clearing only one noncritical action, the maintenance personnel could be preempted into a higher priority job and the aircraft would be restored to an "up" condition and returned to the Ready Pool or to the aircraft operations flow and further preparation for flight. To preclude undesirable program oscillation, the minimum number of noncritical actions which must be cleared prior to returning the aircraft to an "up" status will have to be determined by the programmer through personal discussion with maintenance personnel in the field. The developers of VALUE IV have indicated that detailed discussions with maintenance personnel in the field, i.e., actually on board various carriers, was an invaluable data source for the solution of similar programming details.

Aircraft must pass through this subroutine to enter the Inflight subroutine.

2.4.3.3 Inflight Subroutine

See Figure 11 in regard to ARMS as well as Figure 14 in regard to VALUE IV. This subroutine covers all activities which might occur from the time an aircraft becomes airborne until it returns to the home station. In VALUE IV, the Flight Loop of the Aircraft Mainline subroutine simulates the comparable portion of the Navy mission. VALUE IV, however, considers only the abort condition where the aircraft returns to the carrier, while ARMS is designed to consider various actions which may occur as a result of inflight failure. Since the objective of ARMS is to evaluate any action which could influence system availability, the detailed flow involving aircraft loss and a variety of emergency landing situations prior to recovery of the aircraft at the home station is included in the ARMS flow. These events are not contained in the VALUE IV program.

2.4.3.4 Postflight Subroutine

See Figure 12 in regard to ARMS as well as Figure 15 in regard to VALUE IV. The control of scheduled inspections by elapsed flying time in ARMS has resulted in a rather extensive addition to the VALUE IV logic in this subroutine. Subsequent to each flight, the aircraft flying time must be evaluated for inspection due. In the case of Depot Overhaul, ARMS evaluates and clears the maintenance actions, as required, for movement of the aircraft to the depot. For example, if the aircraft must be flown to the depot, the "down" squawks must be cleared prior to flight. Also, Depot Overhaul is the point where all deferred maintenance actions are cleared; i.e., when the aircraft returns to the Ready Pool from Depot Overhaul, there are no write-ups for maintenance.

If the aircraft does not require a schedule inspection after the flight, the subroutine in ARMS is very similar to VALUE IV in assessing the requirements for turnaround inspection and unscheduled maintenance prior to returning the aircraft to the Ready Pool.

2.4.4 Inspection Routine

The fundamental difference between the VALUE IV and ARMS scheduled maintenance routines arises because VALUE IV inspections are based on both calendar intervals and cumulative flying time. In both cases, most of scheduled time is devoted to inspection, but there are certain prescribed maintenance actions for both Army and Navy procedures. In setting up the ARMS flow, it was decided not to break out daily inspection as a subroutine but to keep it as an optional part of the Line Inspection subroutine.

2.4.4.1 Line Inspection Subroutine

See Figure 16 in regard to ARMS as well as Figures 18 and 19 in regard to VALUE IV. A point that should be noted is that daily inspections are combined with all the other flight-generated inspections as mentioned above. It should also be noted that under certain circumstances, the second shift can be bypassed in favor of a recall procedure.

2.4.4.2 Scheduled Inspection Subroutine

See Figure 17 in regard to ARMS as well as Figure 20 in regard to VALUE IV. This subroutine covers more lengthy intervals than that shown in the previous subroutine. These inspections are primarily generated by maintenance doctrine which is accepted as input by both VALUE IV and ARMS.

A special feature here is a requirement for a test flight. In VALUE IV it is mandatory; in ARMS it is optional, depending on pertinent Army regulations. But, given a requirement for a test flight, the VALUE IV and ARMS logics are similar.

2.4.5 Repair Assessment Routine

All of the unscheduled maintenance actions are accomplished in this routine in both ARMS and VALUE IV.

2.4.5.1 Repair Location Subroutine

See Figure 21 in regard to ARMS as well as Figure 22 in regard to

VALUE IV. The chief difference between the ARMS and VALUE IV versions is that in VALUE IV, if an alert or standby aircraft is discovered to be in a down state, replacement is assumed and accomplished by diminishing the Ready Pool by one. The procedure is consistent with the use of aggregate unit statistics in VALUE IV. On the other hand, in ARMS this replacement process is in the Aircraft Operations routine. The difference arises since replacement is not called unless the projected repair delays (including GSE and NORS) exceed the allowable ready time. Individual projections are possible since ARMS tracks by serial number. Otherwise, in this subroutine, the Navy's flight deck and hangar deck repair locations are considered to be comparable to the Army's flight line and maintenance shack areas, and the delay logic associated with repair location respot is retained in ARMS.

2.4.5.2 Repair Part Assessment Subroutine

See Figure 21 in regard to ARMS as well as Figure 23 in regard to VALUE IV. This subroutine for ARMS was taken directly from VALUE IV without change. The flow diagram (Figure 21) is considered to be self-explanatory except for one item, i.e., "Time Delay Limit." This is a programming constraint to prevent an aircraft from spending an excessive period of simulation time in repair. The constraints, themselves, are developed by the program operators based on their experience in operating the simulation.

2.4.5.3 Manpower Assessment Subroutine

See Figure 21 in regard to ARMS as well as Figure 24 in regard to VALUE IV. After a part failure has been identified, the requirements for the number of men and skill types in the repair team are identified in both ARMS and VALUE IV. In VALUE IV, requirements are rather inflexible and queues form if the proper teams are not available. On the other hand, ARMS allows for the fact that certain maintenance men are cross-trained in other jobs. For example, on the helicopter flight line, any man whose MOS number begins with the digits "67" is assumed to be equally skillful in all jobs calling for an MOS number beginning with "67." In other cases, a man with a particular MOS when working out of skill would be considered "unskilled." After determination of allowable substitutions, ARMS then adjusts times to repair to reflect the use of unskilled personnel. Another input vector which should be modified is the probability of successful repair. Ideally, this vector should vary if substitutions are made in the specified teams for particular repairs. Logic is provided in ARMS for this effect, even though data on skill versus successful repair may be difficult to obtain.

2.4.5.4 MTTR Subroutine

See Figure 21 in regard to ARMS as well as Figure 25 in regard to VALUE IV. As in the previous subroutine, the significant difference between the ARMS and VALUE IV versions arises because of MOS substitution. Also, the effect of augmenting a repair team by men working either in or out of skill is considered.

2.4.5.5 GSE Delay Subroutine

See Figure 21 in regard to ARMS as well as Figure 25 in regard to VALUE IV. After determination of repair time, an additional delay must be imposed; namely, delay, if any, for acquisition of proper Ground Support Equipment (GSE). The ARMS and VALUE IV subroutines are identical.

2.4.6 Unscheduled Maintenance Routine

It is within this routine in both ARMS and VALUE IV that unscheduled aircraft repair is actually accomplished. There is one difference between the ARMS and the VALUE IV logic in this area. In ARMS, there is a provision for the substitution of maintenance men from other specialties when the required men are not available. The decision statistics and criteria which allow the assessment of the effect of the substitution are contained in the input data.

2.4.6.1 Manpower Acquisition Subroutine

See Figure 21 in regard to ARMS as well as Figure 28 in regard to VALUE IV. This subroutine contains the ARMS provision discussed above. An addition can be made very easily to the VALUE IV program to insert this logic; otherwise, the VALUE IV program can be used intact for the ARMS logic.

2.4.6.2 Aircraft Release and Reassembly Subroutine

See Figure 27 in regard to ARMS as well as Figure 29 in regard to VALUE IV. All completed actions carried out within the flows are collected and assembled against an individual aircraft in this subroutine, and the aircraft is then sent to a test hop or to ready status. The VALUE IV flow and program should require no change for use in ARMS.

2.4.7 NORS/Cannibalization Routine

See Figure 30 in regard to ARMS as well as Figure 31 in regard to VALUE IV. Two features of the VALUE IV flow should be noted. VALUE IV uses this routine for, among other things, collecting and processing various maintenance and logistics data. Another feature is that there are two methods of cannibalization. For aircraft defined to the component or part level, aircraft in down status are examined on a serialized basis (even though output is not by serial number) for availability of the required part. If the part is present, the proper maintenance personnel and facilities are assigned to the aircraft in question awaiting parts.

On the other hand, for CAE,* the availability of a part is determined by generating a random number and deciding whether a part is available by reference to the historical probabilities that cannibalization for a particular part is possible. This VALUE IV feature for aircraft defined only to the level of a relatively few subsystems is considered to be quite useful and would be used by ARMS for CAE (without reference to the priority scheme described below). For non-CAE simulations, though, ARMS would use a more detailed approach as follows.

Since ARMS tracks individual helicopters, the tactical status of NORS aircraft must be checked. If a NORS helicopter is on mission, alert or standby call, the expected time to restore the aircraft to an "up" condition is compared to the remaining time to possible or actual takeoff. For helicopters assigned missions, the takeoff times are assigned. For helicopters on alert or standby, there are maximum permissible ready times: e.g., the alert aircraft must be ready to fly in ½ hour; the standby must be ready in 4 hours. The expected time for "up restoration" would be either the MTTR for a part (non-stochastic) or replacement time from GS or Depot, plus associated on-site maintenance time. It is also possible that the user might add a safety factor to expected restoration time where the safety factor could be based on the standard deviation of restoration time. If the expected time to place the aircraft in an "up" condition is not compatible with operational requirements, a replacement aircraft is selected.

In VALUE IV, an aircraft enters NORS status by receiving a stock-out response from sampling (Monte Carlo) the supply function when parts are required. In this case, cannibalization is attempted as the next step; if unsuccessful, the expected time to parts replacement determines the NORS delay. While this aircraft is being retained in NORS, another aircraft may issue a call for the same part, receive an in-stock response from supply, and continue into the repair portion of the model.

In ARMS, if cannibalization is possible, it may be that more than one NORS aircraft could supply the required part. If so, the aircraft with the longest NORS delay prior to removal of the part is designated as "Hangar Queen." With this procedure, there are two possibilities: (1) if the NORS delay due to removal of the part in question is less than the previous NORS delay (maximum of parts delay), cannibalization has no adverse impact on NORS or availability; and (2) if the new NORS delay is greater than the delays already assessed, the final NORS delay for the aircraft is minimized by the procedure. The added flows in the ARMS routine compared to VALUE IV are:

- Interaction between NORS delay and operational requirements
- Priority scheme for assigning replacement or repaired parts to aircraft
- Priority scheme for cannibalization ("Hangar Queen" designation)

When a part is returned from repair in ARMS, if there are more than one

*Conceptual Aircraft Evaluation

aircraft awaiting parts, then the part is assigned to that aircraft having minimum delay time after installation of the part. Under this arrangement, if the installation of the part will return an aircraft to ready status from NORS, then that is the aircraft selected to receive the part. If more than one aircraft falls in this category, then the aircraft that has been NORS for the longest period of time is selected to receive the part.

2.4.8 Maintenance Determination Routine

See Figure 32 in regard to ARMS as well as Figure 33 in regard to VALUE IV. The Maintenance Determination routine in ARMS is identical to the Failure Determination routine in VALUE IV. The aircraft proceeds through this routine from other sections of the program whenever maintenance actions have occurred. The routine determines the hierarchy of the maintenance actions or failure, i.e., system, component and part, as applicable. The actions are then filed against the individual aircraft concerned. Once all the actions have been evaluated, the determination is made regarding the "up" or "down" status of the aircraft. If the aircraft is in a "down" status, it is forwarded directly to the Unscheduled Maintenance routine. If the aircraft is in an "up" status, it is returned to the originating routine for further flights if required. If the flying schedule is no longer active for the day, then the "up" squawk aircraft are forwarded to the Unscheduled Maintenance routine to compete for maintenance.

2.4.9 Manpower Control Routine

It is within this routine that the maintenance manpower timing is established and controlled. There is only one minor difference between ARMS and VALUE IV logic flow; that is, the capability in ARMS to have maintenance personnel work overtime.

2.4.9.1 Shift Termination Subroutine

See Figure 34 in regard to ARMS as well as Figure 35 in regard to VALUE IV. Although second shifts are not used by the Army when operating in combat, the subroutine is retained intact from VALUE IV to ARMS so that the effects of second-shift operation can be assessed, if desired, either in the combat or the peacetime/training environment.

2.4.9.2 Shift Change Subroutine

See Figure 34 in regard to ARMS as well as Figure 35 in regard to VALUE IV. This subroutine considers the actual operation of the shift. The ARMS consideration of overtime work occurs in this subroutine. In VALUE IV, all the men are released after the shift time has expired; in ARMS, men may be held for overtime not to exceed a maximum workday limit which is specified by the user in the input data. Otherwise, the VALUE IV logic flow and programming are used without any change.

2.4.9.3 Manpower Reduction Subroutine

See Figure 34 in regard to ARMS as well as Figure 35 in regard to VALUE IV. The user may specify variations in maintenance manpower through this subroutine. The variations are established as options through the input data which may be exercised or not, as the user desires. The ARMS and VALUE IV logic flows are identical in this subroutine.

2.4.10 Organization and Direct Support (DS) for Repair Routine

See Figure 36 in regard to ARMS as well as Figure 37 in regard to VALUE IV. Both ARMS and the VALUE IV routines start with a decision to repair or scrap a part where the logic to make the decision is input by the user. As in VALUE IV, ARMS then makes an organizational repair capability decision (either because the part is not supposed to be repaired at the level specified, the usual definition of Beyond Capability of Maintenance (BCM), or because of a lack of resources). Then ARMS adds a BCM decision (usual definition) at the DS level. Thus, DS support to the organization is provided if needed. Next, both ARMS and VALUE IV consider the possibility of false alarm. If maintenance is triggered by a false alarm (false alarm probability is an input), repair is considered successful. ARMS sends the part to a NORS/Cannibalization Aircraft if needed, or to supply if not needed. In VALUE IV, the part goes directly to supply with implications discussed below. ARMS also sends parts returning from GS/Depot, after specified delay, to NORS/Cannibalization Aircraft or to Supply as above. On the other hand, VALUE IV sends returned Depot parts only to Supply.

If repair is unsuccessful, ARMS recycles the part through either organization or DS until success is achieved. In the VALUE IV flow, a determination is made after every unsuccessful repair as to whether a part is BCM. Since data on probability of BCM as a function of number of unsuccessful repairs may be difficult to obtain from Army data, ARMS uses a simpler logic. Finally, after successful repair, ARMS and VALUE IV dispose of the part as in the false alarm and return from Depot cases.

It should be noted that repaired parts go only to supply in VALUE IV without reference to aircraft in NORS (for any reasons, including cannibalization). Hence, overall NORS delays are specified in VALUE IV without reference to the possibility of repairing individual aircraft in NORS queues. On the other hand, given the GS/Depot NORS delay inputs, the NORS delay on individual aircraft is computed internally by ARMS. (GS delays would also be internal if the model were scoped at brigade level). ARMS also handles cannibalization on a serial number basis.

2.4.11 Data Compilation Routine

This routine collects data from throughout the program. The calculations which are required to produce the desired output are performed. The outputs from the model may be structured to meet the users' demands. VALUE IV is constructed to provide some "standard" outputs, i.e., availability, NORS, NORM, MMH, etc. This output section of the VALUE IV program is used intact by ARMS for this report. When the ARMS program is written, the format and/or content of this section may be easily structured to meet the specific demands of the user.

3.0 INPUT AND OUTPUT

3.1 Input Data

3.1.1 General

In specifying ARMS inputs, the basic assumptions of VALUE IV were made; namely, independent failure rates (except for combat damage) and independence of mission and maintenance. That is, conditional failure probabilities and conditional mission calls are not specified. It was also assumed that the simulation would not extend beyond Direct Support; hence, no specific Depot outputs are called out. However, separate inputs are required for the levels modeled (organizational, D/S, possibly G/S). Other assumptions used in specifying inputs are discussed under the headings below.

3.1.2 Procedural Inputs

Operational and maintenance procedures in VALUE IV are based on typical practices in the fleet. Procedural optimization by means of such techniques as dynamic and nonlinear programming is not considered compatible with the structure of the model. The VALUE IV "typical procedure" approach is considered sound and is recommended for ARMS. However, the ARMS model should be flexible enough to accept specified procedural changes. To illustrate, it might be desirable to compare availability using the current procedure of a daily helicopter inspection versus the same type of inspection performed after each landing. But in any event, the baseline case would be current Army practice. Therefore, as emphasized by those connected with VALUE IV, every effort should be made to ascertain actual field procedures wherever there is a possibility of divergence from those prescribed in Army regulations. Further, operational/maintenance practices may vary among organizations, so information for a representative cross section of units should be obtained. Obviously, the weighting factors used to combine the field information into a single baseline procedural logic (for each environment) will be in part subjective. This baseline procedural logic should cover the following.

3.1.2.1 Operational Procedures

- Typical mission lead times; e.g., mission call is received 12 hours before first takeoff.
- Permissible delays before mission is canceled.
- Alert/Standby procedures; e.g., x helicopters must be ready to fly in h hours and y helicopters in n hours.
- Method for transferring aircraft from Ready Pool to Standby/Alert.

3.1.2.2 Inspection Procedures

- Type: Calendar, cumulative flying time, functional (e.g., after maintenance).
- Schedule: Calendar intervals or time between overhauls (TBO) and associated Depot delays if any.
- Subsystems which are inspected.
- Mandatory maintenance or service actions.
- Subsystems stressed; e.g., engine run-up or not, rotor engaged or not.
- Test flight required upon completion.

3.1.2.3 Maintenance Procedures

- Method of assignment of parts repair to organization, D/S, G/S, or Depot.
- Repair priority systems within critical/noncritical failure categories.
- Correspondence between MOS speciality and subsystem/ part to be repaired or inspected. Also, designation of MOS's assignable to certain repair job on an unskilled basis. Alternately, composition of team by MOS assigned to repair or inspect specific sub-systems.
- Correspondence between required GSE and subsystem/ part to be repaired or inspected.
- Repair versus scrap logic; i.e., probability that part which normally would be repaired is so damaged that part is condemned.
- Maximum noncritical maintenance items allowable per aircraft (can also be treated as a parameter).
- Standard Depot delay for parts not repairable by organization within model.
- Manpower recall procedure.
- Designation of maintenance actions that may require a test flight.
- Probability of the designated maintenance actions

actually requiring a test hop.

- Method for designating "Hangar Queen" for cannibalization purposes.

3.1.3 Mission Inputs

- Mission frequency functions (designated as to whether regular or surge conditions prevail)
- Special mission requirements, by type of mission; e.g., if a configuration change is involved or if special requirements, such as ordnance, are involved.
- Mission duration and frequency for each condition/type above.
- Mission priorities.

3.1.4 Parts Inputs

It is necessary to identify all subsystems and parts to be considered in the simulation. Preferably, parts will be identified by the decimal system work unit code used in VALUE IV (Ref. 2).

3.1.5 System/Subsystem/Parts Failure Inputs

Failure Frequencies on a When-Discovered Basis (Ground Crew/Air Crew Preflight, Takeoff, Inflight, Scheduled Maintenance).

If a negative exponential distribution is assumed, then failure rates (λ_i) are sufficient. Also, if a negative exponential is used for all parts, only one failure function need be stored in computer memory. Naturally, though, the "unit Lambda" needs to be multiplied by factors corresponding to each parts failure rate. If failure rates are not available on a when-discovered basis, total failure rates for each subsystem/part may be used if the assumption is made that mechanical failures occur only because of stress. Thus, "K" factor inputs are needed to convert total mission times to equivalent stress time. That is, equivalent overall mission time $= \sum K_i t_i$, where t_i = duration of various phases of the mission from pre-to-postflight inspection and K_i are environmental factors usually furnished by the helicopter contractors. Alternatively, separate failure rates may be designated for helicopter operational and nonoperational periods. This breakout is especially convenient for Conceptual Aircraft Evaluation (CAE).

Classification of Subsystem/Part Failure by Consequence.

Consequences are: immediate crash, immediate flight abort (because of real failures or false alarm indications), flight abort followed by return to base (mission aborts could be scored by determining whether the failure occurred before or after one-half total mission time), ground abort, critical malfunctions during flights precluding future flights but not causing mission aborts, and noncritical malfunctions. Further, the percentages of time that a given failure results in the consequences above are required.

3.1.6 Repair and Inspection Times

3.1.6.1 Data Format

In the VALUE IV Model, it is assumed that time-to-repair follows a negative exponential distribution. Thus, mean-time-to-repair (MTTR) can be used to generate stochastic repair times. Helicopter MTTR's are sometimes referred to as "Flat Rates," as in Reference 3. In this reference, Flat Rates are given for CONUS, rear-area field, and combat-field conditions; hence, environment influences MTTR. However, use of MTTR for probabilistic calculations entails the exponential assumption. If the exponential assumption does not hold, repair times may actually follow a log normal or some empirical distribution, and multiple observations on time to repair specific subsystems are needed. This follows since, if repair times are log normally distributed, inputs on MTTR and standard deviations of repair time are required. If an empirical distribution is used, data on individual repair times for a particular part under a specified environment are needed to allow for development of cumulative distribution functions.

3.1.6.2 Team Problem

The Flat Rates from Reference 3 are given on a team basis. In VALUE IV, teams are called Work Centers and are composed of a fixed number of men comprising a variety of specialities and skill levels. (A team can be one man, of course). The situation where teams are augmented or reduced (with men working in or out of skill) cannot be treated.

Accordingly, it is considered desirable to specify team MTTR as a function of team size and MOS composition. If MTTR as a function of team size and MOS is not available, impact of maintenance manpower on system availability may be investigated by varying the number of teams rather than the team size and composition.

3.1.6.3 Basis for MTTR

In using MTTR data for simulation input, it will be important to define exactly what MTTR includes. If, for example, the Flat Rates are based upon a certain sequence of operations for fault isolation, the quoted Flat Rates are not suitable for investigating changes in fault isolation procedures or to evaluate the impact of diagnostic equipment such as BITE (Built-In Test Equipment). For example, if a certain three-compartment subsystem fails, the mechanic may be instructed first to check Part A, then Part B, then Part C. The Flat Rates would reflect this procedure and the relative probabilities of failure of the three parts. Under these circumstances, knowing that a particular part had failed would not impact the MTTR as it should.

3.1.6.4 Probability of Successful Repair

To measure maintenance training and individual effectiveness, the probability that a given repair results in transition of a part from a failed to an operating state is required.

3.1.6.5 False Alarm Failures and Repair

To score missions lost due to false indications, the rates for each failure mode of applicable display equipment will have to be established. That is, the rate at which the display shows "green" when, in fact, "red" prevails or the rate at which the display shows "red" when, in fact, condition "green" prevails should be defined. The MTTR's may also reflect false alarm repairs; specifically, removal of good parts for repair.

3.1.6.6 Inspection Times

The foregoing remarks on MTTR apply also to inspection times. However, it is possible that these times might be treated as non-stochastic parameters without undue loss of realism. Also, the sequence of inspection is not as critical as the prescribed sequence of activities for fault isolation and repair.

3.1.6.7 Service Times

VALUE IV does require service time inputs, which presumably include fuel and lubricant service and ordnance loading. Deterministic inputs are recommended here. Moreover, since members of the service teams are generally not highly skilled, inputs formulated on a team (rather than by individual MOS) basis are acceptable.

3.1.7 Organizational Inputs

The TOE of all organization types included in the model will be required at least as base-line inputs, plus any modifications to the TOE that are typically made in the field. It will also be necessary to define all maintenance teams (VALUE IV Work Centers) in terms of number and types of MOS comprising each team. In addition, maintenance activities and their capabilities and capacities must be identified. Finally, availability factors for manpower to account for leave, sickness, school attendance, non-maintenance duties, etc., are required. These availability factors should, if possible, be factored for environment. For example, time spent on guard duty by a maintenance man in a combat environment will lower his availability more than the time spent on guard duty in a peacetime/training environment.

3.1.8 Logistic Inputs

3.1.8.1 Probabilistic Approach

In VALUE IV and ARMS, the basic logistic inputs are independent probabilities of "stock-out" on a particular subsystem/part. That is, the probability of a particular part's being out of stock at time "t" is independent of the probability of a similar stock-out at some later time "t+Δt". Accordingly, it is convenient to specify logistic input as a vector of stock-out probabilities and associated stock replenishment delay times. Associated with this vector is one defining probabilities that parts are bad on issue.

3.1.8.2 Cannibalization Probabilities

Simulation of the actual process of cannibalization for evaluation of field maintenance procedures is recommended. In this case no special input other than helicopter parts lists and the procedure for selecting the "Hangar Queen" is required. However, for CAE, the probabilistic approach used in VALUE IV is recommended. That is, availability of a subsystem is determined by independent generation of random numbers. This approach is used when an aircraft is defined to the level of only a few major subsystems. If an aircraft is defined in this way, an unrealistically high NORS arises, since failure of even one minor component not in stock calls for utilization of a major subsystem (containing many parts) as the part replacement.

3.1.9 Combat Damage Inputs

Combat damage can and does impose a severe and highly variable load on both maintenance and logistics. This burden extends from flight line maintenance in a combat zone to repair and overhaul. Accordingly, consideration of combat damage is recommended. For example, given that a projectile enters a subsystem at a certain position, velocity, and angle, failure of the components will not be independent, to mention one problem. To bypass the correlated failure problem and the problem of deriving distributions, based on helicopter geometry, a more aggregated approach is suggested for the present. To implement this approach, the following inputs are required:

1. Probability of combat damage for each type of mission.

2. Distribution of repair times for <u>all</u> types of damages classified as battle induced. That is, total repair times aggregated for all maintenance actions associated with combat damage are needed.

3. Number and kind of MOS needed for combat damage repair corresponding to a particular repair time, or repair time interval. To illustrate, all jobs lasting from 1 to 2 hours require certain MOS's. Depending on data availability, the MOS call could be programmed on a deterministic or stochastic basis. If deterministic, a single set of MOS requirements is input for each

repair time. If stochastic, the magnitude of the random repair time drawn would indicate the particular MOS requirements distribution to be sampled. (For example, a long repair time might weight MOS requirements toward airframe mechanics).

From the standpoint of ARMS programming logic, use of the suggested approach confines all combat damage to one "dummy" helicopter part, but a distribution of repair times rather than a single MTTR is required for the "dummy" part.

3.1.10 Miscellaneous Inputs

3.1.10.1 Environment

As mentioned, it may be possible to segregate data by operational environment. This can be done by use of Flat Rates or possibly by use of K factors that are applicable to combat or noncombat operation in a particular geographic area. It is strongly recommended that advantage be taken of any environmental data that does exist (such as environmental oriented Flat Rates) to gain some idea of the effect of environment on R&M policies and on system availability.

3.1.10.2 Ground Support Equipment (GSE)

The type and amount of GSE are specified in the applicable TOE's, but GSE reliability does not greatly influence VALUE IV outputs as it stands. VALUE IV incorporates GSE availability in its program logic, and this feature can be used, assuming that GSE capacity and capability are defined in the input. Alternately, GSE impact can be specified as a probability of delay for a specified time as in VALUE IV. The VALUE IV GSE input format is recommended for ARMS.

3.1.10.3 Weather

Weather inputs are not required for VALUE IV, and due to the ambiguous effect of weather on aircraft availability, it does not appear desirable to include a weather routine in ARMS.

3.1.10.4 Maintenance Location Routine

It will take some finite time to move and position helicopters for operation, service and maintenance. A subroutine covering these repositioning delays is in VALUE IV (Respot), and use of the subroutine in ARMS will entail collection of data on positioning times. Input in deterministic (averages) format is suggested.

3.1.10.5 Administrative Delays

Unproductive administrative time during the maintenance periods does indeed exist. This delay time is extremely variable, depending on the local circumstances. It is, in fact, of so random a nature that care must be exercised to assure the proper input data is used each time the simulation is operated.

3.1.11 Mathematical and Computer Considerations

3.1.11.1 Form of Input Frequency Functions

Since probabilistic output is desired, input data in the form of cumulative distribution functions will be required. These can be specified either as a theoretical distribution such as negative exponential or in empirical table look-up form. Use of the theoretical form is desirable since evaluation of future operations would depend less on the peculiarities of the data used as a basis for defining the function of interest. Also, theoretical distributions generally require less computer capacity than the corresponding distribution in empirical form.

However, use of theoretical distributions depends on verifying a satisfactory fit of the data to a distribution by some statistical procedure such as Chi Square or Kolmogorov-Smirnov.

If a fit to a theoretical distribution were rejected, then an empirical distribution would have to be used. One way to define empirical distributions is in terms of a finite empirical distribution. Random numbers drawn for any particular stochastic process (such as mission length) can be adjusted to the nearest lattice point, and the desired process output obtained. Alternately, a piecewise linear empirical function could be constructed and probabilities determined by linear interpolation.

3.1.11.2 Simulation Constraints

Presumably, all operational constraints (e.g., maximum permissible hours worked per man per day) will be embodied in the procedural inputs. However, for computational purposes, certain other constraints may have to be imposed on the model in the form of variable constraints. For instance, it may be convenient to impose a limit to aircraft that are awaiting repair or inspection. Certain such limits are imposed in VALUE IV. Presumably, the basis for these constraints was actual operating experience using a particular computer. Accordingly, it is recommended that such purely computational constraints be defined by the judgment of those operating the simulation on a given computer.

3.1.11.3 Start-up Parameters

It is recommended that the program be started in a "loaded" condition to minimize start-up transients. That is, based on historical records, flying hours and maintenance actions outstanding should be assigned initially to each helicopter by serial number. If operation of a newly arrived unit is desired, the parameters can, of course, be set to values consistent with initial deployment of new aircraft.

3.2 Output Data

3.2.1 General

In this section, desirable outputs for the ARMS Model are defined. The philosophy adopted here is that it would be impossible to evaluate the impact of any particular R&M decision on the basis of one single measure of effectiveness. Hence, there will be a vector of outputs associated with any particular evaluation. The various outputs will have to be weighted by the Army. However, the method of weighting or combining the outputs to arrive at a judgment is considered beyond the scope of this report.

3.2.2 Force Operations Outputs

The following output statistics are of general use in evaluating the impact of almost any change in R&M and logistics on helicopter operation:

	Desired Outputs	Comments
1.	Availability, Percent (Organization and Serial No.)	Serial No. statistic not available (n.a.) in VALUE IV
2.	NORM, Percent (Organization and Serial No.)	Serial No. n.a. VALUE IV
3.	NORS, Percent (Organization and Serial No.)	Serial No. n.a. VALUE IV
4.	Number, Percent Sorties Cancelled (by Type)	Available VALUE IV
5.	Number, Percent Late Sorties and Aborts (by Type)	Not available VALUE IV
6.	Number of Sorties (by Type)	Available VALUE IV
7.	Total Flying Hours (Organization and Serial No.)	Serial No. n.a. VALUE IV
8.	Hours Waiting From Mission Call to Takeoff	Available VALUE IV
9.	Hours Standing	Available VALUE IV

3.2.3 Maintenance Personnel Outputs

	Desired Outputs	Comments
1.	Repair Queues for Each MOS or Shop. Note: Whenever MOS is mentioned, comparable statistics on DS and GS shops are also desired (GS statistics only required if model scoped to brigade level).	Available VALUE IV. However, introduction of GS level requires changes.
2.	Hours Worked by MOS (Also Broken Out by Type of Maintenance, i.e., Scheduled, Unscheduled, Support, Inspection, Cannibalization)	Available VALUE IV
3.	Recall Hours (Broken Out as in 2 Above)	Recall procedure not in VALUE IV
4.	Hours Worked Out of Skill by Each MOS	Not Available VALUE IV
5.	Number of Hours of Support to a Particular MOS Furnished by Other MOS Skill	Not Available VALUE IV
6.	Idle Hours While on Duty by MOS	None
7.	Average Jobs in Process per MOS	None
8.	Maintenance Man-Hours (MMH/Sortie)	Available VALUE IV
9.	MMH/Flight Hour	Available VALUE IV
10.	Utilization, Percent by MOS and by Total, i.e., MMH/Total Available Hours	Available VALUE IV
11.	Number of Times Men Working in a Particular Job Had to Switch Jobs Because of Preempt	None
12.	Total MMH and Mean Elapsed Maintenance Time (MEMT) Broken Out as to:	

Desired Output (Cont.)	Comments (Cont.)
a. Army Designation (Organization, DS, GS)	Available VALUE IV
b. Maintenance Type (Scheduled, Unscheduled Combat)	Partially Available VALUE IV
c. Maintenance Function (Remove, Repair, False Alarm, Condemn)	Available VALUE IV
d. Maintenance Activity (Calendar or Cumulative Flying Hours, Inspection, Cannibalization, Support to Direct Maintenance and Service)	All outputs available in VALUE IV. Except all VALUE IV inspections performed on calendar basis, no inspections based on cumulative flying hours.
13. Average Number of Repairs/Helicopter Waiting for Men	Not Available in VALUE IV
14. Inspections Performed	Available VALUE IV

3.2.4 Helicopter Reliability Outputs

Desired Outputs	Comments
1. Number of Maintenance Actions Resulting From:	
a. Preflight Inspection	Available VALUE IV
b. Air Crew Inspection	Available VALUE IV
c. Airborne Failures	Available VALUE IV
d. Calendar Inspections	Available VALUE IV
e. Flight/Hour Inspections	Not Available VALUE IV
f. Air/Ground Aborts	Available VALUE IV
2. Number of Air Aborts and Percent of Missions Ending in Aborts by Type of Abort; i.e., Catastrophic, Immediate (Helicopter Forced to Land Before Ultimately Returning	Statistics on catastrophic and immediate aborts are not available in VALUE IV since aircraft is always assumed to return to carrier.

Desired Outputs (Cont.)	Comments (Cont.)
to Base), Return (Helicopter Ends Flight at Base). Also, Takeoff Aborts May be Classified Under the Return Abort Reading.	
3. Helicopter Status by Serial Number; i.e., in Critical or Noncritical Maintenance, Inspection Standby/Alert, Preflight, Service, Loading, Flying, Standing (Doing Nothing) - by Hours	Not available in VALUE IV because model does not track by tail number.
4. Average Repairs/Helicopter	None
5. Number and Percent of Sorties Without Maintenance Actions	Available in VALUE IV
6. Number of Cannibalizations, Total	Available in VALUE IV
7. Number of Helicopters Sent to Depot or GS if GS Not Modeled. (If Model Limited to Battalion Level, GS Company Would be Outside Model Since GS Company Services More Than One Battalion)	Available in VALUE IV

The above statistics would be particularly useful in determining the operational impact of changing the failure mode and failure rate of various subsystems and parts.

3.2.5 Helicopter Logistics Outputs

Desired Outputs	Comments
1. Average Number of Repairs/ Helicopter Waiting for Parts	Not Available VALUE IV
2. Average Number of Helicopters Waiting for Each Particular Part (NORS queue before each part)	Not Available VALUE IV
3. Parts Utilization (by part)	Available VALUE IV

Desired Output (Cont.)	Comments (Cont.)
4. Parts in NORS, Parts Cannibalization, Parts BCM* (Each Level; i.e., Organization, DS, GS)	Available VALUE IV

3.2.6 Maintenance Equipment Outputs

Desirable Output	Comments
1. GSE Delays	Available VALUE IV
2. GSE Utilization, Percent	Available VALUE IV
3. Ground Facilities Utilization, Percent	Available VALUE IV
4. Diagnostic Equipment Utilization, Percent	Not Specifically Available in VALUE IV

3.2.7 Combat Damage Outputs

There are no outputs of this category in VALUE IV. However, the following outputs will be of interest:

1. Percent Nonavailability Due to Combat Damage
2. Percent NORM Associated With Combat Damage
3. MMH, MEMT Associated With Combat Damage Broken Out by Organization, DS, GS
4. Aborts and Cancelled Missions Due to Combat Damage

3.2.8 Miscellaneous Outputs

The following outputs are available in VALUE IV without programming changes:

1. Ordnance Upload Time
2. Test Flight Down Time

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*Beyond capability of maintenance at specified level of organization.

3. Number of Successful Test Flights

4. Respct Down Time

A statistic, not now in VALUE IV, that also might be important to operational planners would be hours from touchdown to completion of either all maintenance or all critical maintenance. This statistic could be expressed as average, maximum or minimum hours.

3.2.9 Rationale for Serial Number Statistics

Statistics based on helicopter serial number are identified as desirable model outputs for ARMS. Since VALUE IV outputs are currently based on aggregate unit (squadron, company) performance, the advantages and disadvantages of serial number capability should be explained. Some advantages are:

- Less Variance in the Results. In VALUE IV, means are derived by averaging the results of each day's run over the time period of the simulation. If the simulation is for 60 days, 60 observations of various outputs such as availability are used to calculate means and standard deviations. On the other hand, if individual statistics are recorded, the daily figure itself will be an average over all the helicopters in a unit. If there are n helicopters in a unit, and the availability figures for individual aircraft were uncorrelative, the standard deviation for the grand average could be reduced by a factor of $1/\sqrt{n}$. In brief, the more observations, the less the variance.

- More Flexibility in Presentation of Statistics. With serial number capability, the statistics can be based either on unit observations for each day averaged over the period of the simulation as in VALUE IV, or on period observations of each helicopter averaged over the number of aircraft in the unit. There will be some degree of correlation among both sets of observations. But it is believed that statistics based on serial numbers will more closely resemble independent sampling than statistics based on daily unit observations. For example, during surge conditions, low availability one day is apt to be followed by low availability the next day. But the availability of helicopter #1 over the whole period should not be too highly correlated with the availability of helicopter #2 over the whole period. In brief, there is less autocorrelation on a cross section than on a time series.

- More Compatibility With Cumulative Flying Time Inspection. As mentioned before, VALUE IV inspections are based on calendar time. In practice, it is assumed that a fairly constant percentage of the unit complement is assigned to inspection at a given time. Thus, the inspection load is fairly even. If inspections are based on "cumulative flying hours," the inspection load is more variable.

A track of cumulative flying hours by serial number will result in outputs reflecting this variability. It might be noted, though, that the inspection load variability can be somewhat reduced by judicious assignment of missions to particular aircraft; simulation of this assignment procedure, however, requires serial number capability.

- Compatibility With Other Studies. Certain studies such as Reference 4 are based on a track of failures and maintenance actions by individual helicopter. Simulation outputs in a similar format would facilitate comparison of the "real world" statistics with the simulation statistics. The chief disadvantage of serial number capability is that greater computer memory capacity (compared to output base' on unit statistics) is required.

4.0 CONCLUSION

The following is a list of changes/additions that were made in the VALUE IV logic/programming during development of ARMS for this report:

- Tail number tracking capability
- TBO's based on calendar and cumulative flying time
- Variable maintenance team (size and composition)
- Air crew (crew chief) repair capability
- Skill substitution (maintenance personnel)
- Overtime work
- Recall of maintenance personnel after shift release
- Third level of maintenance
- Emergency landing and subsequent recovery
- Internal (program) mission/requirement generation
- Variable mission schedule
- Tail number scheduling
- Tail number selection for alert/standby
- Alert/standby selection based on projected maintenance time
- Alert/standby selected daily
- Allowable late takeoff
- NORS/cannibalization procedures based on individual aircraft calls
- Stock-level oriented logistics
- Combat damage consideration

Since most of these items involve additions to the already operational VALUE IV program, it is concluded that the implementation of ARMS as described herein will provide the Army with a valuable tool for use in reliability and maintainability studies and evaluations.

5.0 RECOMMENDATION

It is recommended that the Army implement this simulation as soon as practicable.

ARMS	VALUE IV

1.0 AIRCRAFT COMPLEMENT ROUTINE
  1.1 Ready Pool Subroutine
  1.2 Alert/Standby Subroutine
2.0 MISSION GENERATOR ROUTINE
3.0 AIRCRAFT OPERATIONS ROUTINE
  3.1 Mission Assignment and Summary Subroutine
  3.2 Preparation and Preflight Subroutine
  3.3 Inflight Subroutine
  3.4 Postflight Subroutine
4.0 INSPECTION ROUTINE
  4.1 Line Inspection Subroutine
  4.2 Scheduled Inspection Subroutine
5.0 REPAIR ASSESSMENT ROUTINE
  5.1 Repair Location Subroutine
  5.2 Repair Parts Assessment Subroutine
  5.3 Manpower Assessment Subroutine
  5.4 MTTR Subroutine
  5.5 GSE Delay Subroutine
6.0 UNSCHEDULED MAINTENANCE ROUTINE
  6.1 Manpower Acquisition Subroutine
  6.2 Aircraft Release and Reassembly Subroutine
7.0 NORS/CANNIBALIZATION ROUTINE
8.0 MAINTENANCE DETERMINATION ROUTINE
9.0 MANPOWER CONTROL ROUTINE
  9.1 Shift Termination Subroutine
  9.2 Shift Change Subroutine
  9.3 Manpower Reduction Subroutine
10.0 ORGANIZATIONAL AND DIRECT SUPPORT PARTS REPAIR ROUTINE
11.0 DATA COMPILATION ROUTINE
	1.0 AIRCRAFT ROUTINE
	  1.1 Squadron Definition Subroutine
	    1.1.1 Aircraft Complement Loop
	    1.1.2 Standby Aircraft Loop
	  1.2 Aircraft Mainline Subroutine
	    1.2.1 Prelaunch Loop
	    1.2.2 Flight Loop
	    1.2.3 Postflight Loop
	2.0 MISSION GENERATOR ROUTINE
	  2.1 Scheduled Mission Subroutine
	  2.2 Flying Termination Subroutine
	3.0 SCHEDULED MAINTENANCE ROUTINE
	  3.1 Daily Inspection Subroutine
	  3.2 Line Maintenance Subroutine
	  3.3 Calendar Maintenance Subroutine
	4.0 MAINTENANCE DETERMINATION ROUTINE
	5.0 REPAIR ASSESSMENT ROUTINE
	  5.1 Repair Location Subroutine
	  5.2 Repair Part Assessment Subroutine
	  5.3 Manpower Assessment Subroutine
	  5.4 MTTR Subroutine
	  5.5 GSE Delay Subroutine
	6.0 UNSCHEDULED MAINTENANCE ROUTINE
	  6.1 Manpower Acquisition Subroutine
	  6.2 Aircraft Release and Reassembly Subroutine
	7.0 NORS/CANNIBALIZATION ROUTINE
	8.0 INTERMEDIATE MAINTENANCE ROUTINE
	9.0 MANPOWER CONTROL ROUTINE
	  9.1 Shift Termination Subroutine
	  9.2 Shift Change Subroutine
	  9.3 Manpower Reduction Subroutine
	10.0 DATA COMPILATION ROUTINE

Figure 1. Logic Flow Structures.

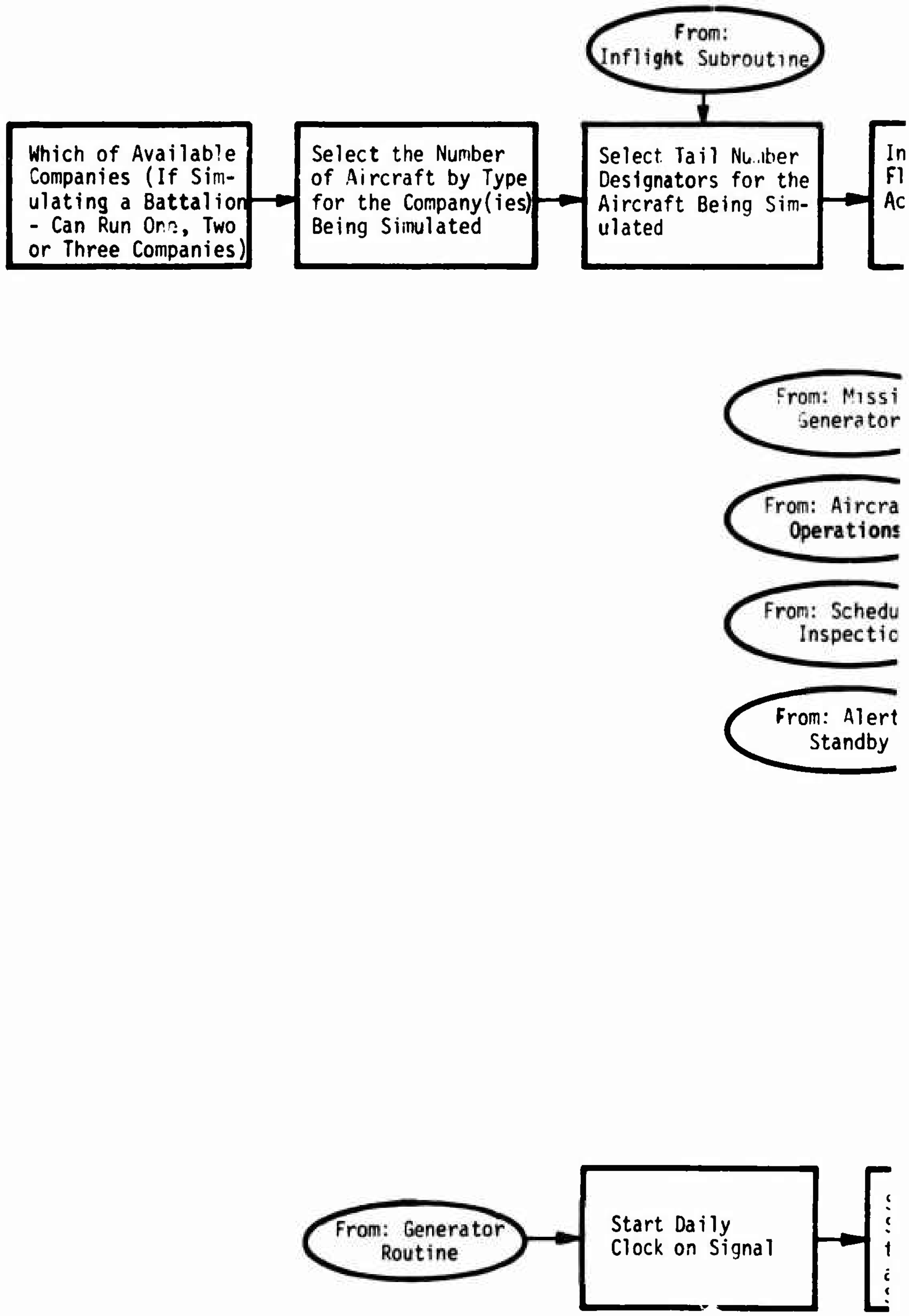
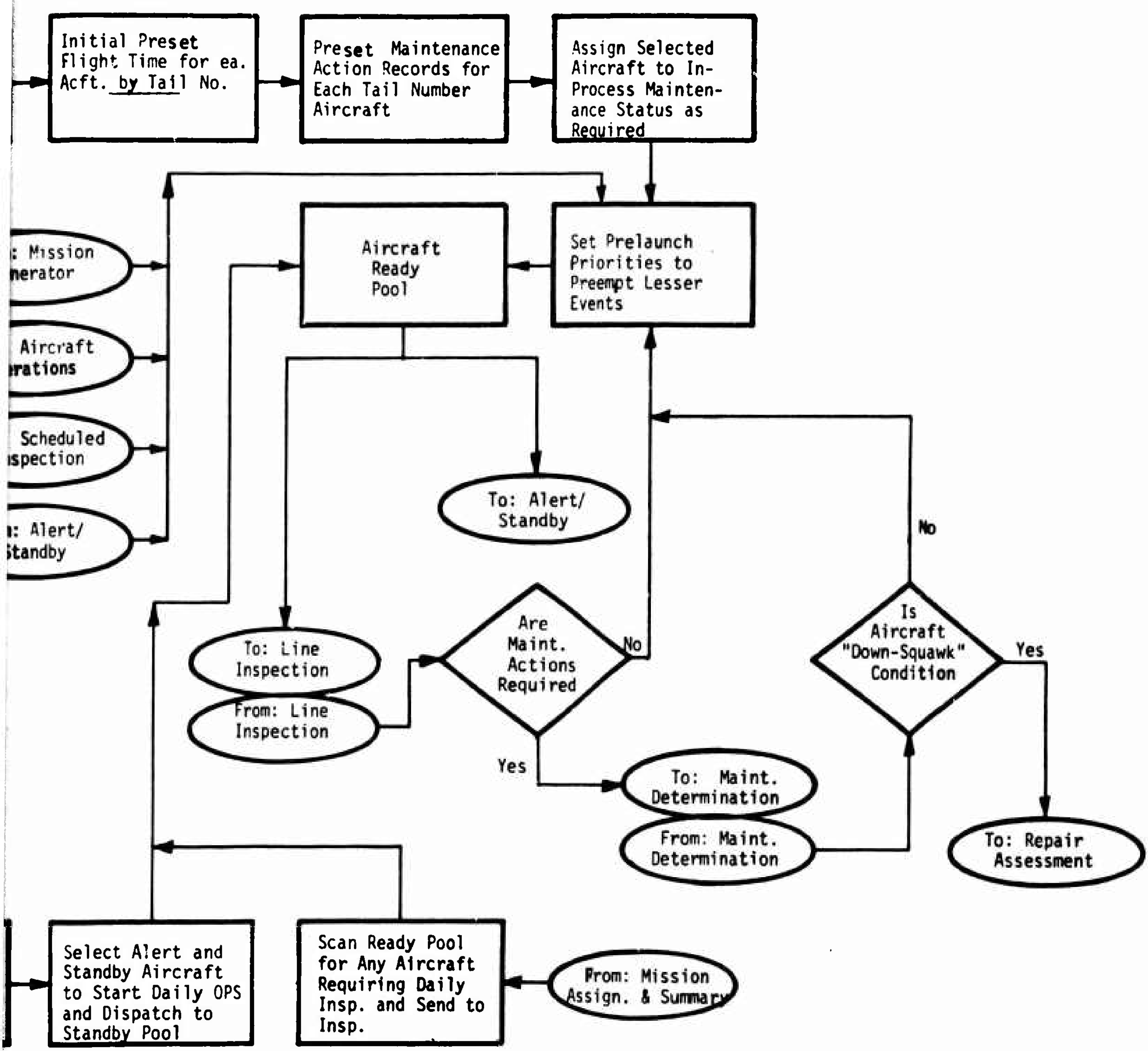


Figure 2. ARMS: Aircraft Complement Routine; Ready Pool Subroutine.



Initial Preset Flight Time for ea. Acft. by Tail No.
Preset Maintenance Action Records for Each Tail Number Aircraft
Assign Selected Aircraft to In-Process Maintenance Status as Required
: Mission nerator
Aircraft Ready Pool
Set Prelaunch Priorities to Preempt Lesser Events
Aircraft rations
Scheduled spection
To: Alert/ Standby
: Alert/ Standby
No
To: Line Inspection
From: Line Inspection
Are Maint. Actions Required
No
Yes
Is Aircraft "Down-Squawk" Condition
Yes
To: Maint. Determination
From: Maint. Determination
To: Repair Assessment
Select Alert and Standby Aircraft to Start Daily OPS and Dispatch to Standby Pool
Scan Ready Pool for Any Aircraft Requiring Daily Insp. and Send to Insp.
From: Mission Assign. & Summary

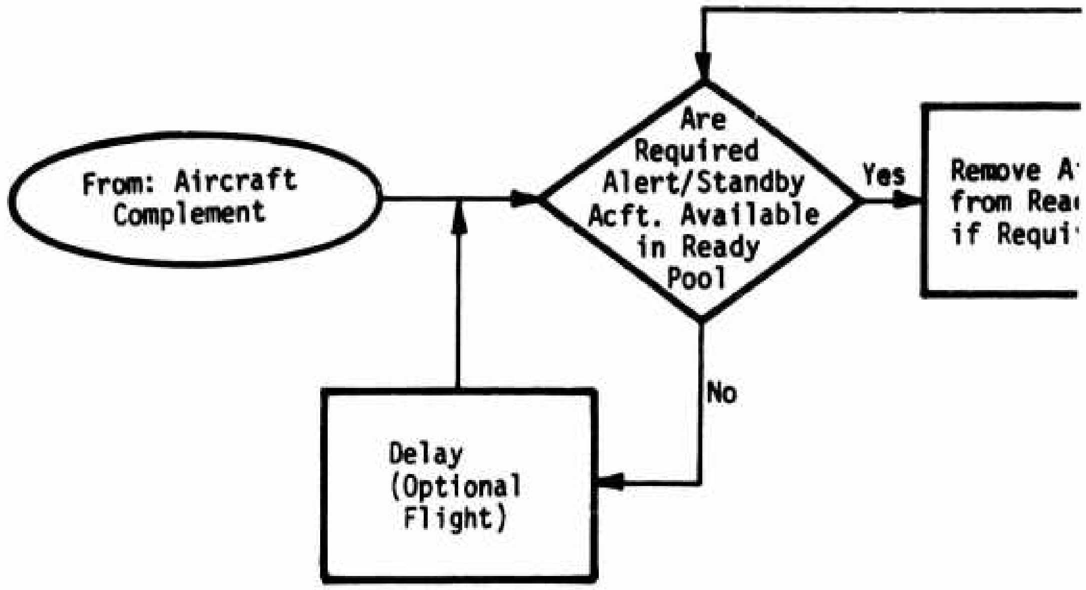
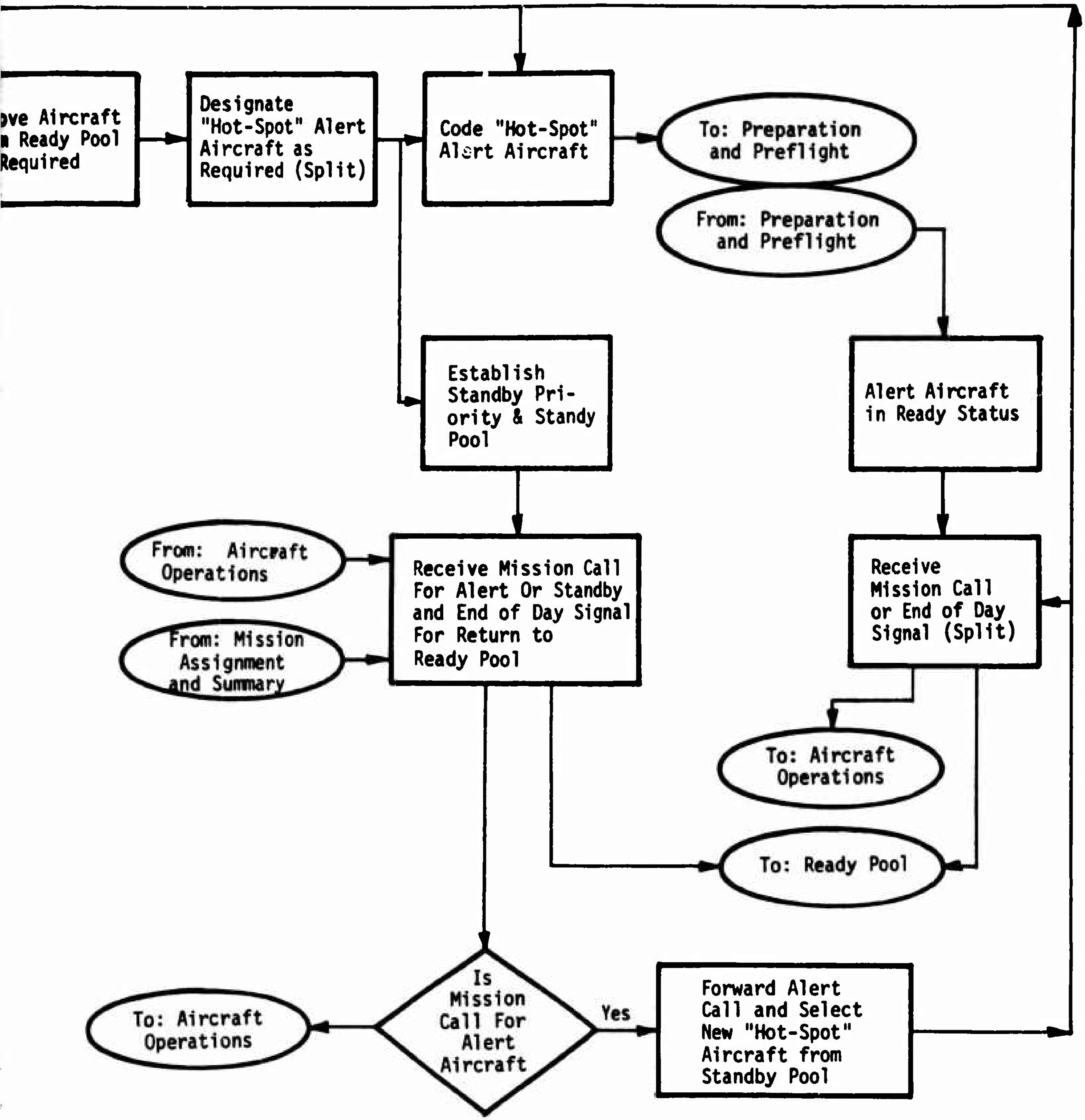


Figure 3. ARMS: Aircraft Complement Routine;
Alert/Standby Aircraft Subroutine.


ove Aircraft
n Ready Pool
Required
Designate "Hot-Spot" Alert Aircraft as Required (Split)
Code "Hot-Spot" Alert Aircraft
To: Preparation and Preflight
From: Preparation and Preflight
Establish Standby Priority & Standy Pool
Alert Aircraft in Ready Status
From: Aircraft Operations
From: Mission Assignment and Summary
Receive Mission Call For Alert Or Standby and End of Day Signal For Return to Ready Pool
Receive Mission Call or End of Day Signal (Split)
To: Aircraft Operations
To: Ready Pool
To: Aircraft Operations
Is Mission Call For Alert Aircraft
Yes
Forward Alert Call and Select New "Hot-Spot" Aircraft from Standby Pool

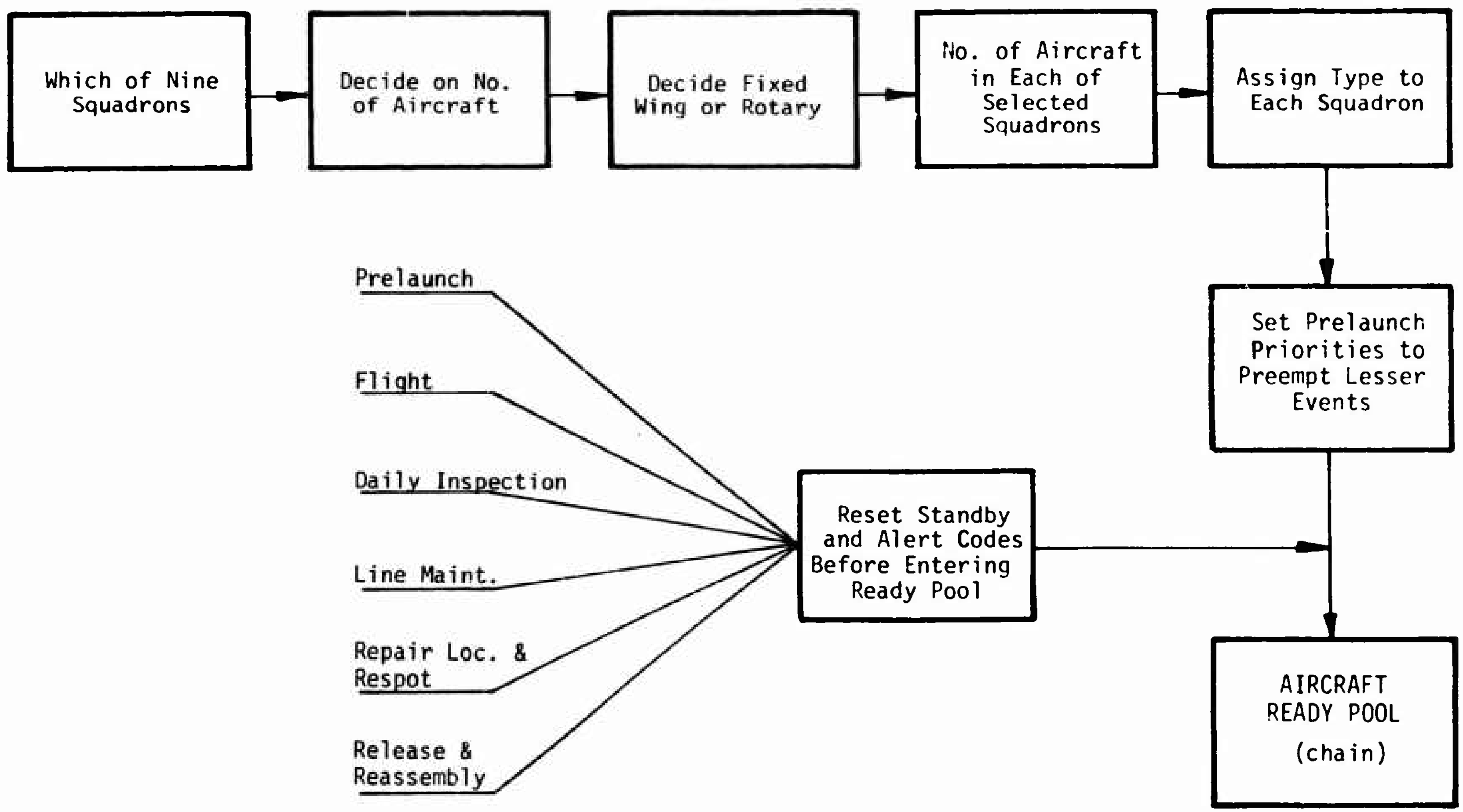


Figure 4. VALUE IV: Aircraft Routine; Squadron Definition Subroutine; Aircraft Complement Loop.

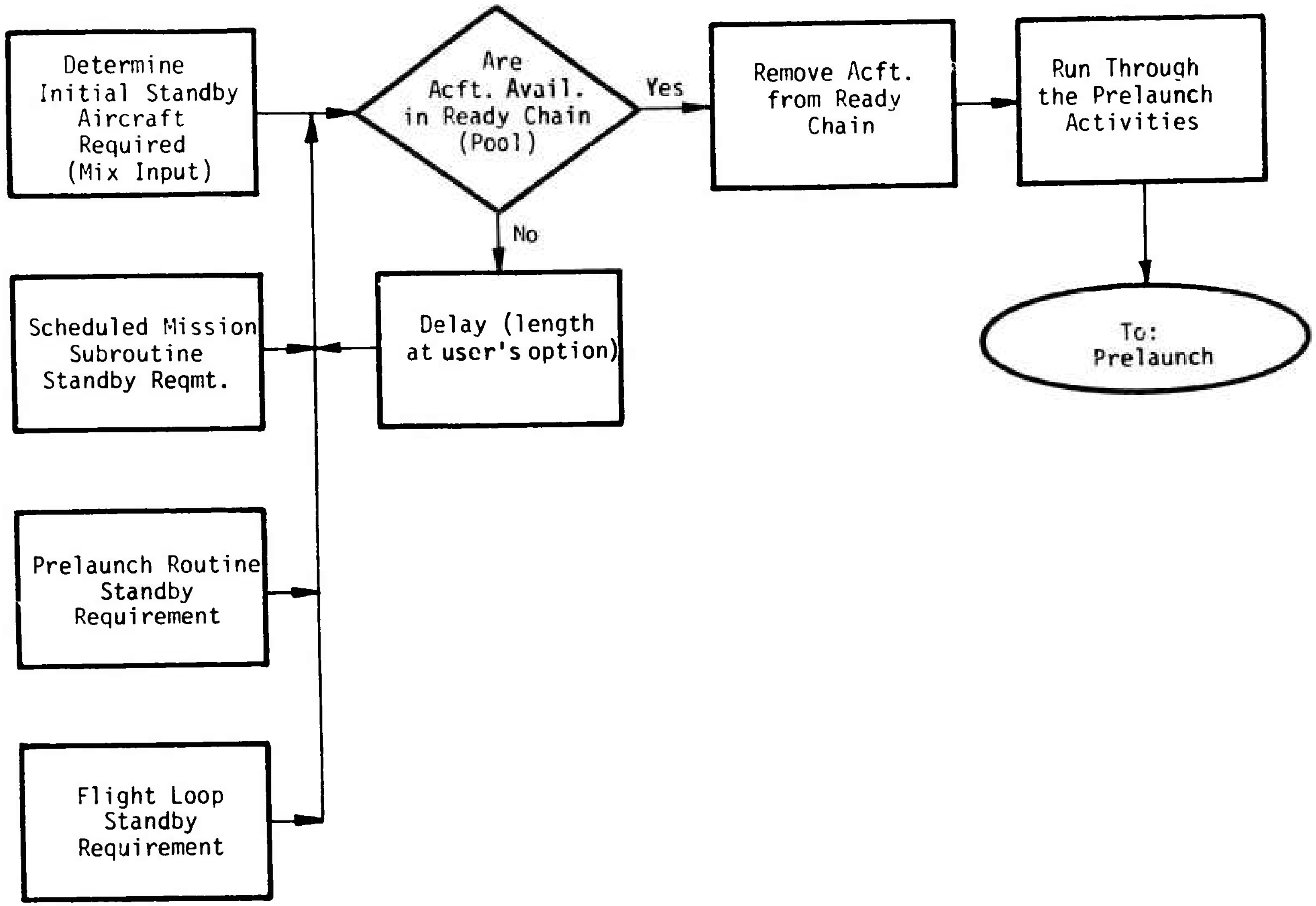


Figure 5. VALUE IV: Aircraft Routine; Squadron Definition Subroutine; Standby Aircraft Loop.

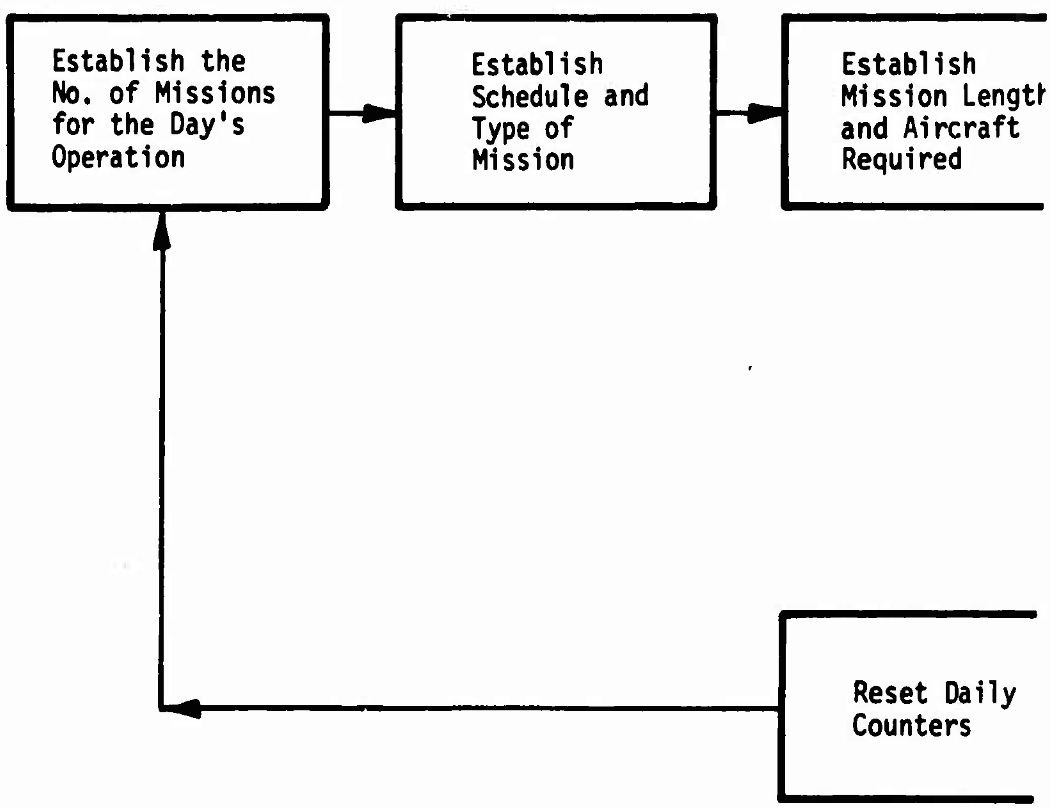
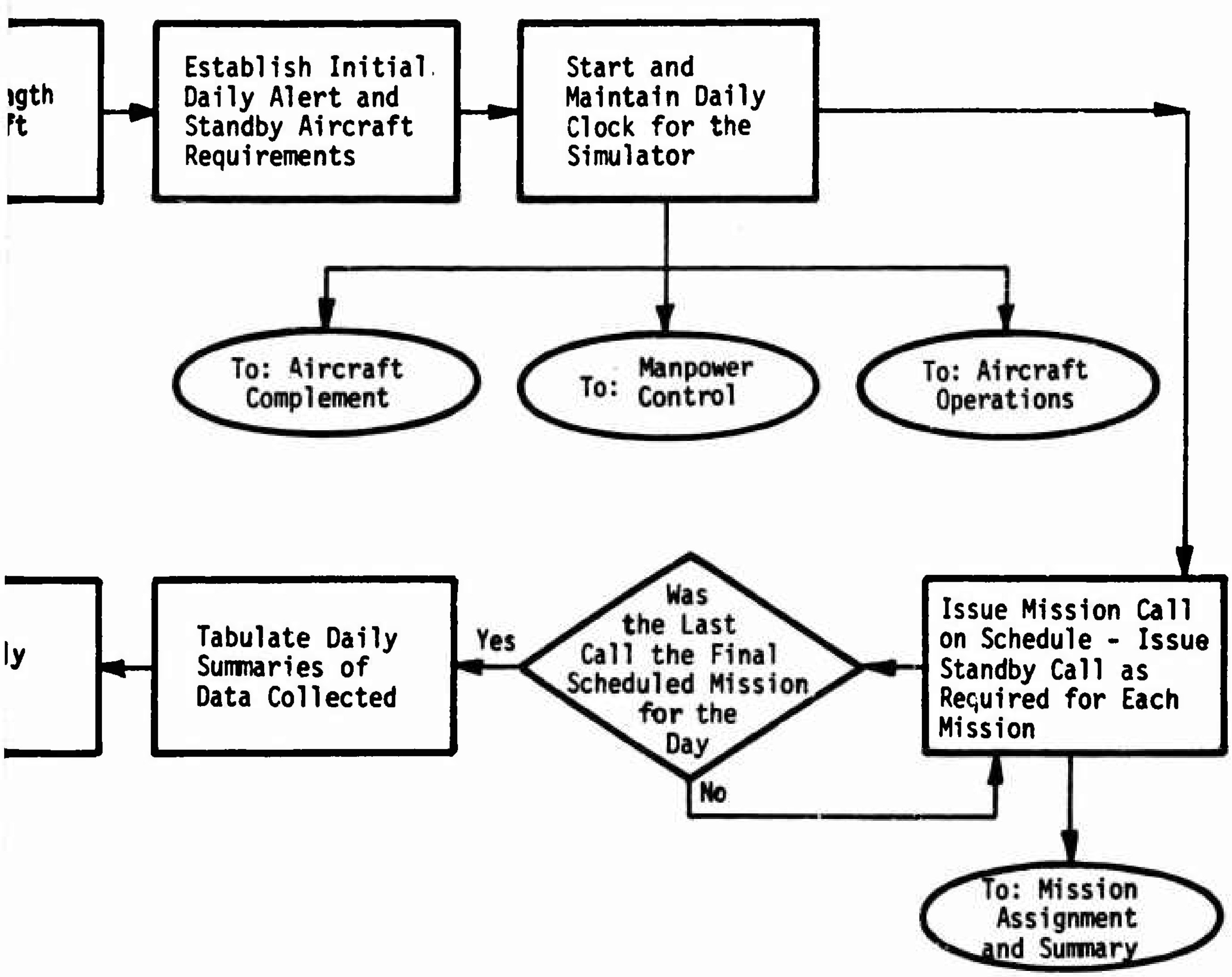


Figure 6. ARMS: Mission Generator Routine.



ngth
ft
Establish Initial Daily Alert and Standby Aircraft Requirements
Start and Maintain Daily Clock for the Simulator
To: Aircraft Complement
To: Manpower Control
To: Aircraft Operations
ly
Tabulate Daily Summaries of Data Collected
Yes
Was the Last Call the Final Scheduled Mission for the Day
No
Issue Mission Call on Schedule - Issue Standby Call as Required for Each Mission
To: Mission Assignment and Summary

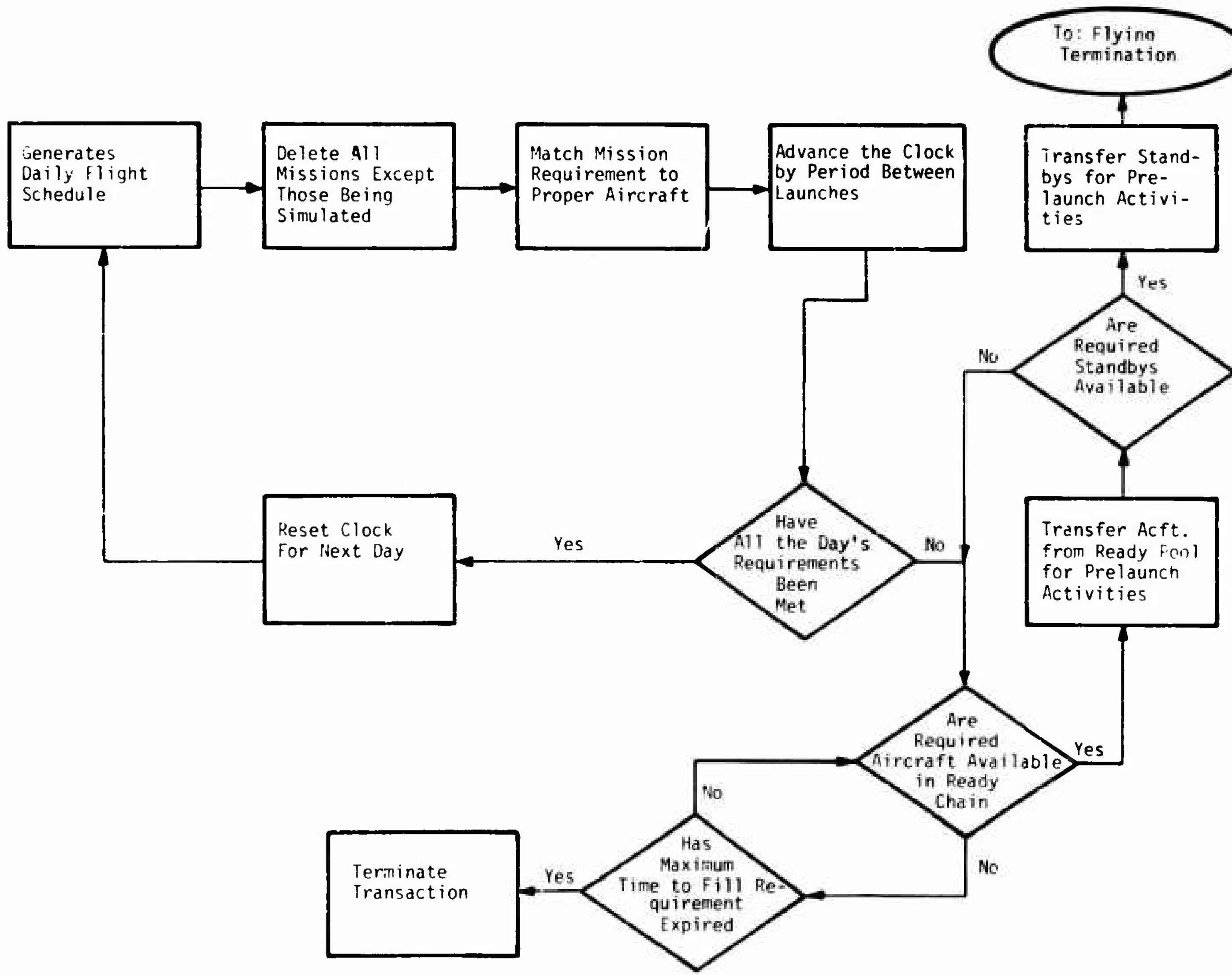


Figure 7. VALUE IV: Mission Generator Routine; Scheduled Mission Subroutine.

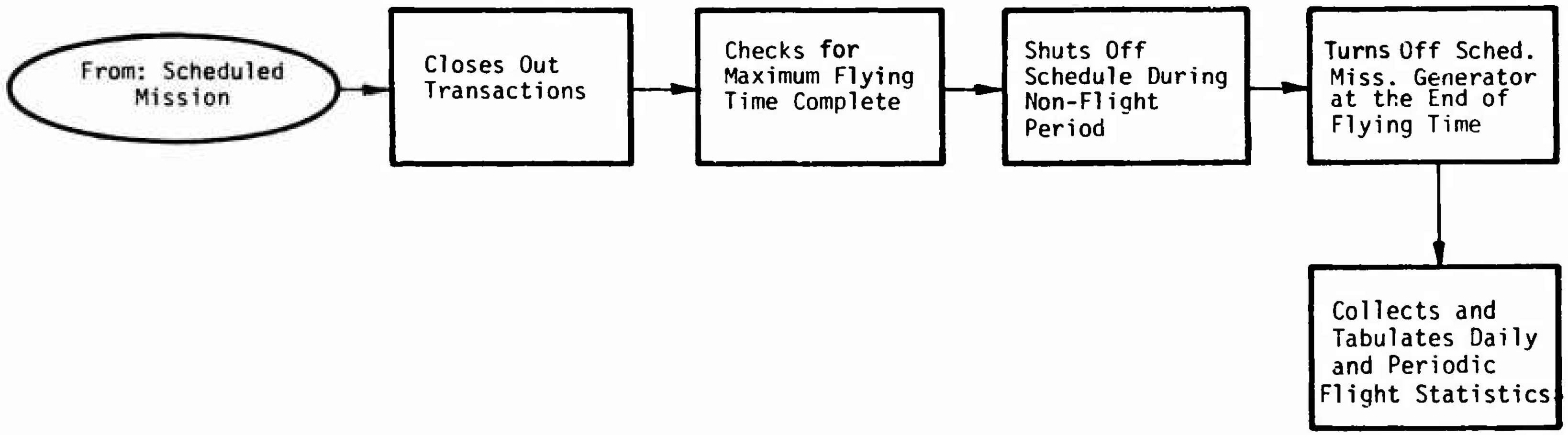


Figure 8. VALUE IV: Mission Generator Routine; Flying Termination Subroutine.

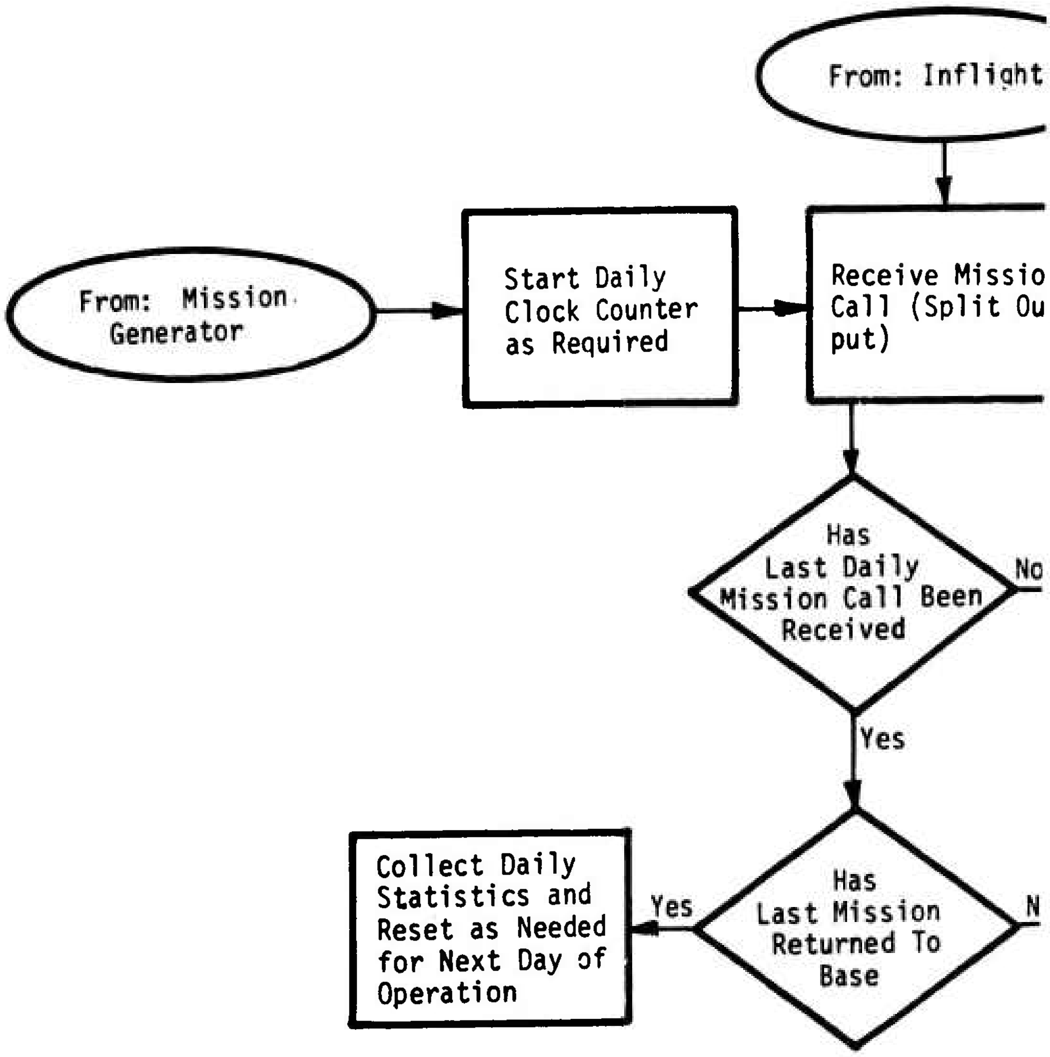
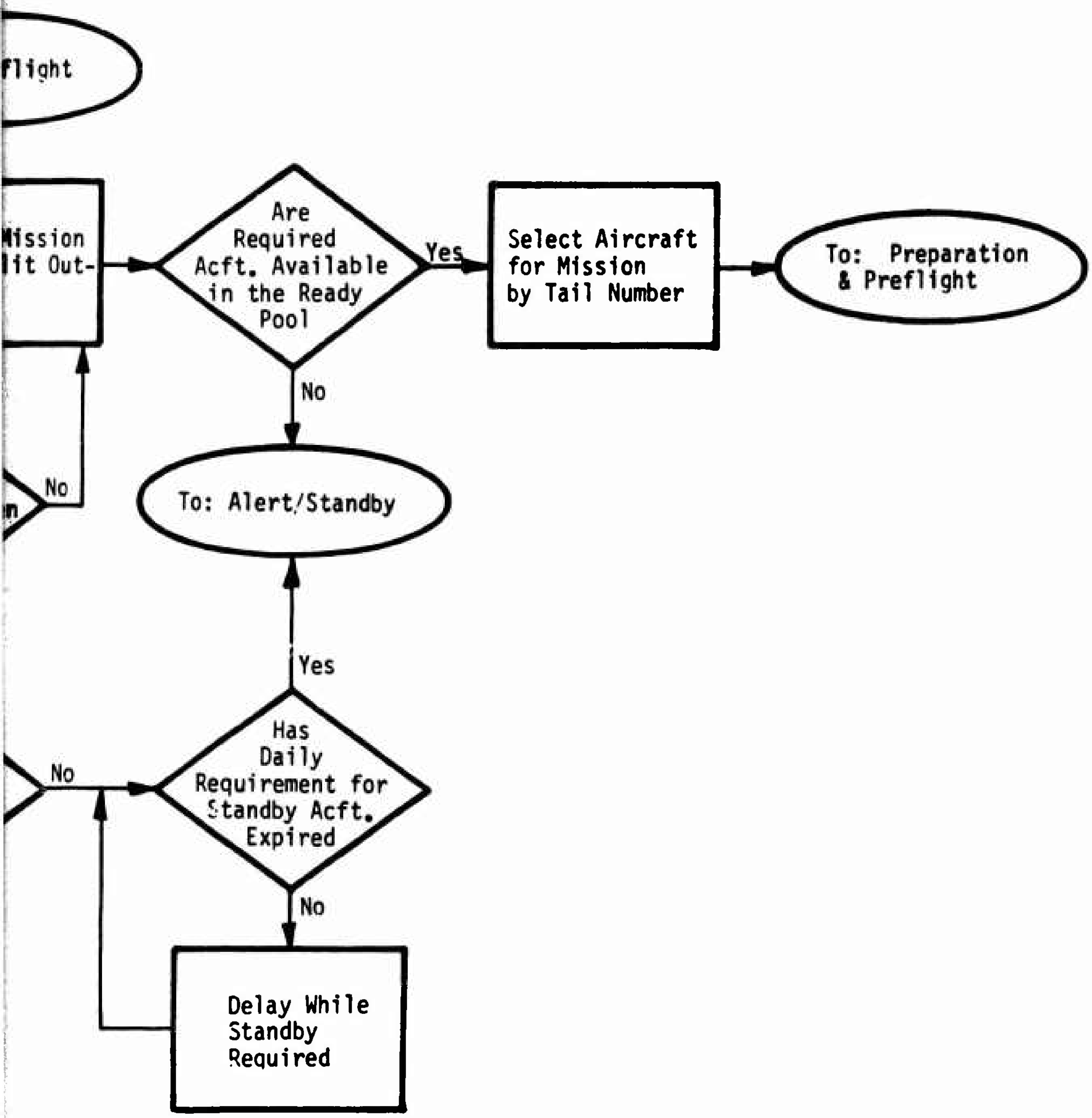


Figure 9. ARMS: Aircraft Operations Routine; Mission Assignment and Summary Subroutine.


flight
Mission
lit Out-
Are Required Acft. Available in the Ready Pool
Yes
Select Aircraft for Mission by Tail Number
To: Preparation & Preflight
No
No
To: Alert/Standby
Yes
No
Has Daily Requirement for Standby Acft. Expired
No
Delay While Standby Required

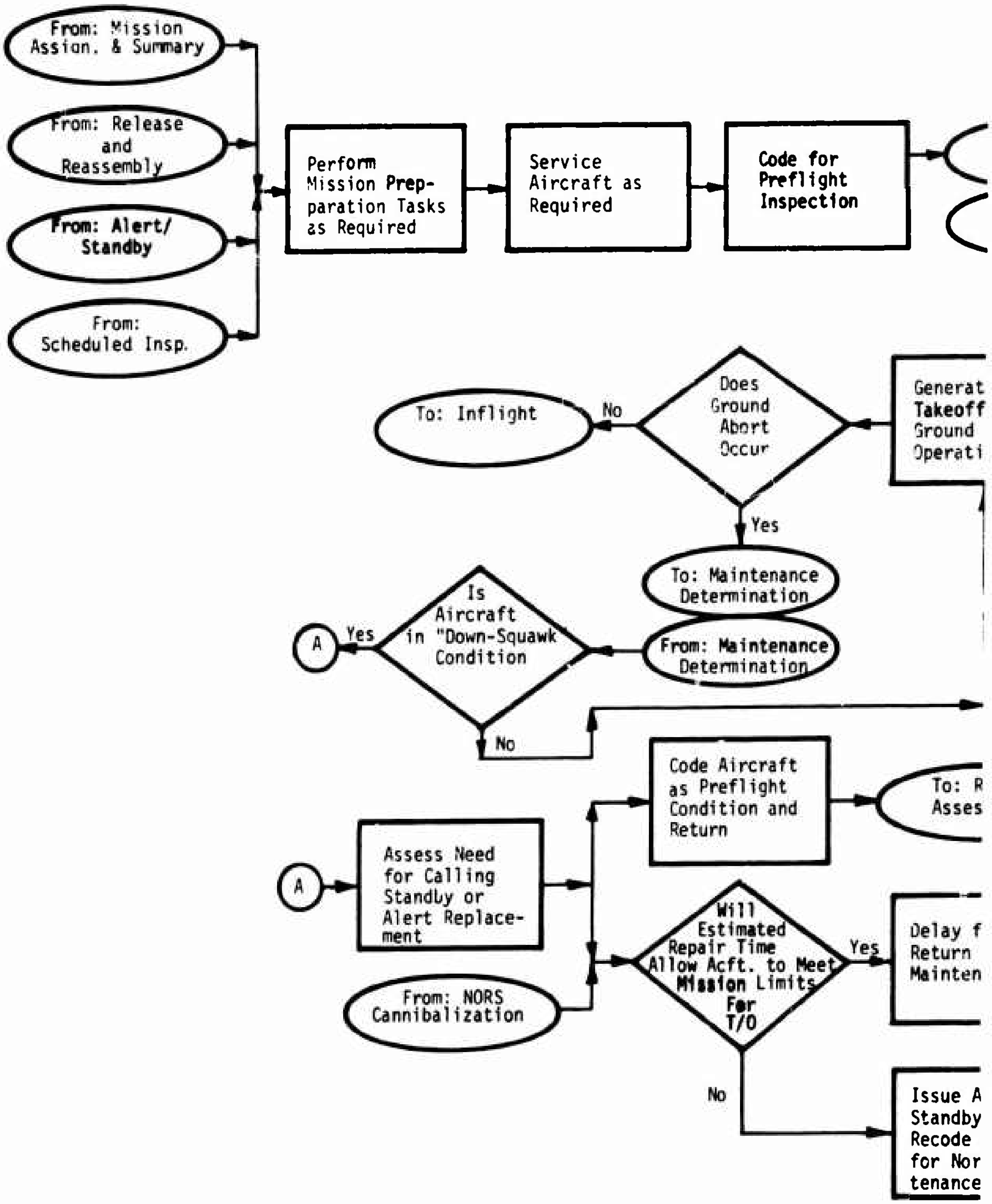
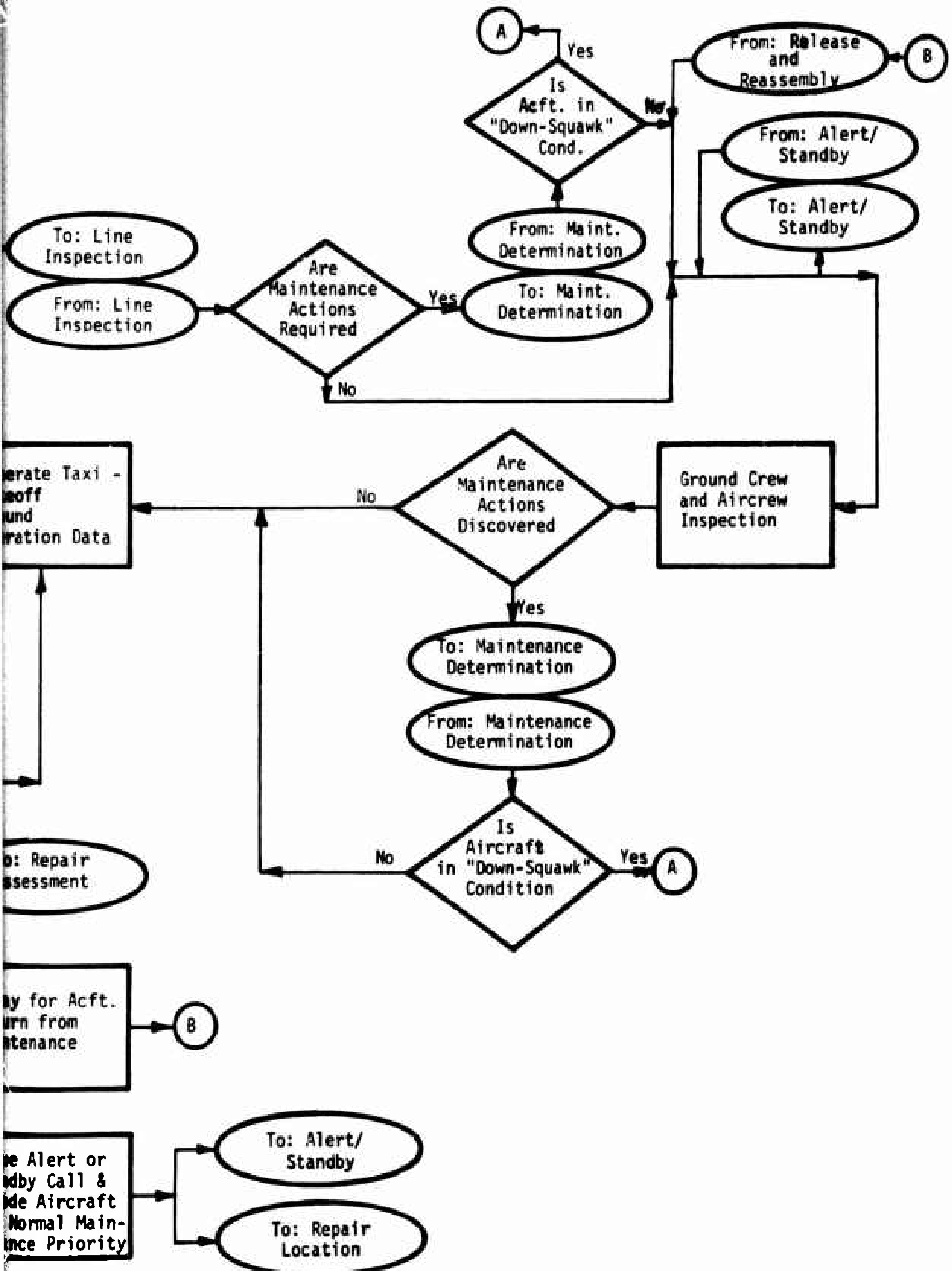


Figure 10. ARMS: Aircraft Operations Routine; Preparation and Preflight Subroutine



A
Yes
Is Acft. in "Down-Squawk" Cond.
No
From: Release and Reassembly
B
From: Alert/ Standby
To: Alert/ Standby
From: Maint. Determination
To: Line Inspection
From: Line Inspection
Are Maintenance Actions Required
Yes
To: Maint. Determination
No
erate Taxi - eoff und ration Data
No
Are Maintenance Actions Discovered
Ground Crew and Aircrew Inspection
Yes
To: Maintenance Determination
From: Maintenance Determination
o: Repair ssessment
No
Is Aircraft in "Down-Squawk" Condition
Yes
A
y for Acft. rn from tenance
B
e Alert or dby Call & de Aircraft Normal Main- nce Priority
To: Alert/ Standby
To: Repair Location

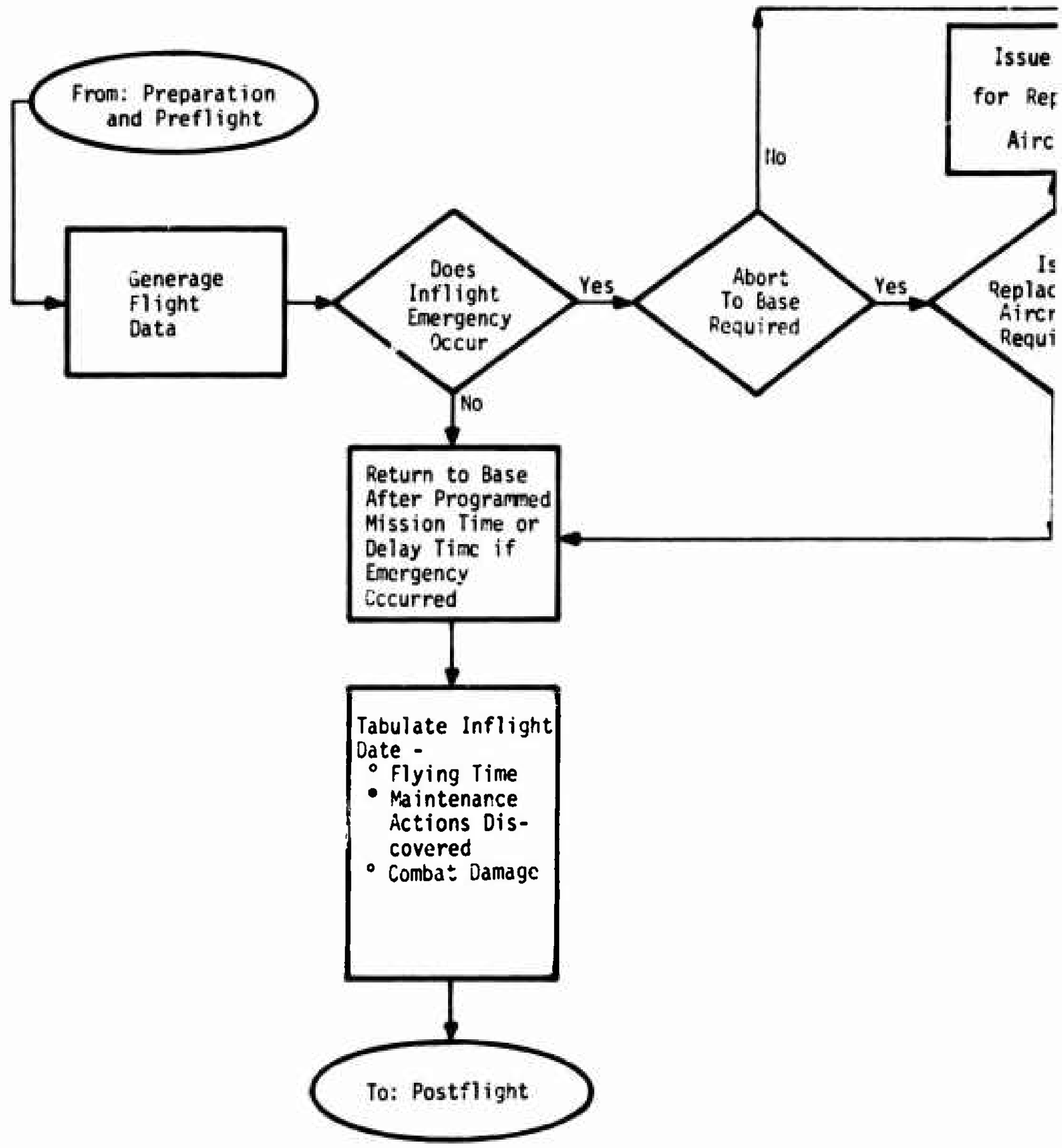
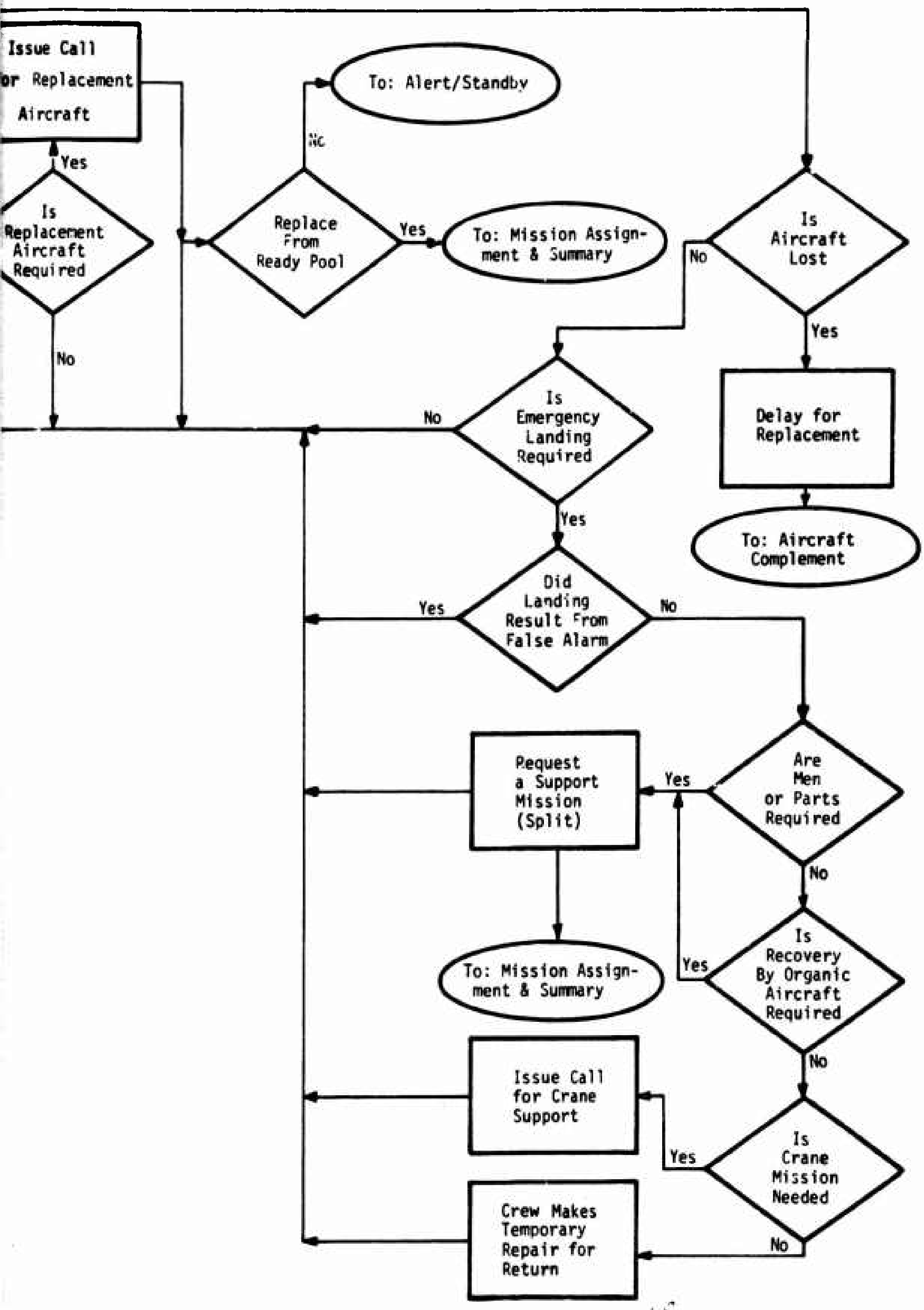


Figure 11. ARMS: Aircraft Operations Routine; Inflight Subroutine.



Issue Call
or Replacement
Aircraft
Yes
Is
Replacement
Aircraft
Required
No
To: Alert/Standby
No
Replace
From
Ready Pool
Yes
To: Mission Assignment & Summary
Is
Aircraft
Lost
No
Yes
Delay for
Replacement
To: Aircraft
Complement
No
Is
Emergency
Landing
Required
Yes
Yes
Did
Landing
Result From
False Alarm
No
Request
a Support
Mission
(Split)
Yes
Are
Men
or Parts
Required
No
To: Mission Assignment & Summary
Yes
Is
Recovery
By Organic
Aircraft
Required
No
Issue Call
for Crane
Support
Yes
Is
Crane
Mission
Needed
No
Crew Makes
Temporary
Repair for
Return

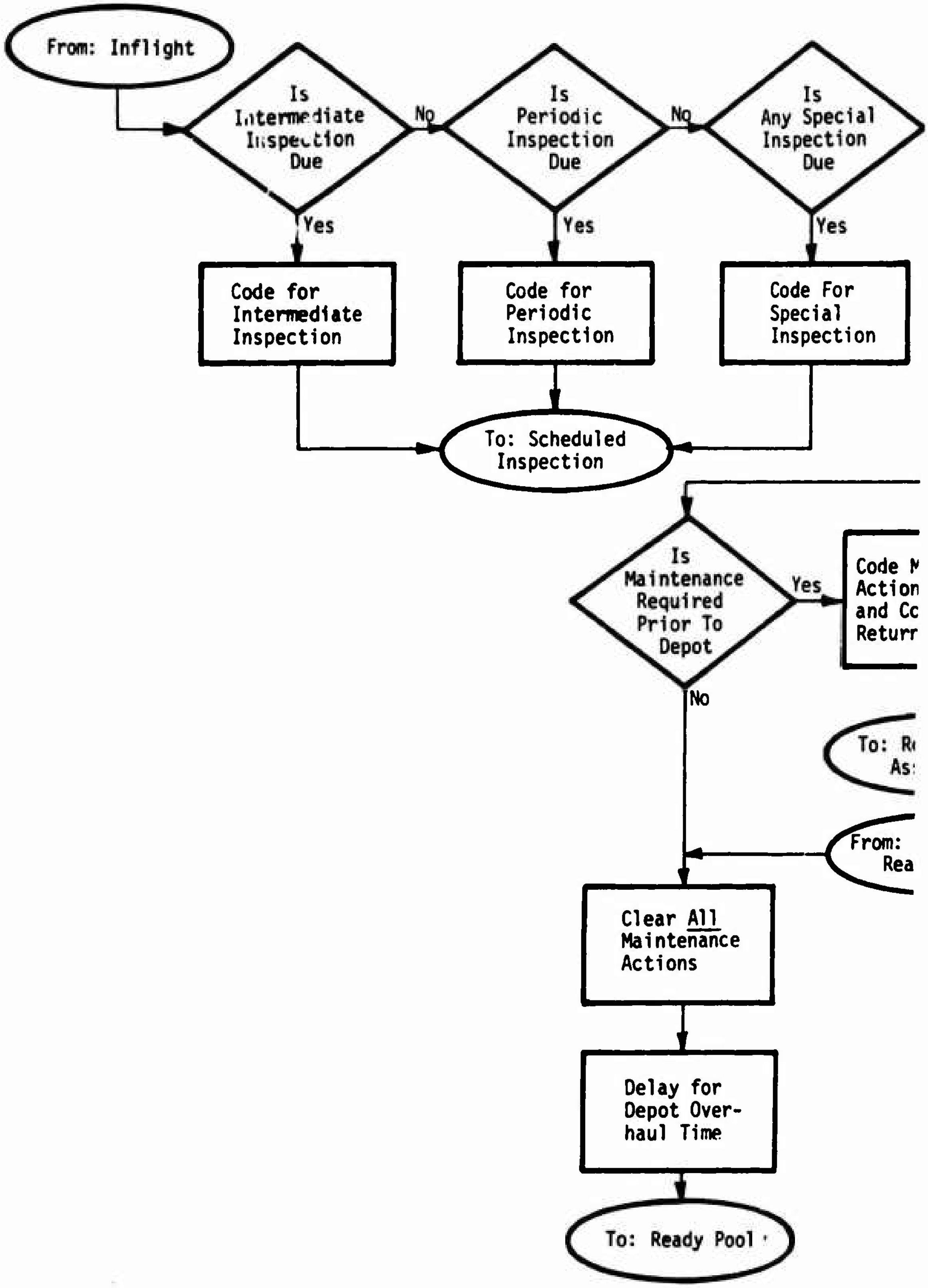
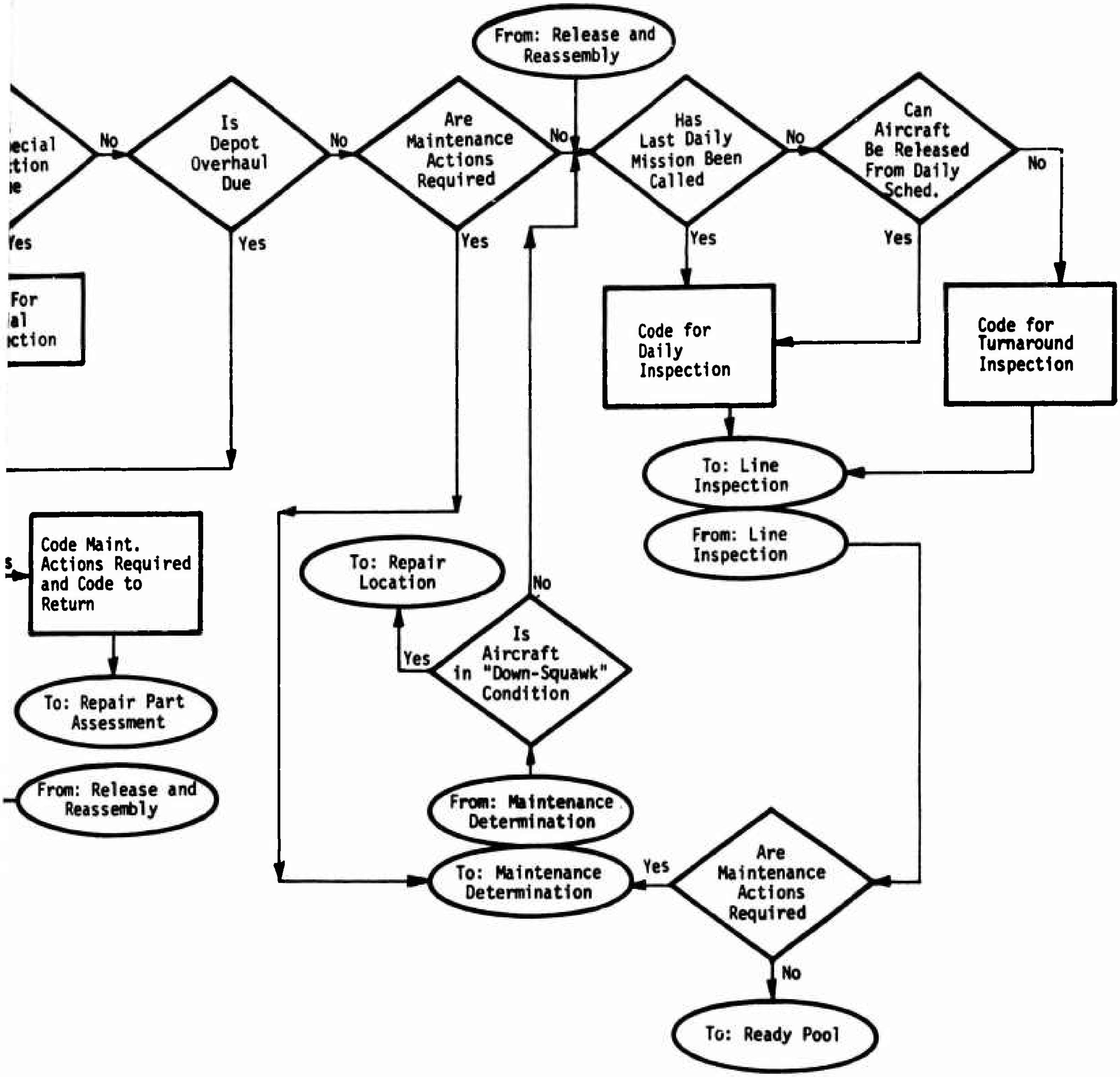


Figure 12. ARMS: Aircraft Operations Routine; Postflight Subroubine.



From: Release and Reassembly
pecial
ction
ue
No
Is Depot Overhaul Due
No
Are Maintenance Actions Required
No
Has Last Daily Mission Been Called
No
Can Aircraft Be Released From Daily Sched.
No
Yes
Yes
Yes
Yes
Yes
For
al
ection
Code for Daily Inspection
Code for Turnaround Inspection
To: Line Inspection
From: Line Inspection
Code Maint. Actions Required and Code to Return
To: Repair Location
No
Is Aircraft in "Down-Squawk" Condition
Yes
To: Repair Part Assessment
From: Release and Reassembly
From: Maintenance Determination
To: Maintenance Determination
Yes
Are Maintenance Actions Required
No
To: Ready Pool

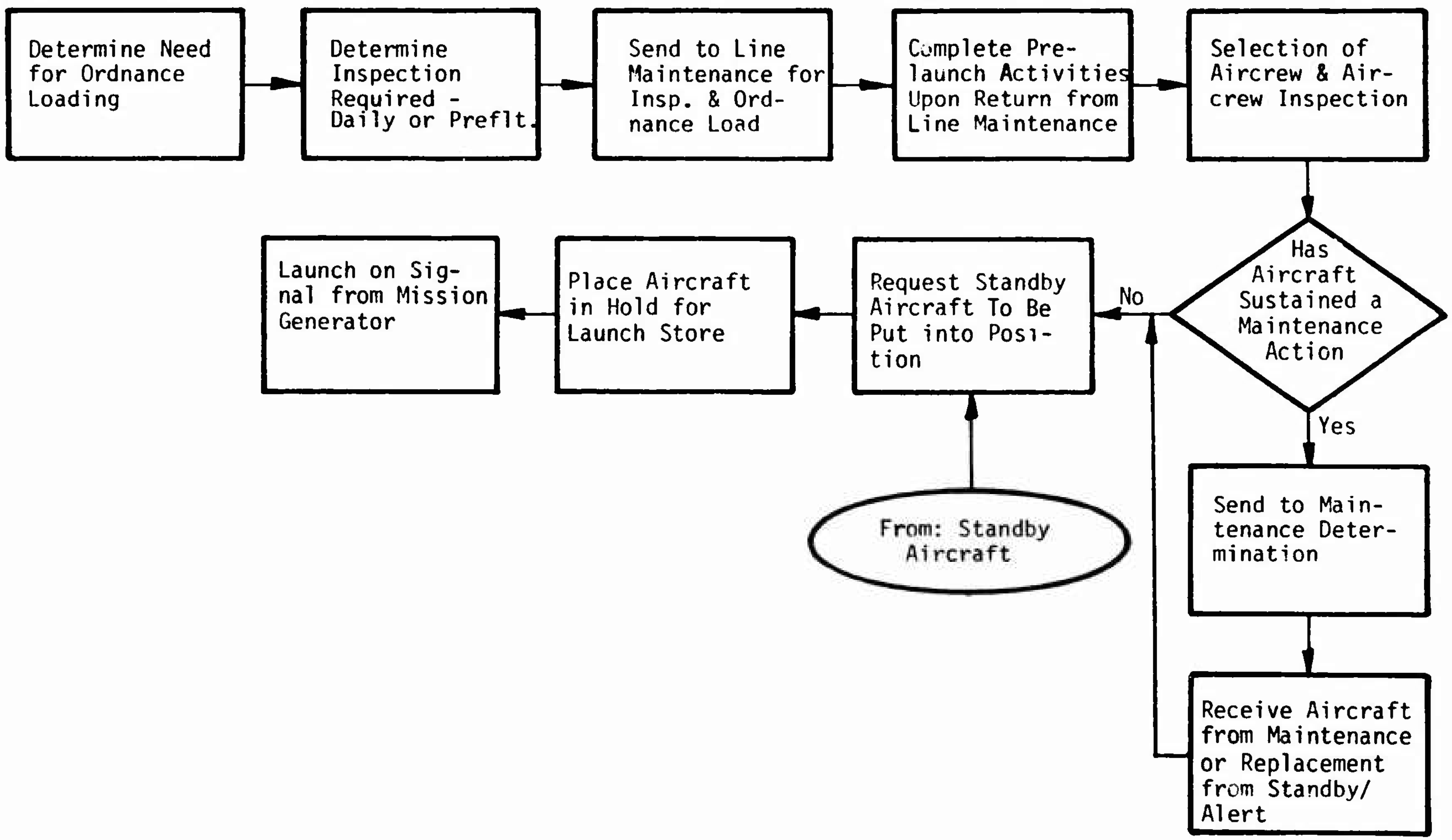


Figure 13. VALUE IV: Aircraft Routine; Aircraft Mainline Subroutine; Prelaunch Loop.

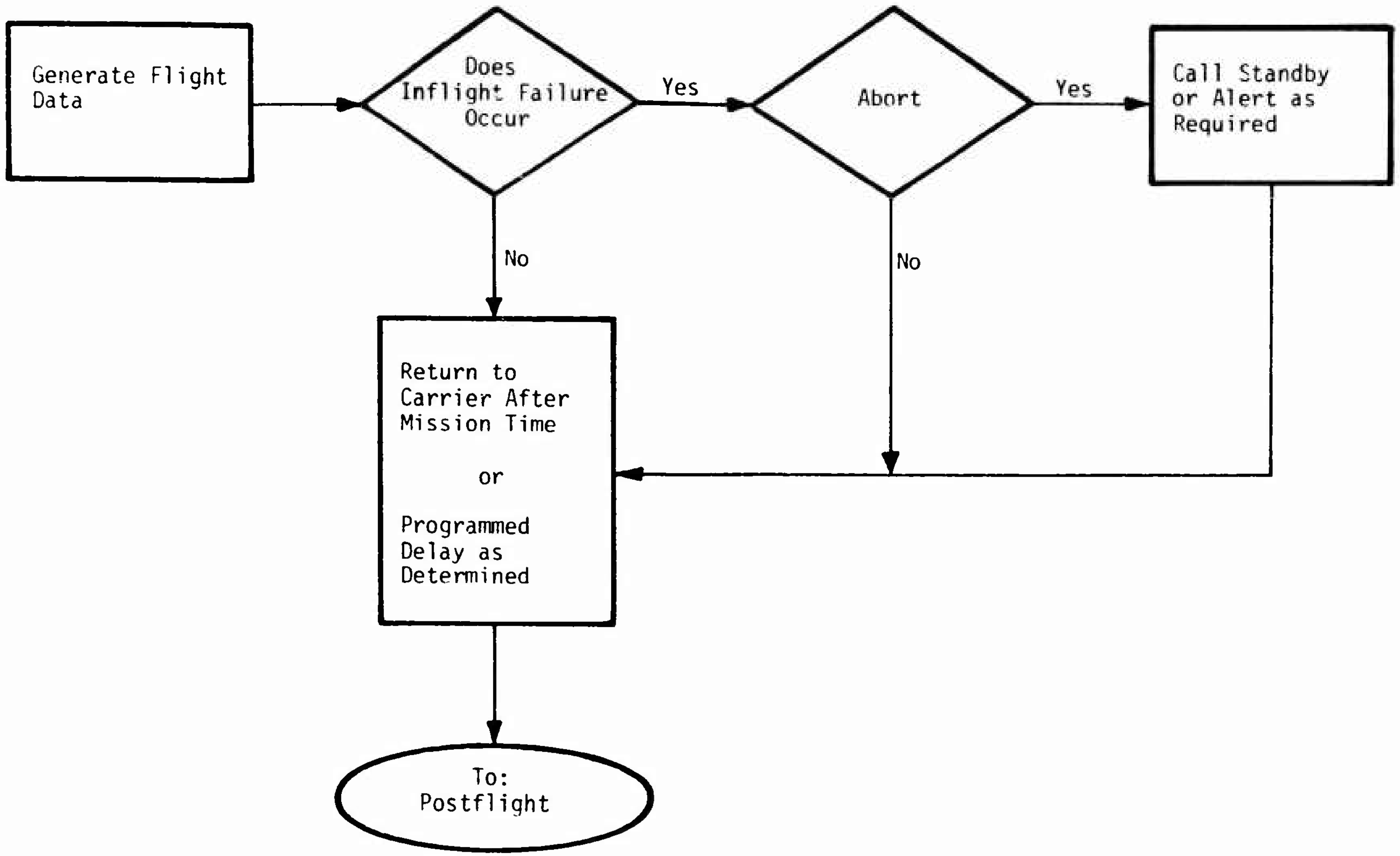


Figure 14. VALUE IV: Aircraft Routine; Aircraft Mainline Subroutine; Flight Loop.

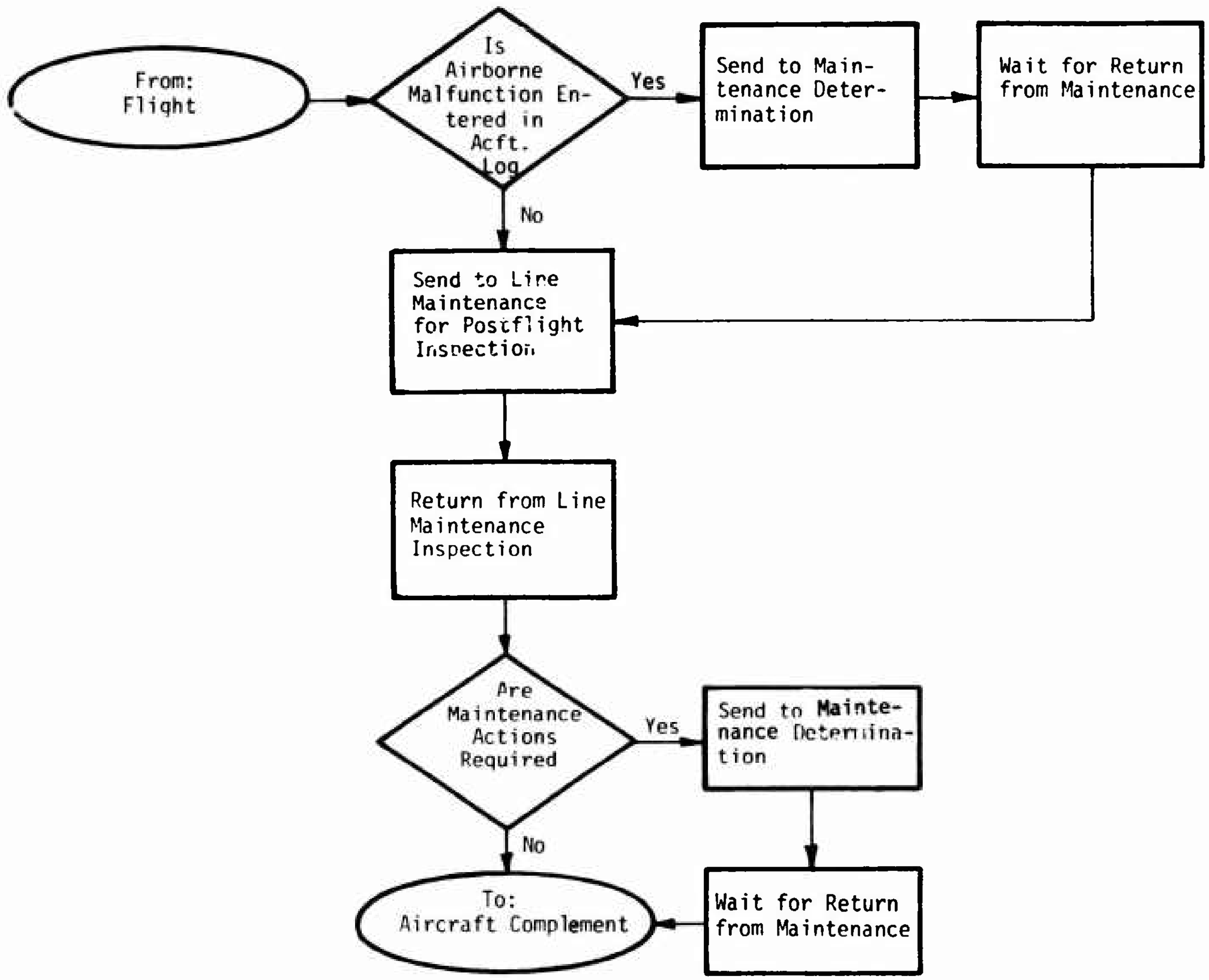


Figure 15. VALUE IV: Aircraft Routine; Aircraft Mainline Subroutine; Postflight Loop.

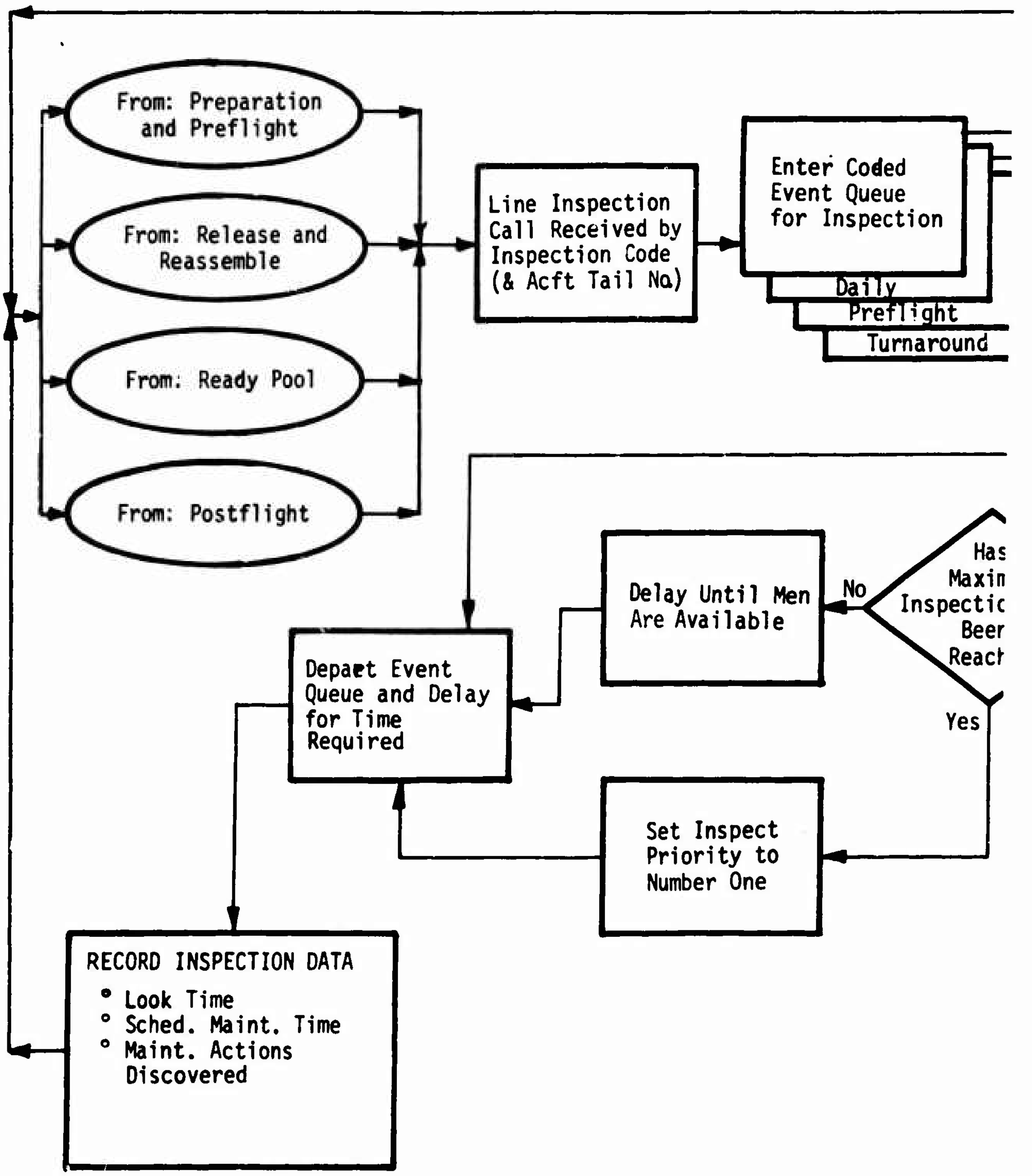
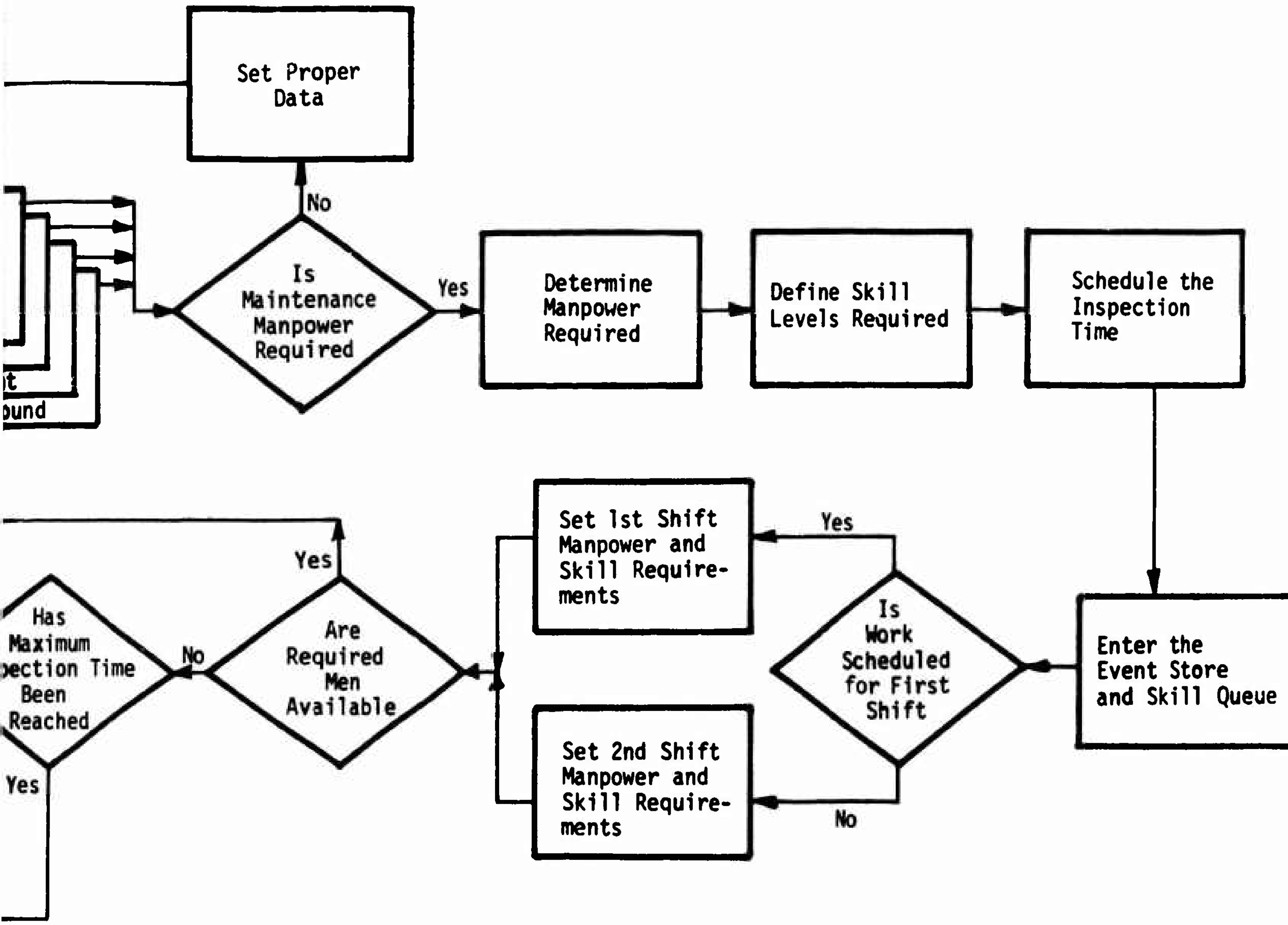


Figure 16. ARMS: Inspection Routine; Line Inspection Subroutine.



Set Proper Data
No
Is Maintenance Manpower Required
Yes
Determine Manpower Required
Define Skill Levels Required
Schedule the Inspection Time
Enter the Event Store and Skill Queue
Is Work Scheduled for First Shift
Yes
No
Set 1st Shift Manpower and Skill Require-ments
Set 2nd Shift Manpower and Skill Require-ments
Are Required Men Available
Yes
No
Reached
Yes

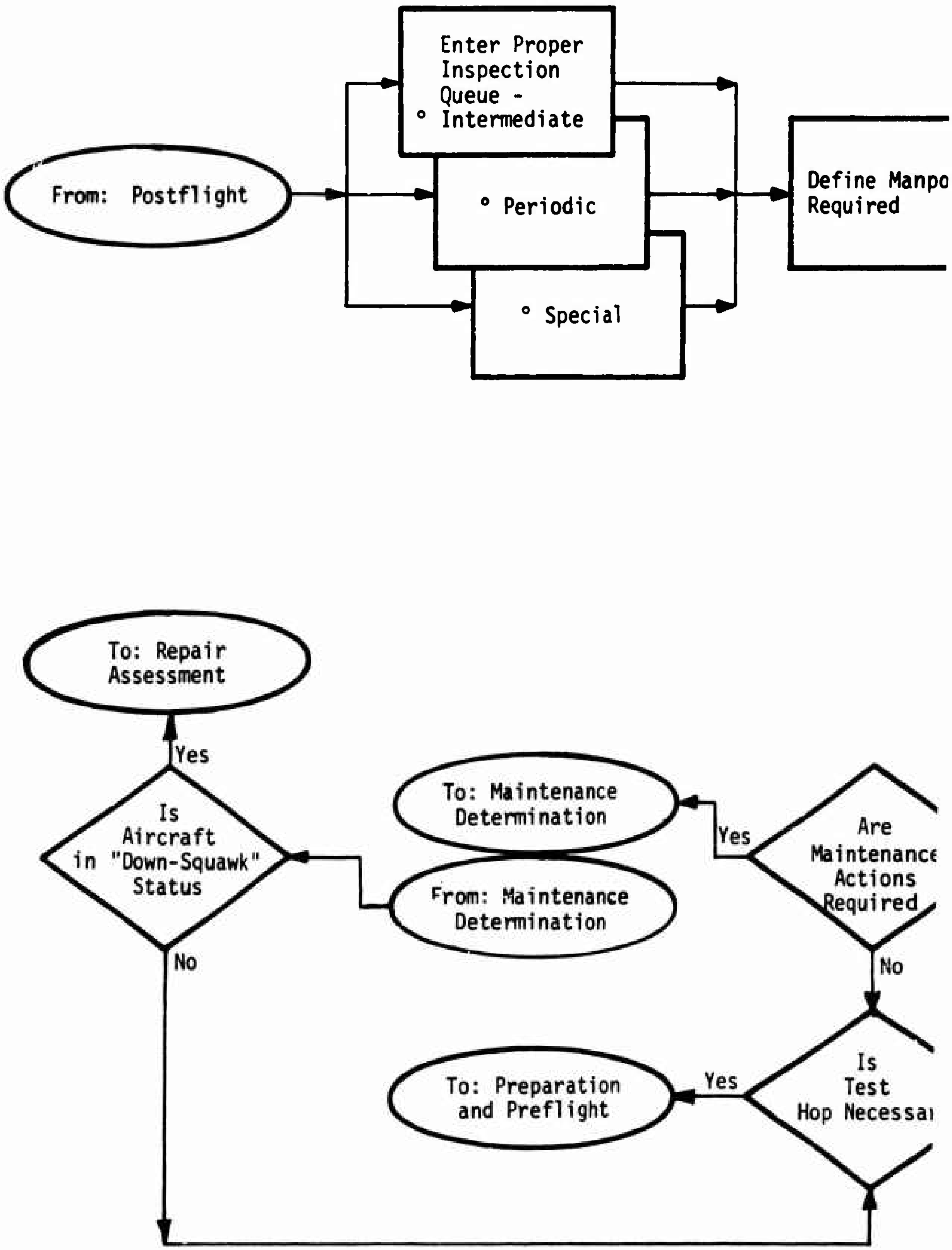
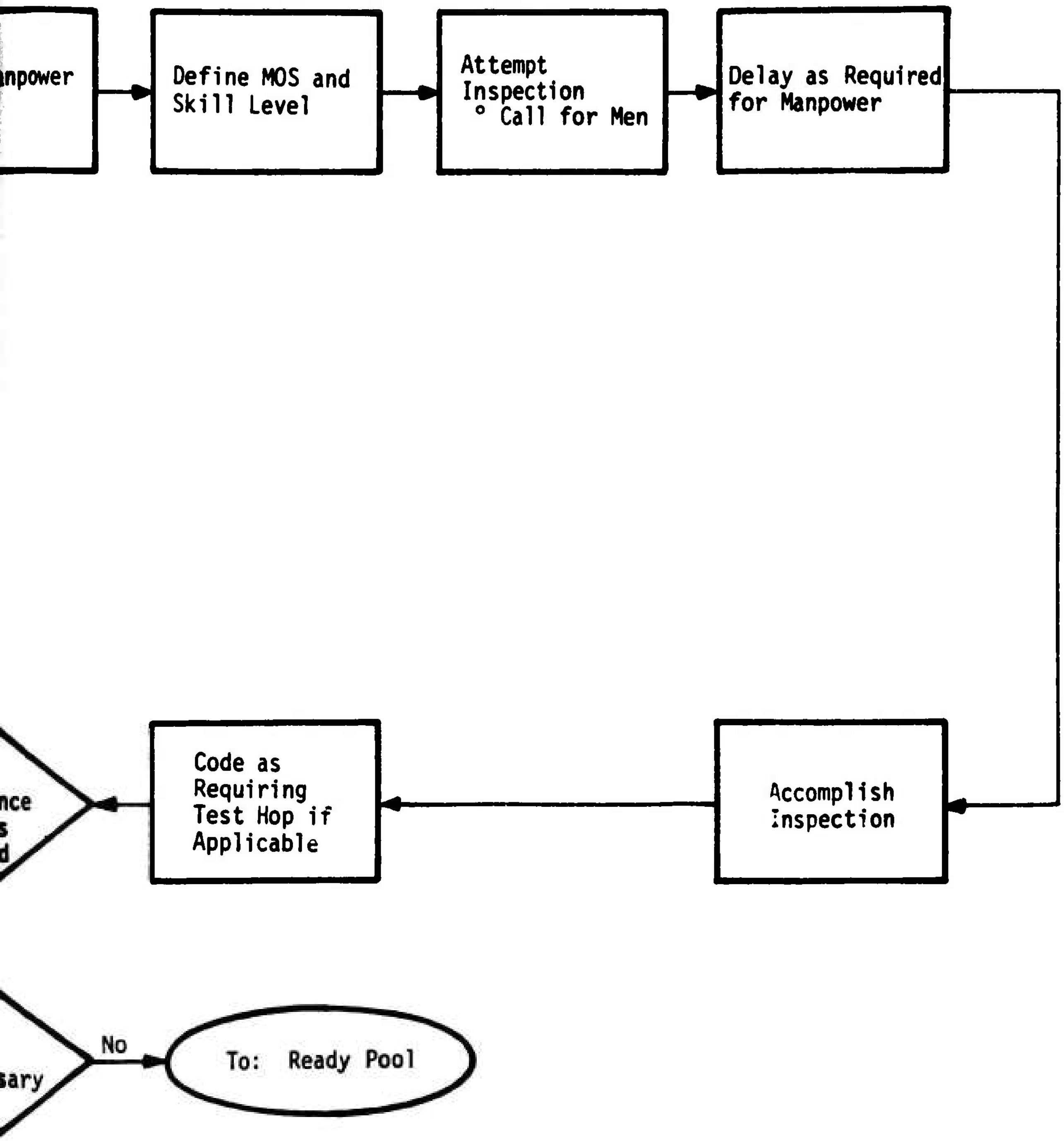


Figure 17. ARMS: Inspection Routine; Scheduled Inspection Subroutine.



npower
Define MOS and Skill Level
Attempt Inspection
° Call for Men
Delay as Required for Manpower
Accomplish Inspection
Code as Requiring Test Hop if Applicable
nce
s
d
sary
No
To: Ready Pool

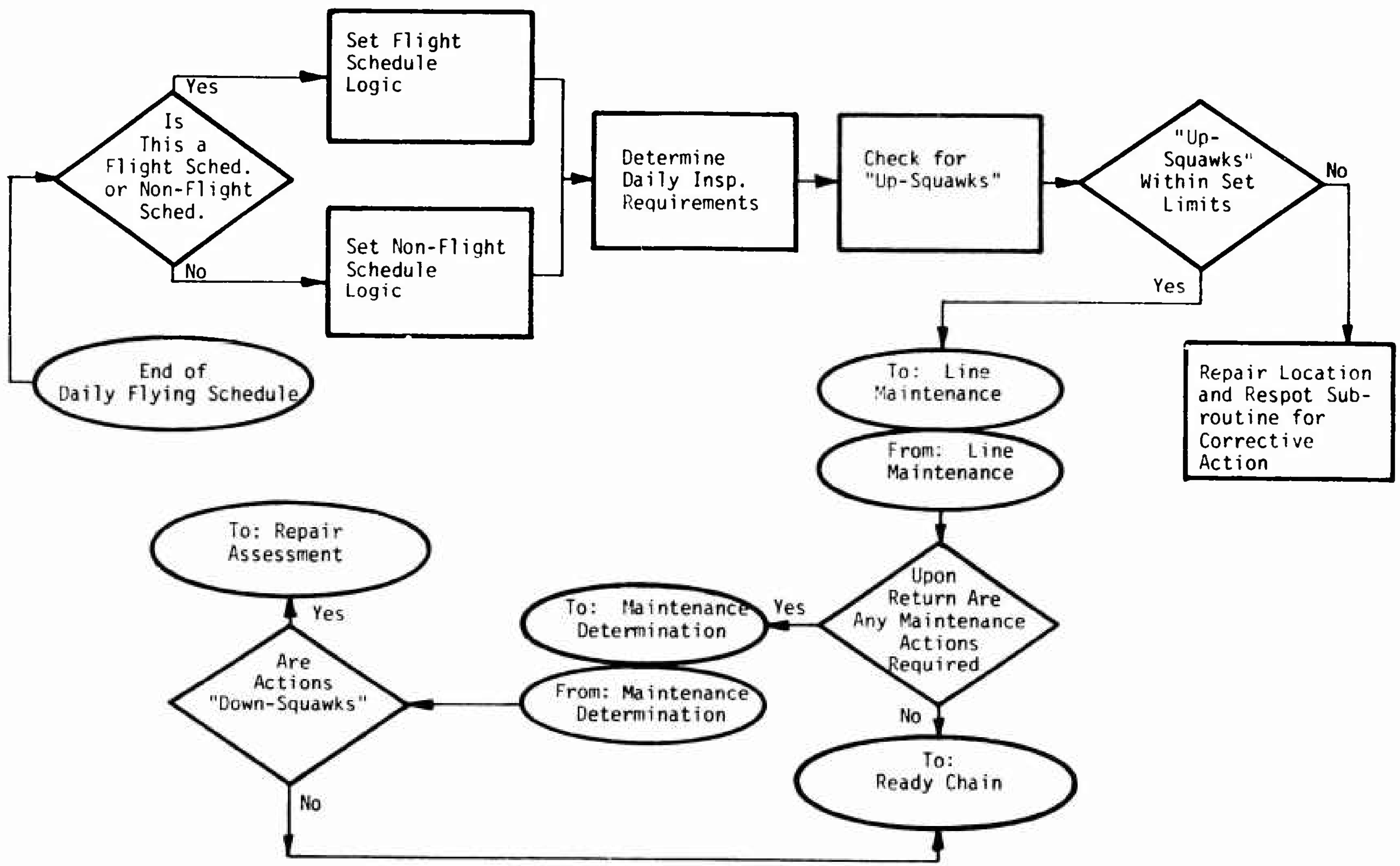


Figure 18. VALUE IV: Scheduled Maintenance Routine; Daily Inspection Subroutine.

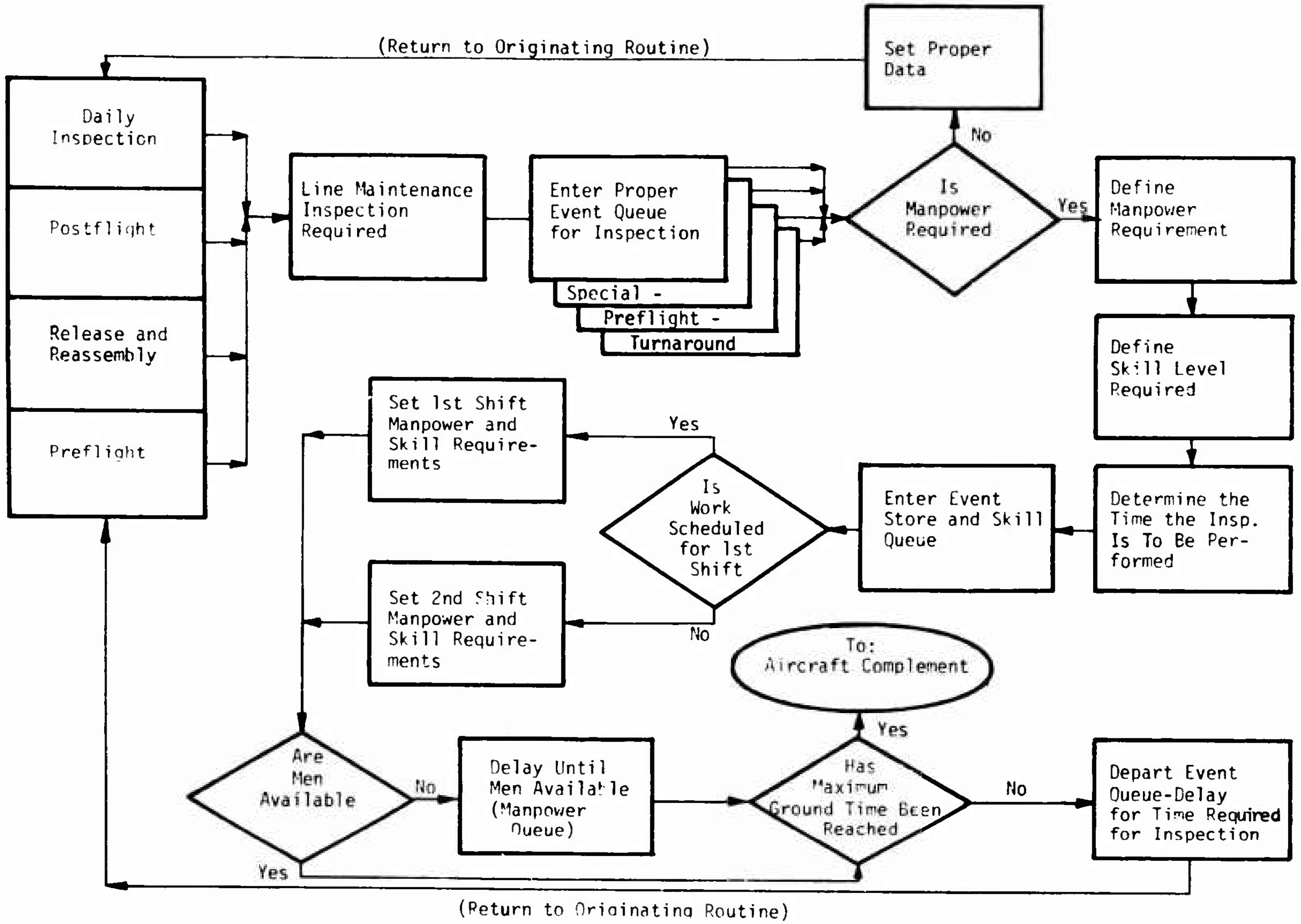


Figure 19. VALUE IV: Scheduled Maintenance Routine; Line Maintenance Subroutine.

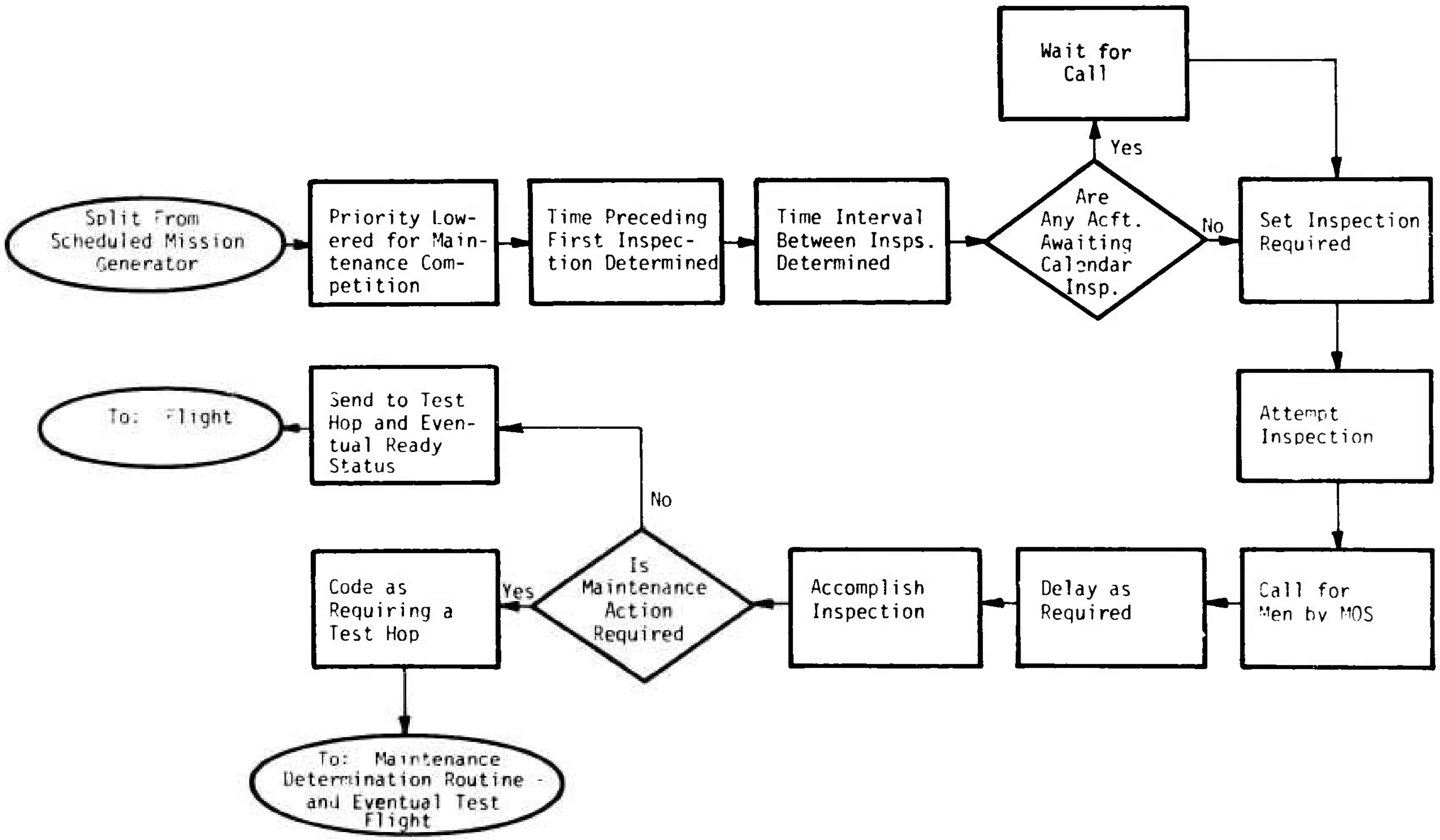


Figure 20. VALUE IV: Scheduled Maintenance Routine; Calendar Maintenance Subroutine.

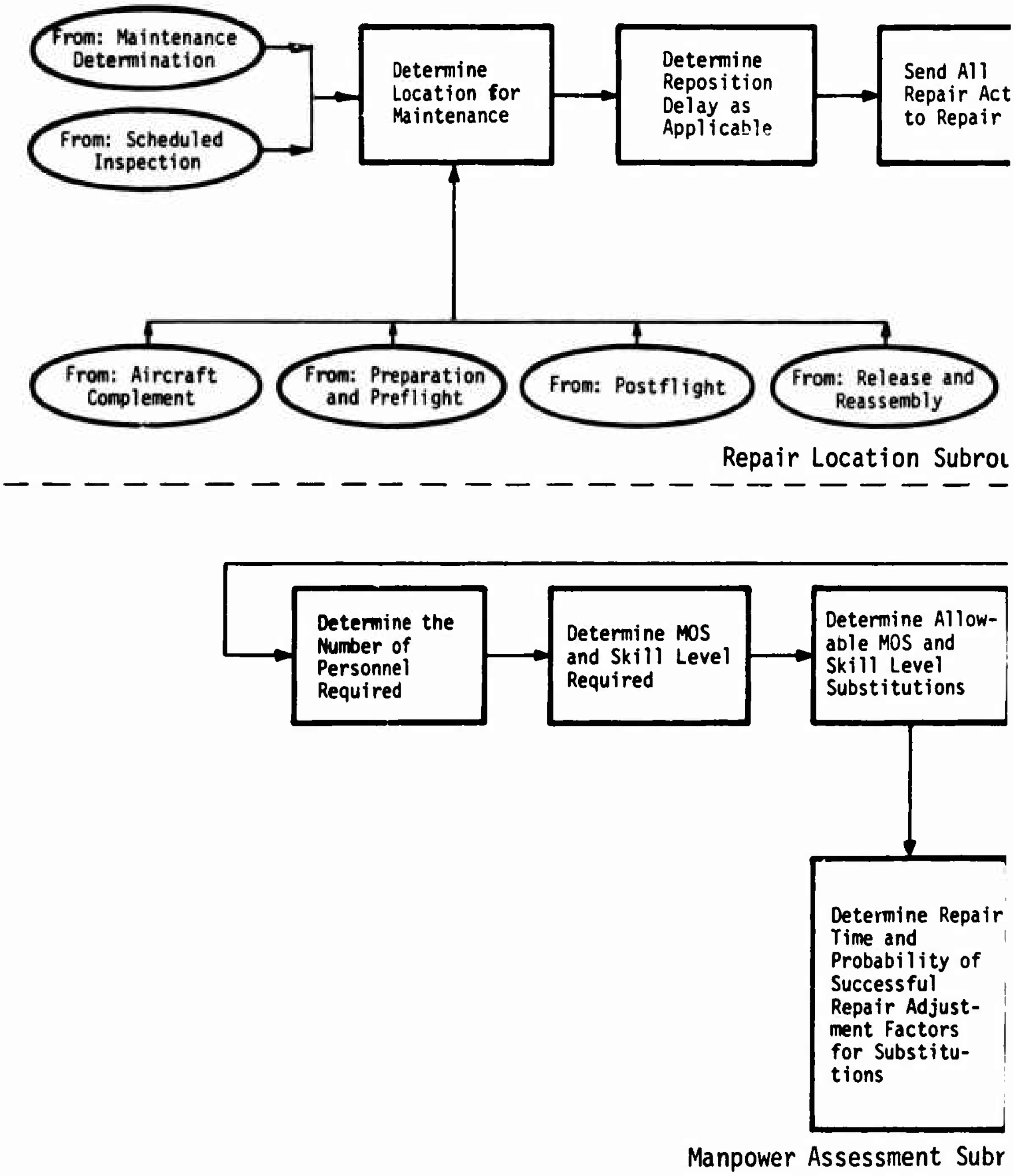
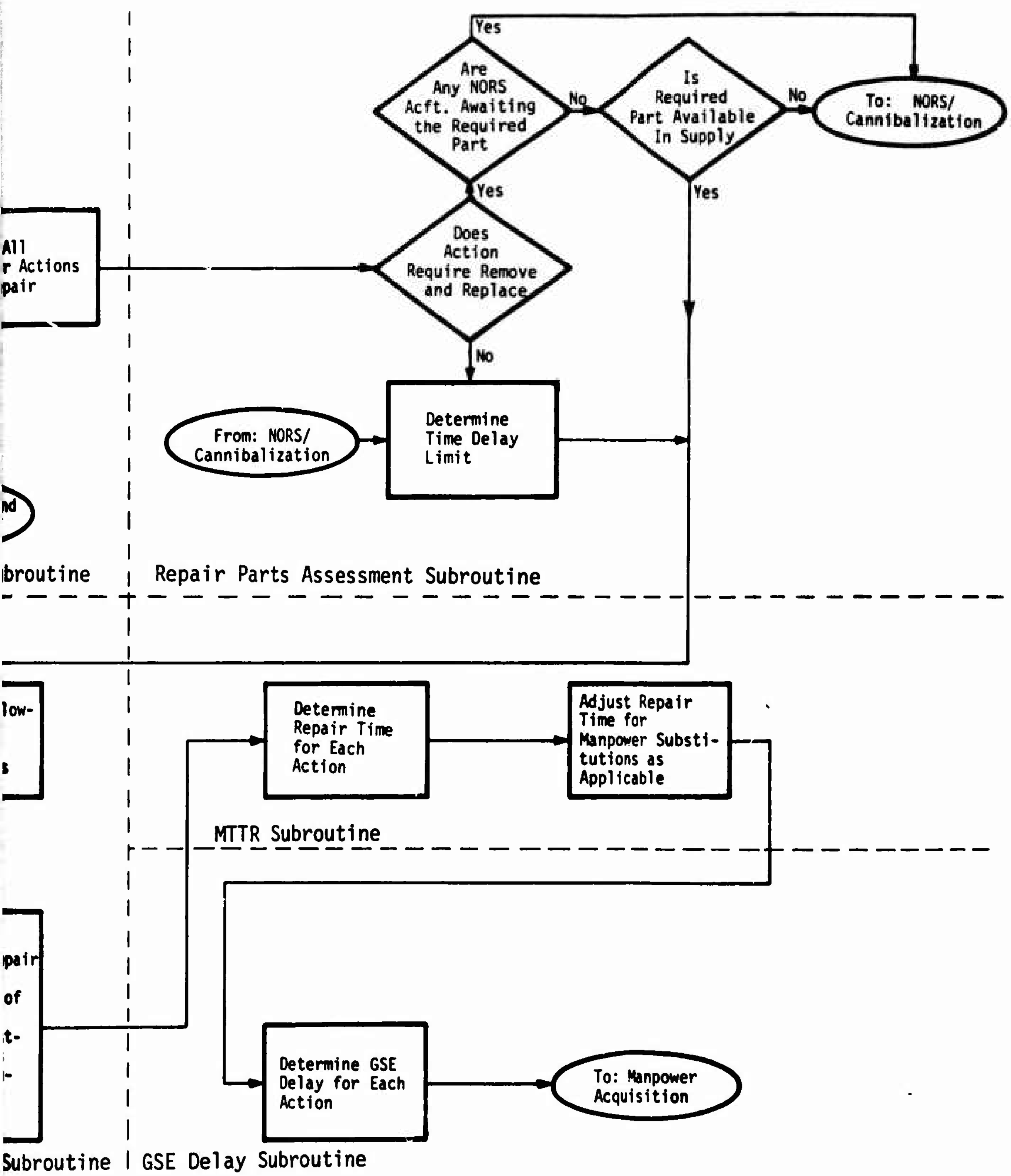


Figure 21. ARMS: Repair Assessment Routine.



Are Any NORS Acft. Awaiting the Required Part
Yes
No
Is Required Part Available In Supply
No
To: NORS/ Cannibalization
Yes
All
r Actions
pair
Yes
Does Action Require Remove and Replace
No
From: NORS/ Cannibalization
Determine Time Delay Limit
nd
broutine
Repair Parts Assessment Subroutine
low-
s
Determine Repair Time for Each Action
Adjust Repair Time for Manpower Substitutions as Applicable
MTTR Subroutine
pair
of
t-
Determine GSE Delay for Each Action
To: Manpower Acquisition
Subroutine
GSE Delay Subroutine

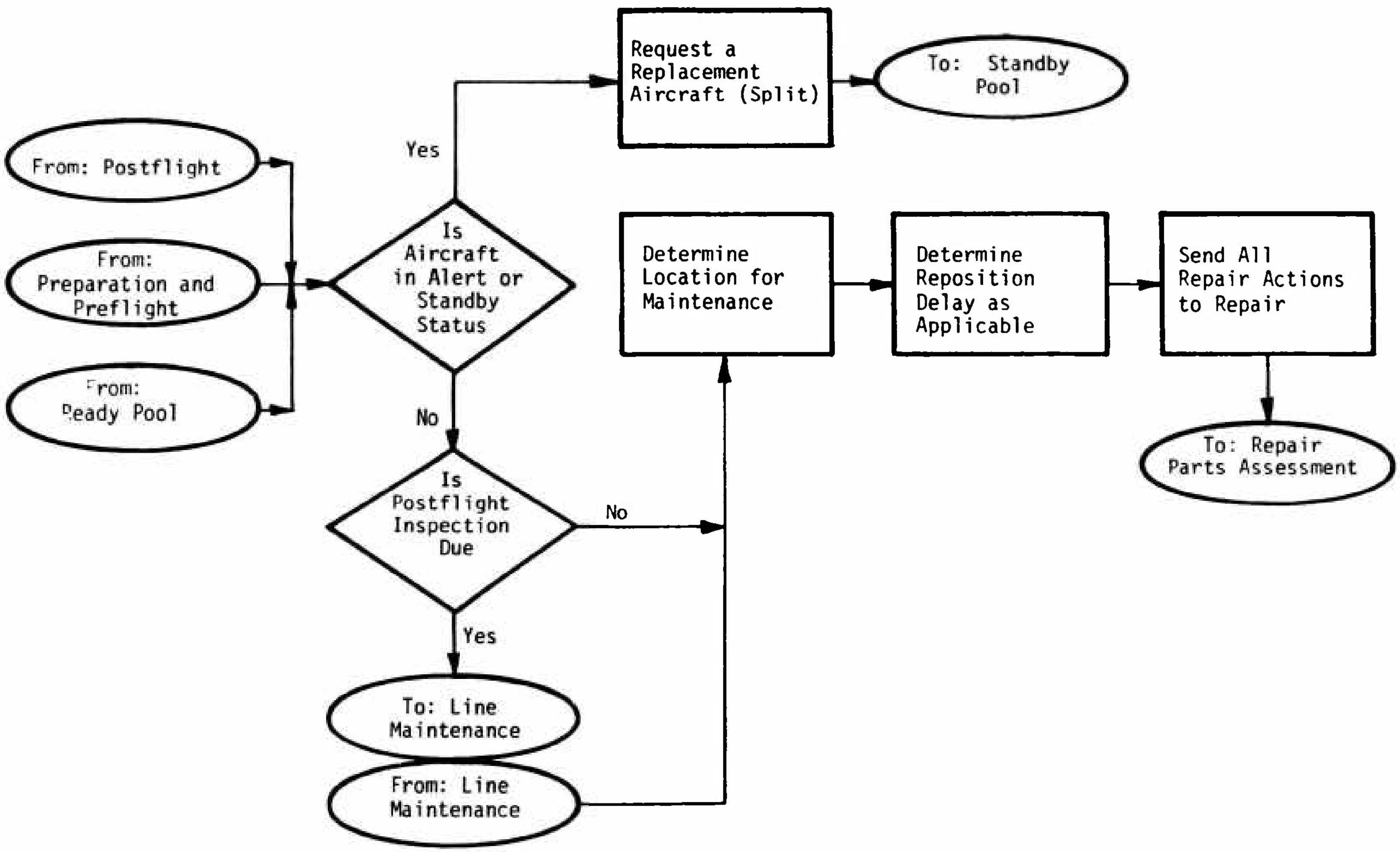


Figure 22. VALUE IV: Repair Assessment Routine; Repair Location (and Respot) Subroutine.

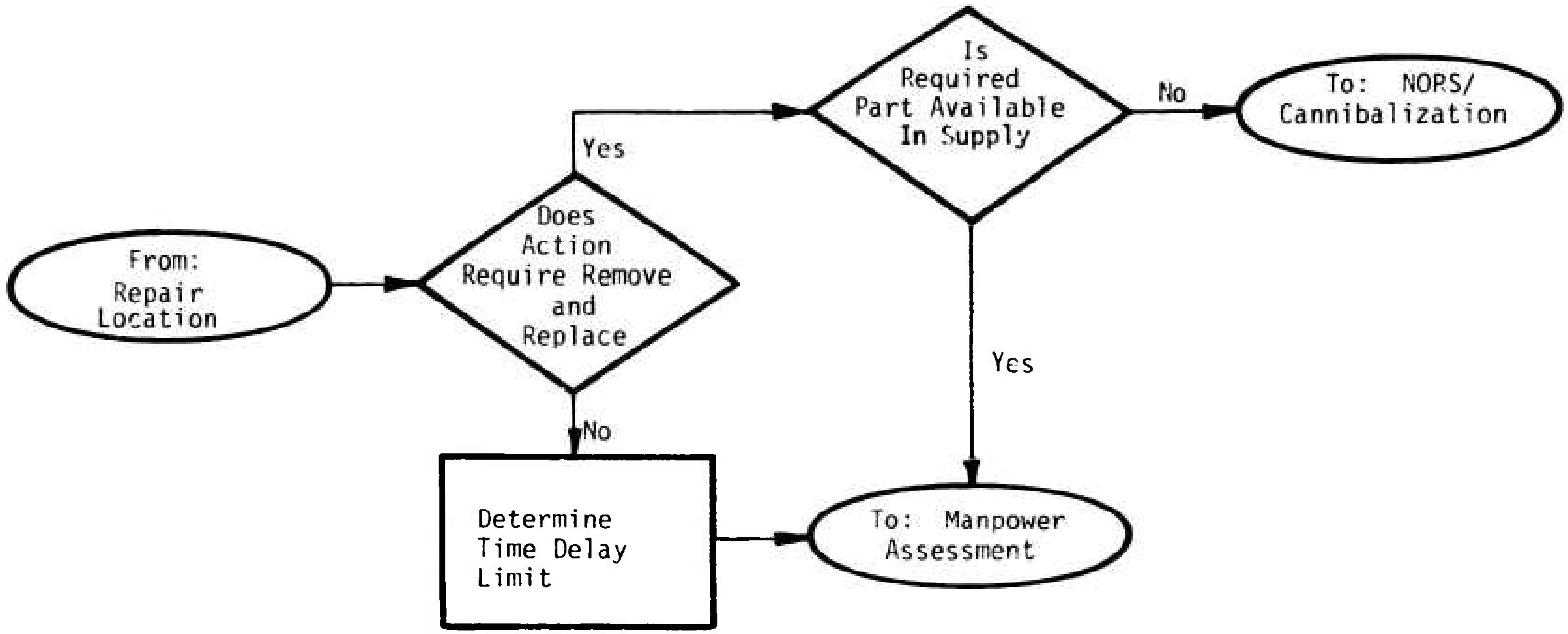


Figure 23. VALUE IV: Repair Assessment Routine; Repair Part Assessment Subroutine.

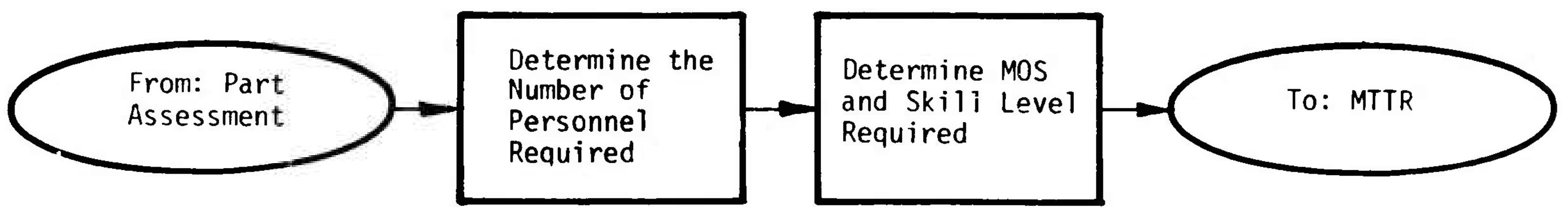


Figure 24. VALUE IV: Repair Assessment Routine; Manpower Assessment Subroutine.

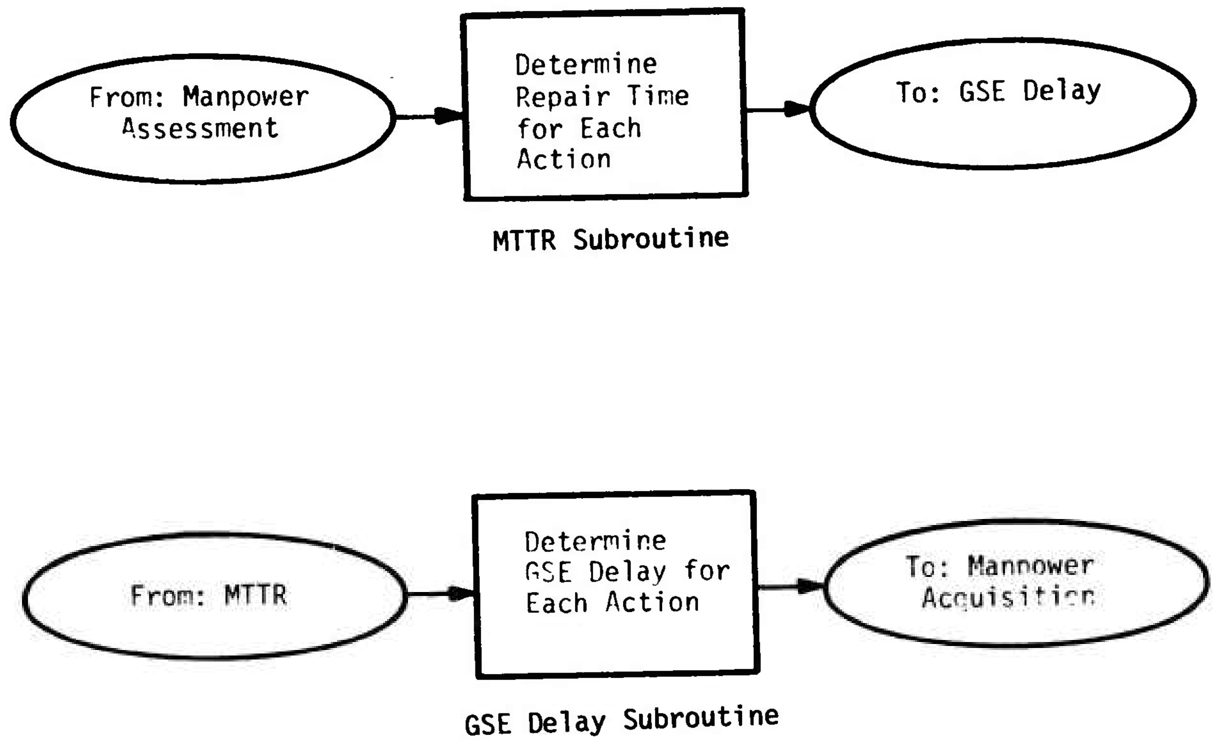


Figure 25. VALUE IV: Repair Assessment Routine.

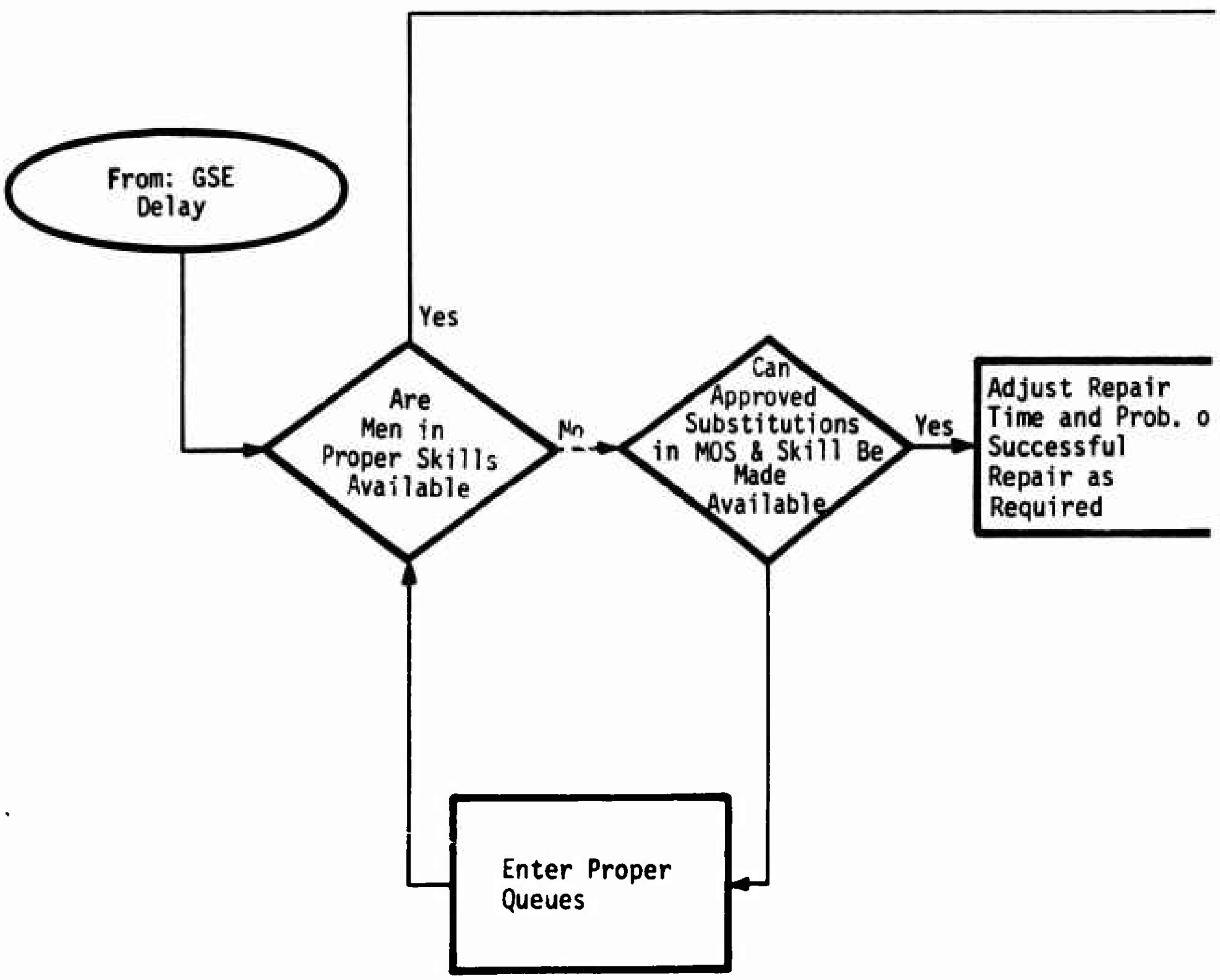
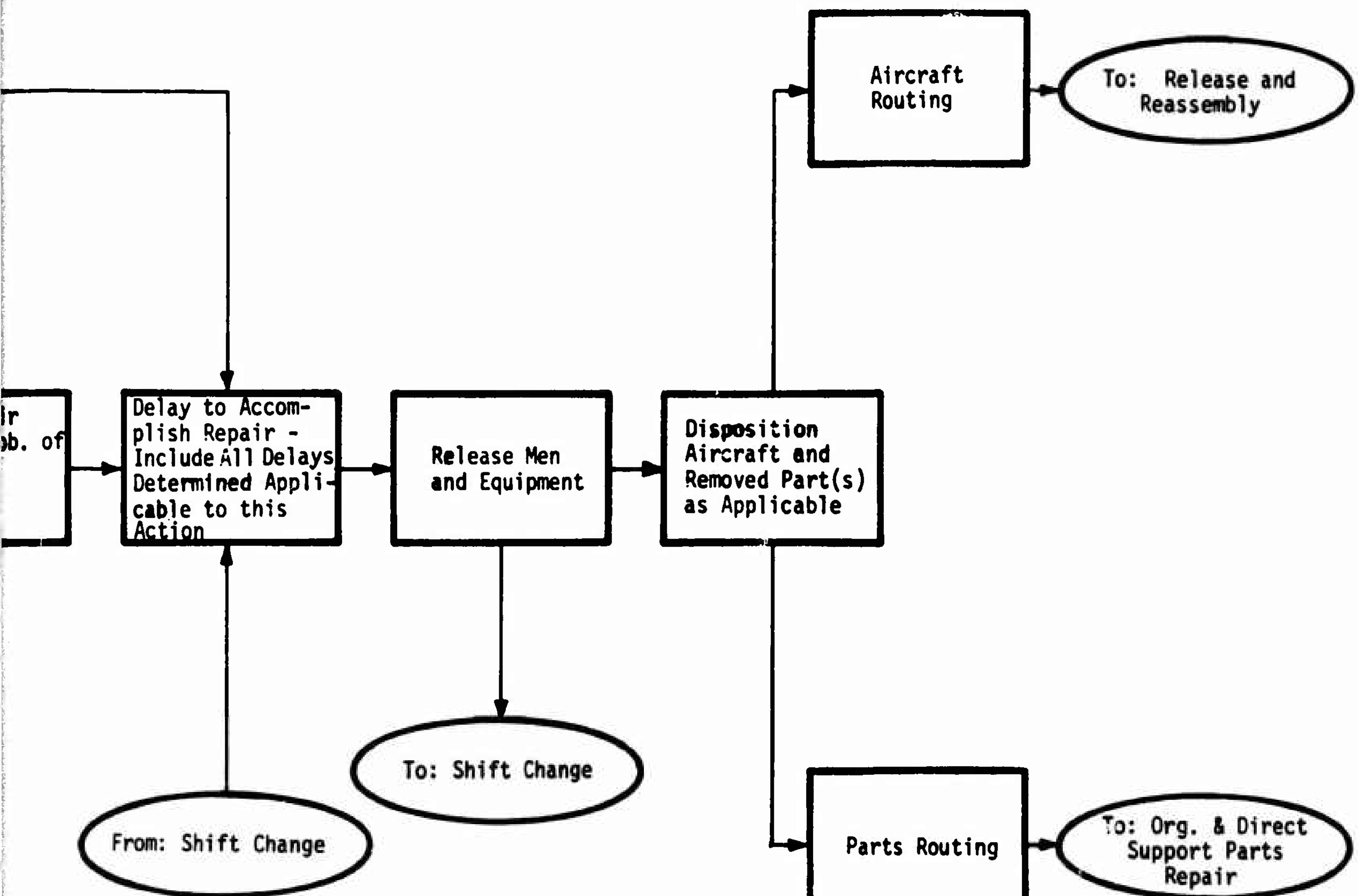


Figure 26. ARMS: Unscheduled Maintenance Routine; Manpower Acquisition Subroutine.


Aircraft Routing
To: Release and Reassembly
Delay to Accomplish Repair - Include All Delays Determined Applicable to this Action
Release Men and Equipment
Disposition Aircraft and Removed Part(s) as Applicable
To: Shift Change
From: Shift Change
Parts Routing
To: Org. & Direct Support Parts Repair

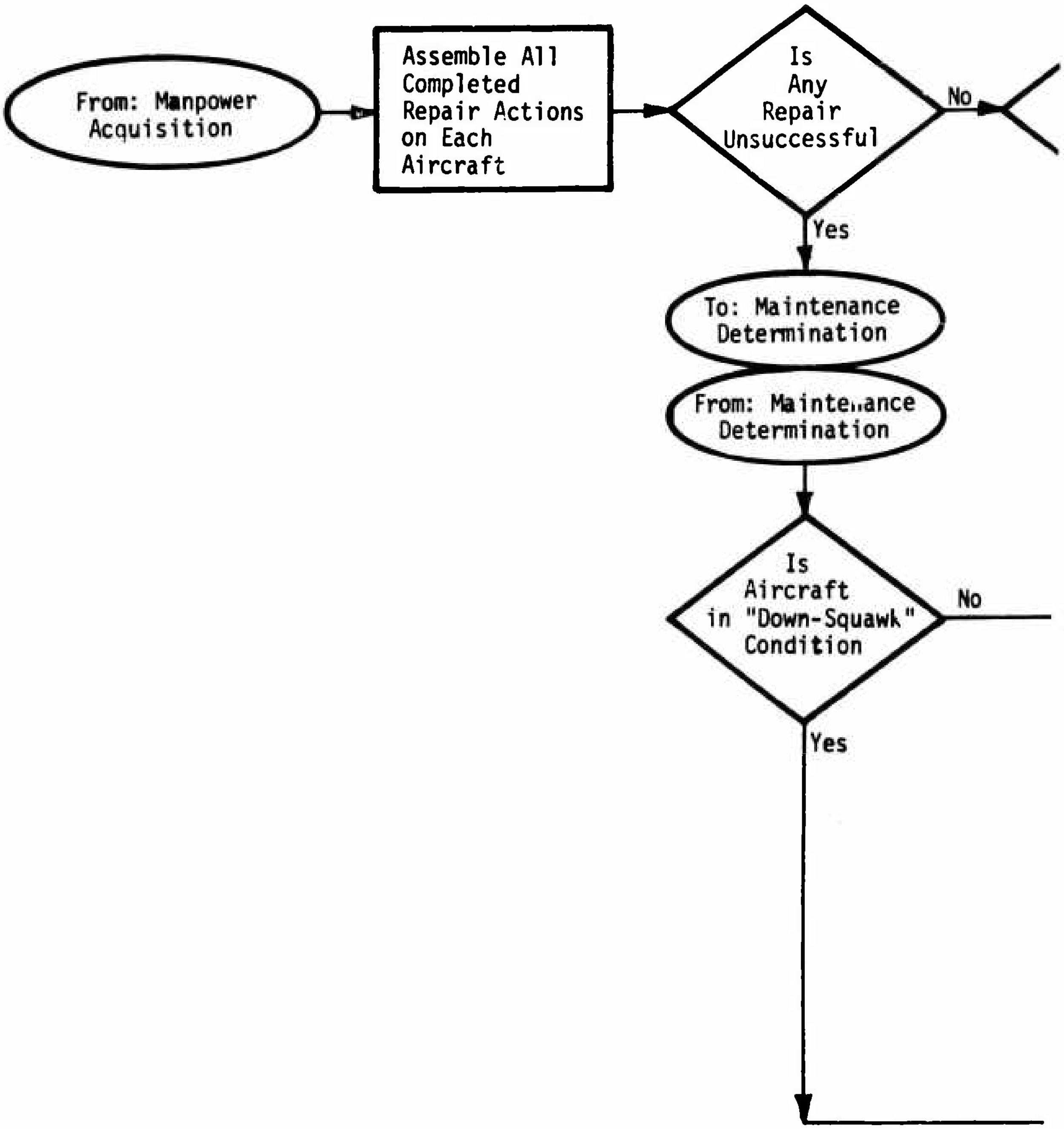
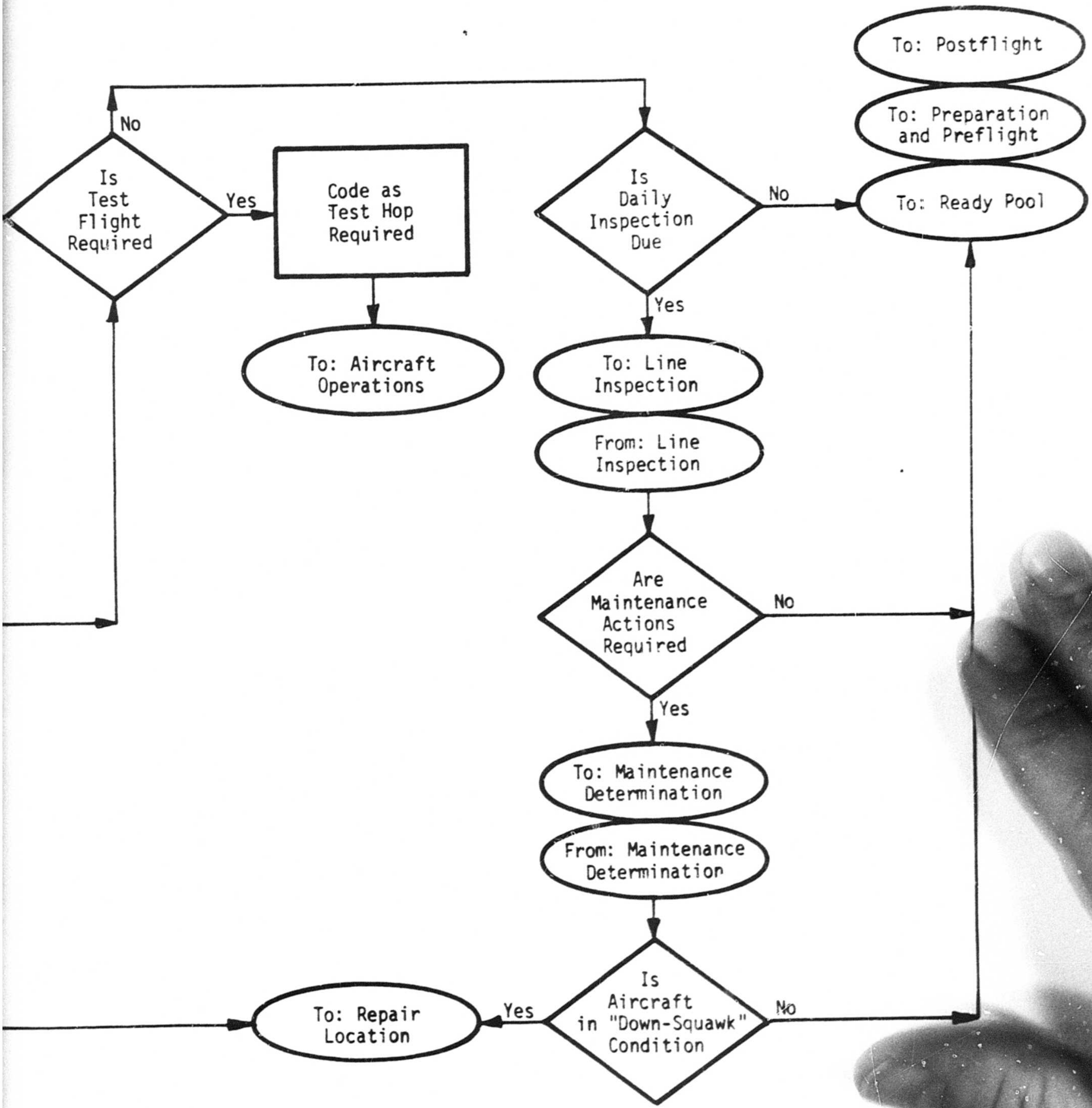


Figure 27. ARMS: Unscheduled Maintenance Routine; Aircraft Release and Reassembly Subroutine.



Is Test Flight Required
No
Yes
Code as Test Hop Required
To: Aircraft Operations
Is Daily Inspection Due
No
Yes
To: Postflight
To: Preparation and Preflight
To: Ready Pool
To: Line Inspection
From: Line Inspection
Are Maintenance Actions Required
No
Yes
To: Maintenance Determination
From: Maintenance Determination
Is Aircraft in "Down-Squawk" Condition
Yes
No
To: Repair Location

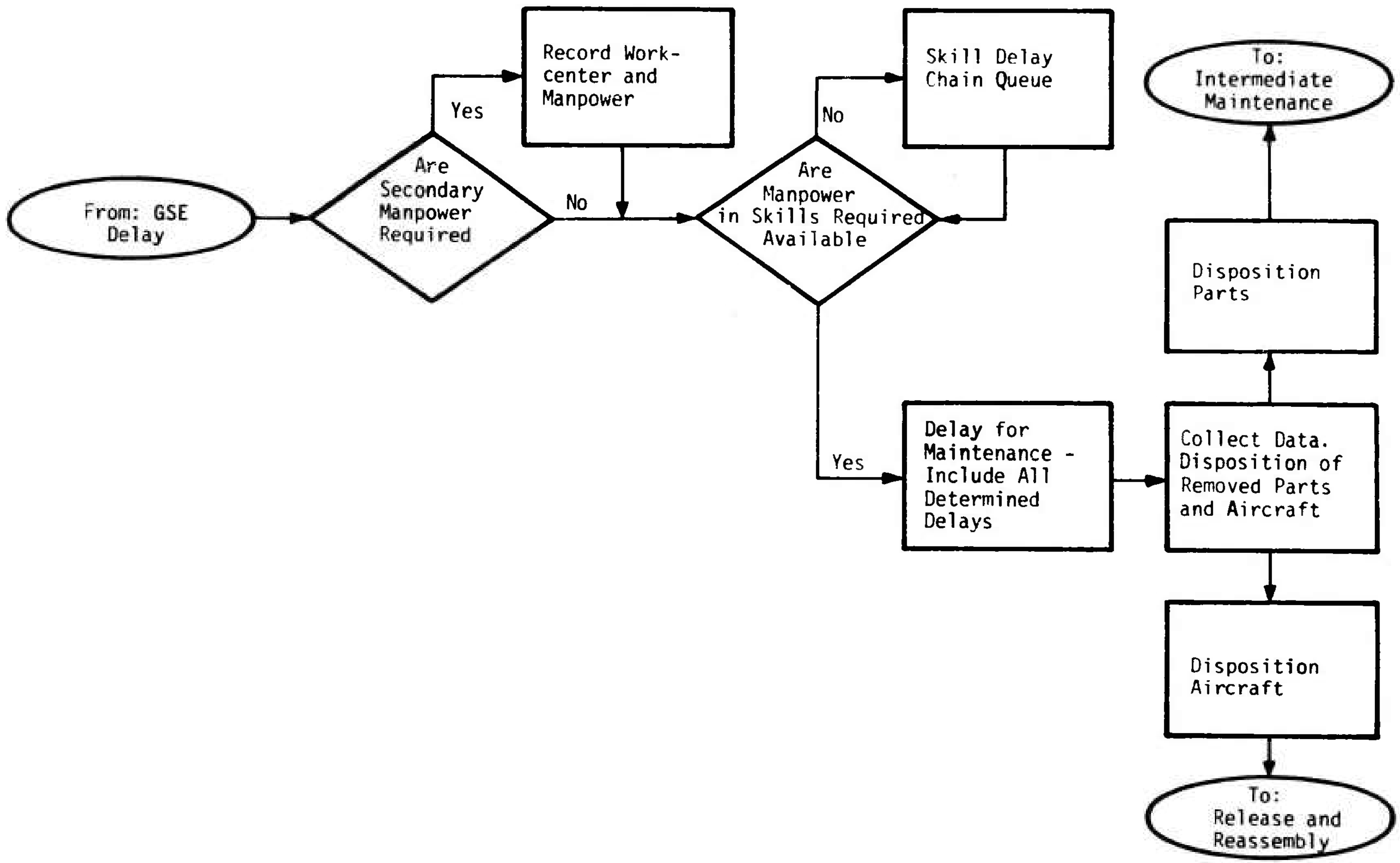


Figure 28. VALUE IV: Unscheduled Mair.tenance Routine; Manpower Acquisition Subroutine.

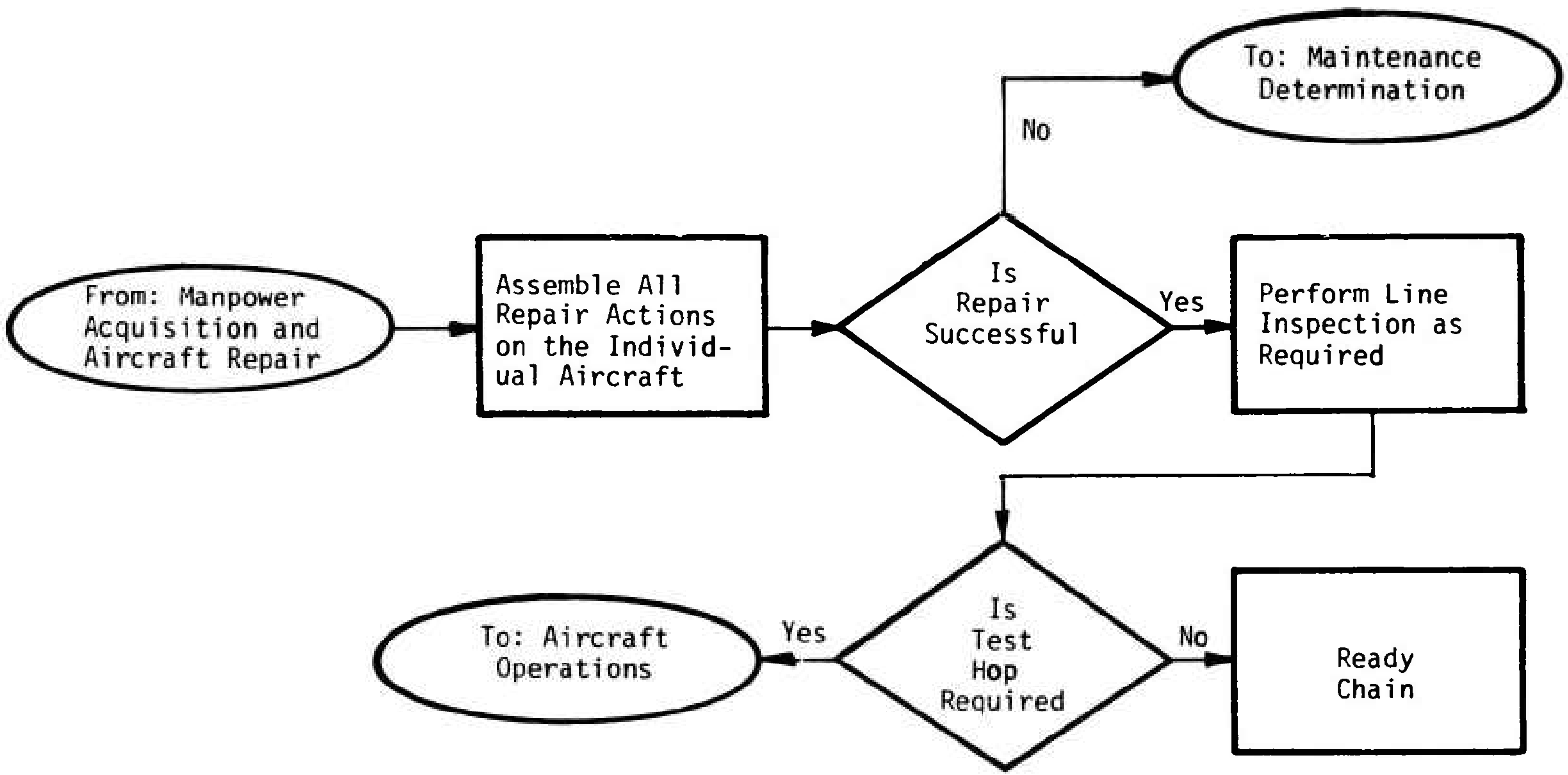


Figure 29. VALUE IV: Unscheduled Maintenance Routine; Aircraft Release and Reassembly Subroutine.

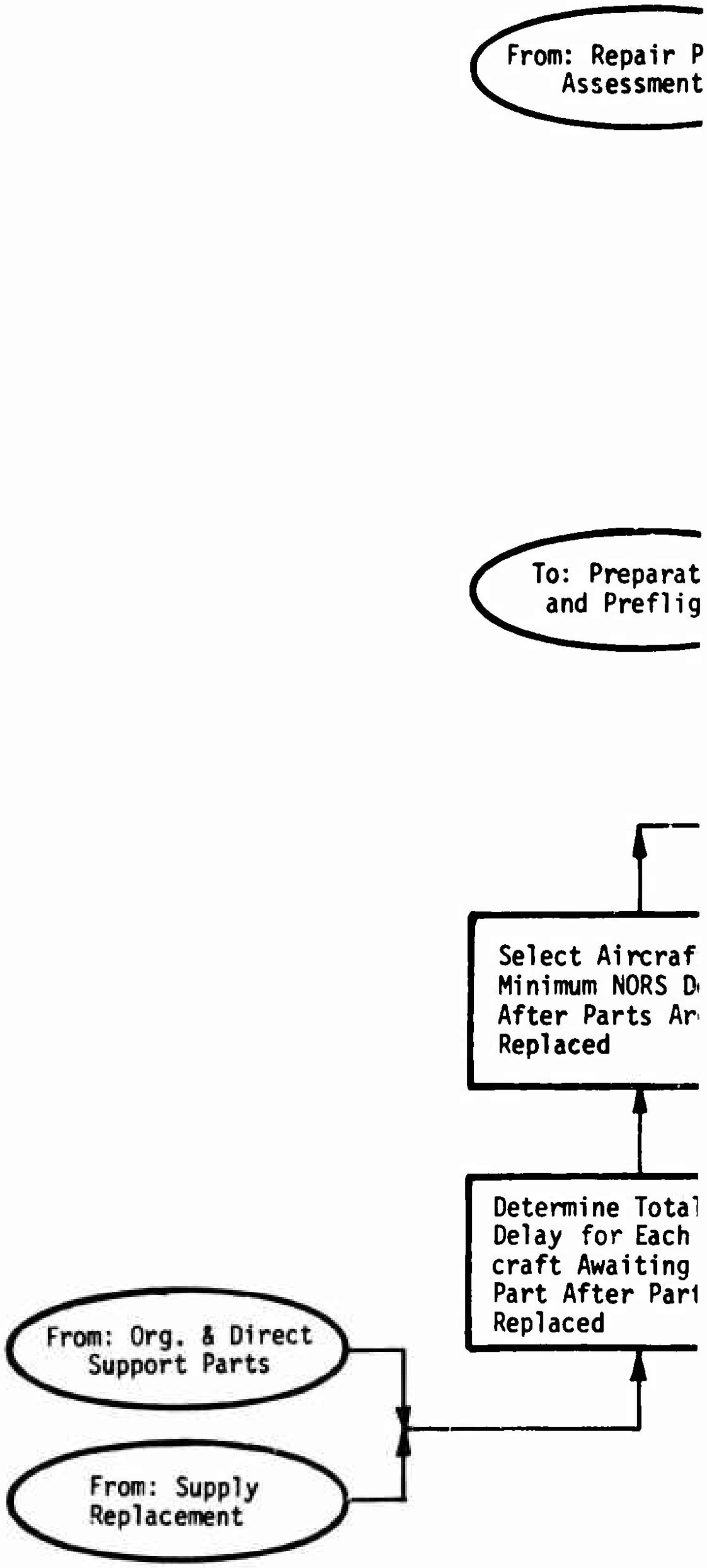
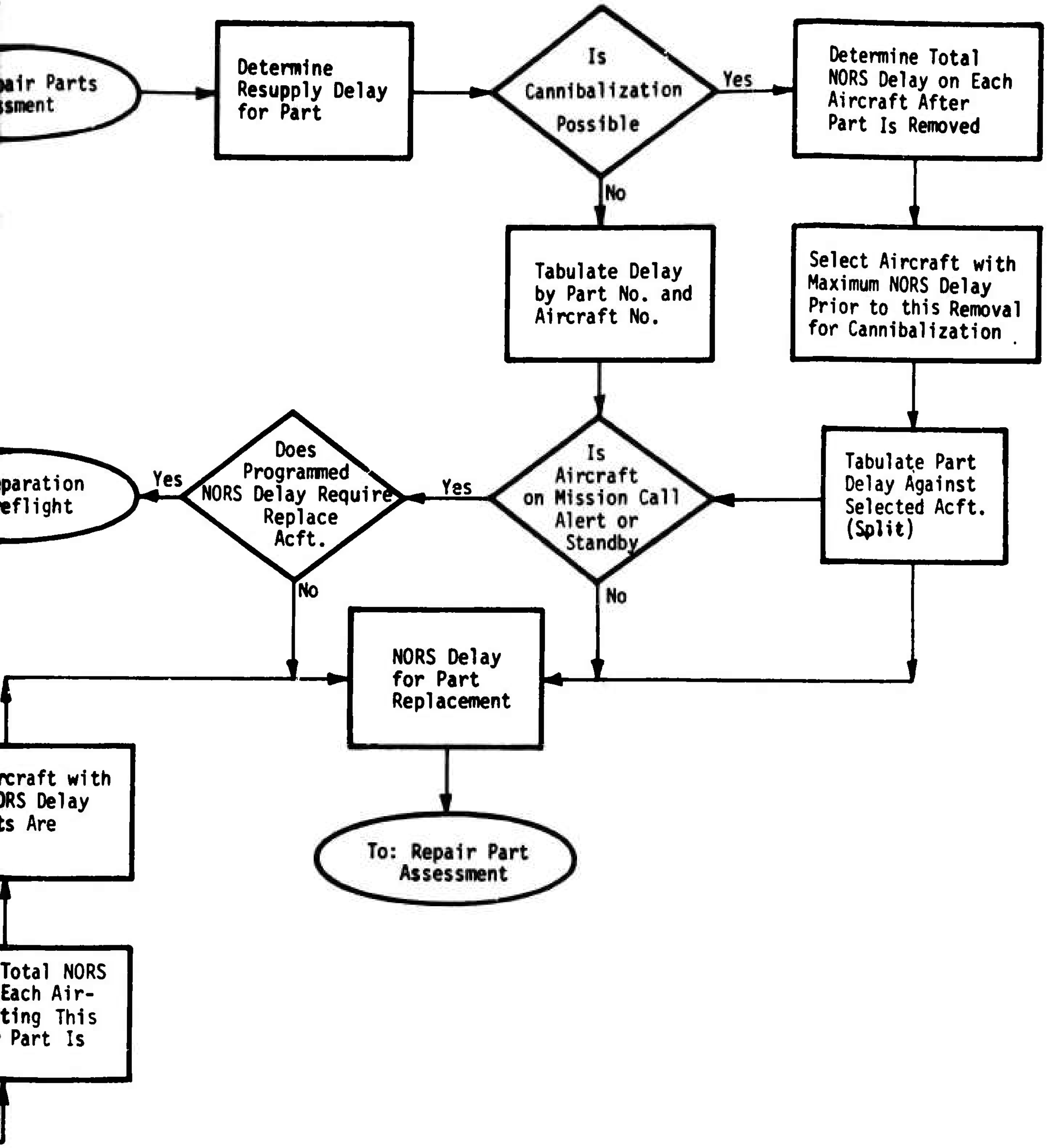


Figure 30. ARMS: NORS/Cannibalizat



ization Routine.

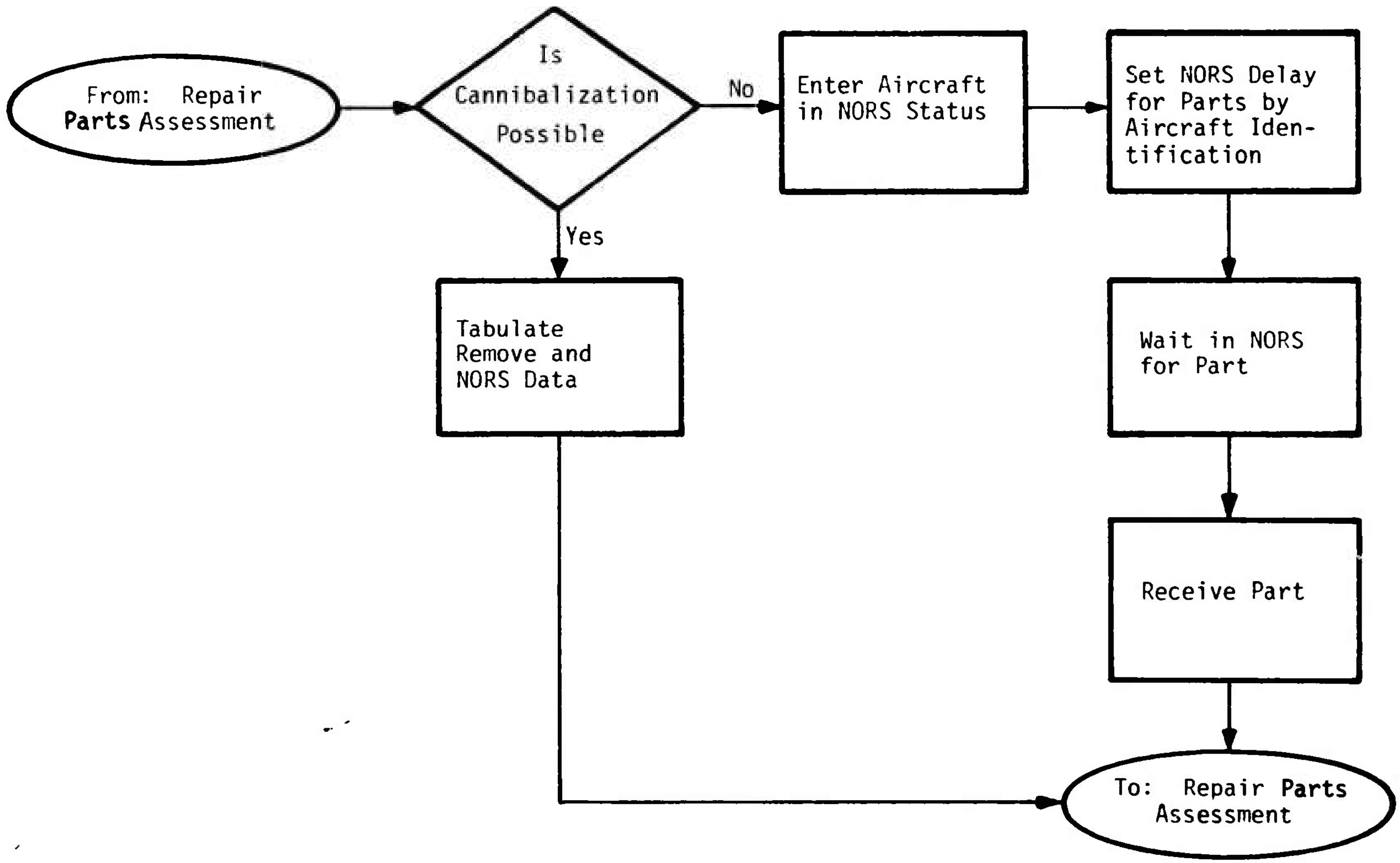


Figure 31. VALUE IV: NORS/Cannibalization Routine.

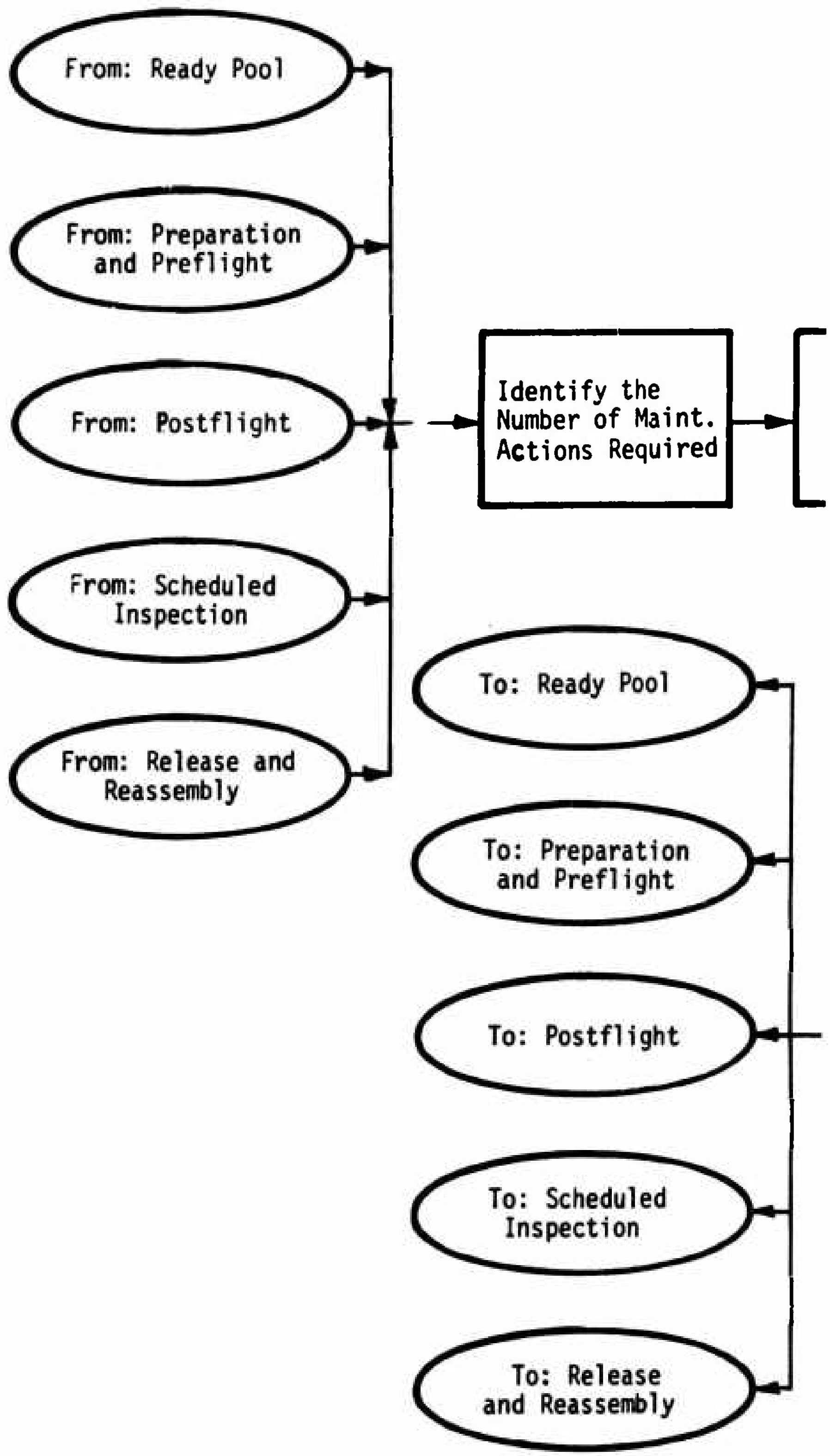
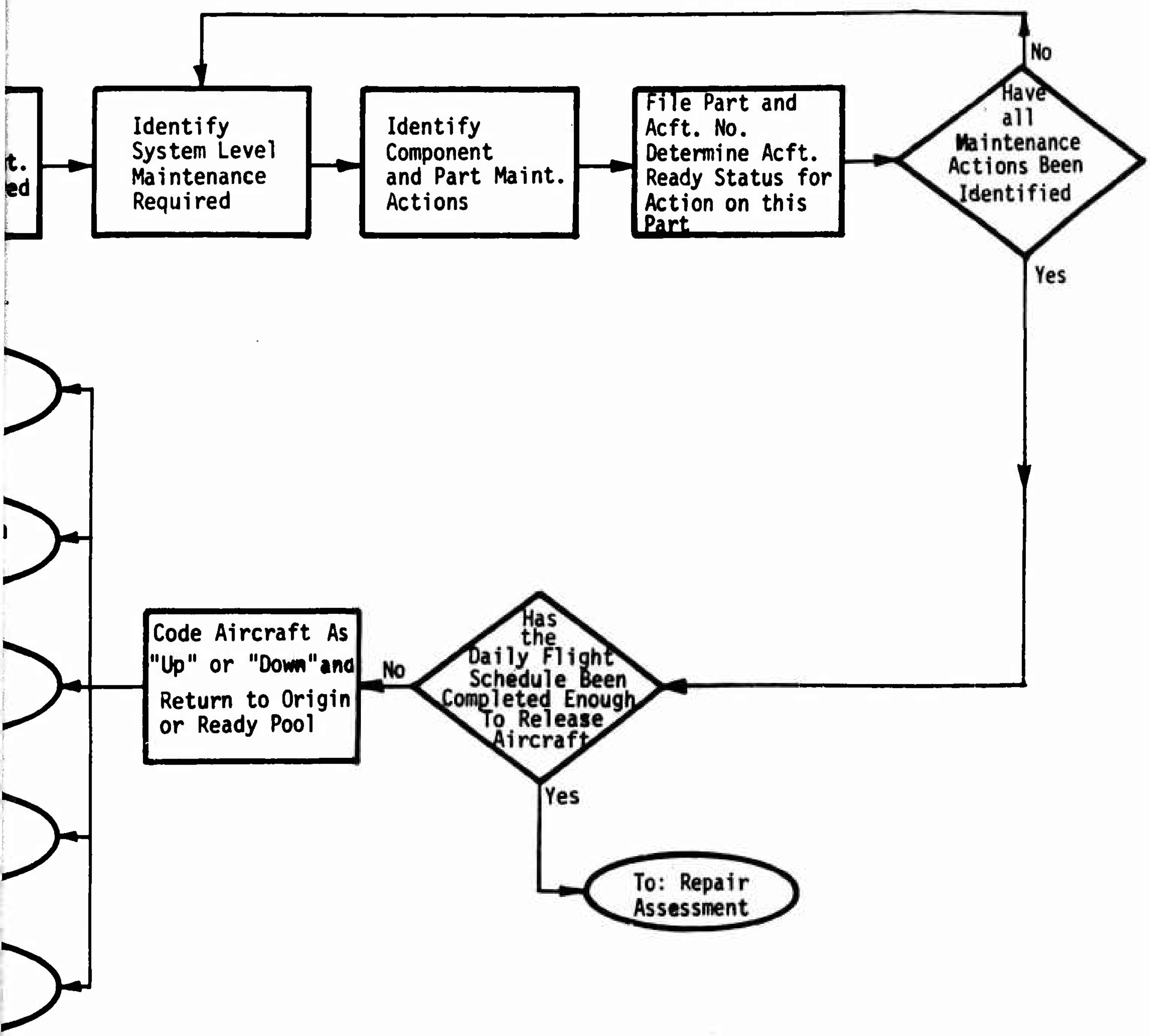


Figure 32. ARMS: Maintenance Determination Routine.


t.
ed
Identify
System Level
Maintenance
Required
Identify
Component
and Part Maint.
Actions
File Part and
Acft. No.
Determine Acft.
Ready Status for
Action on this
Part
Have
all
Maintenance
Actions Been
Identified
No
Yes
Has
the
Daily Flight
Schedule Been
Completed Enough
To Release
Aircraft
No
Yes
Code Aircraft As
"Up" or "Down" and
Return to Origin
or Ready Pool
To: Repair
Assessment

Routine.

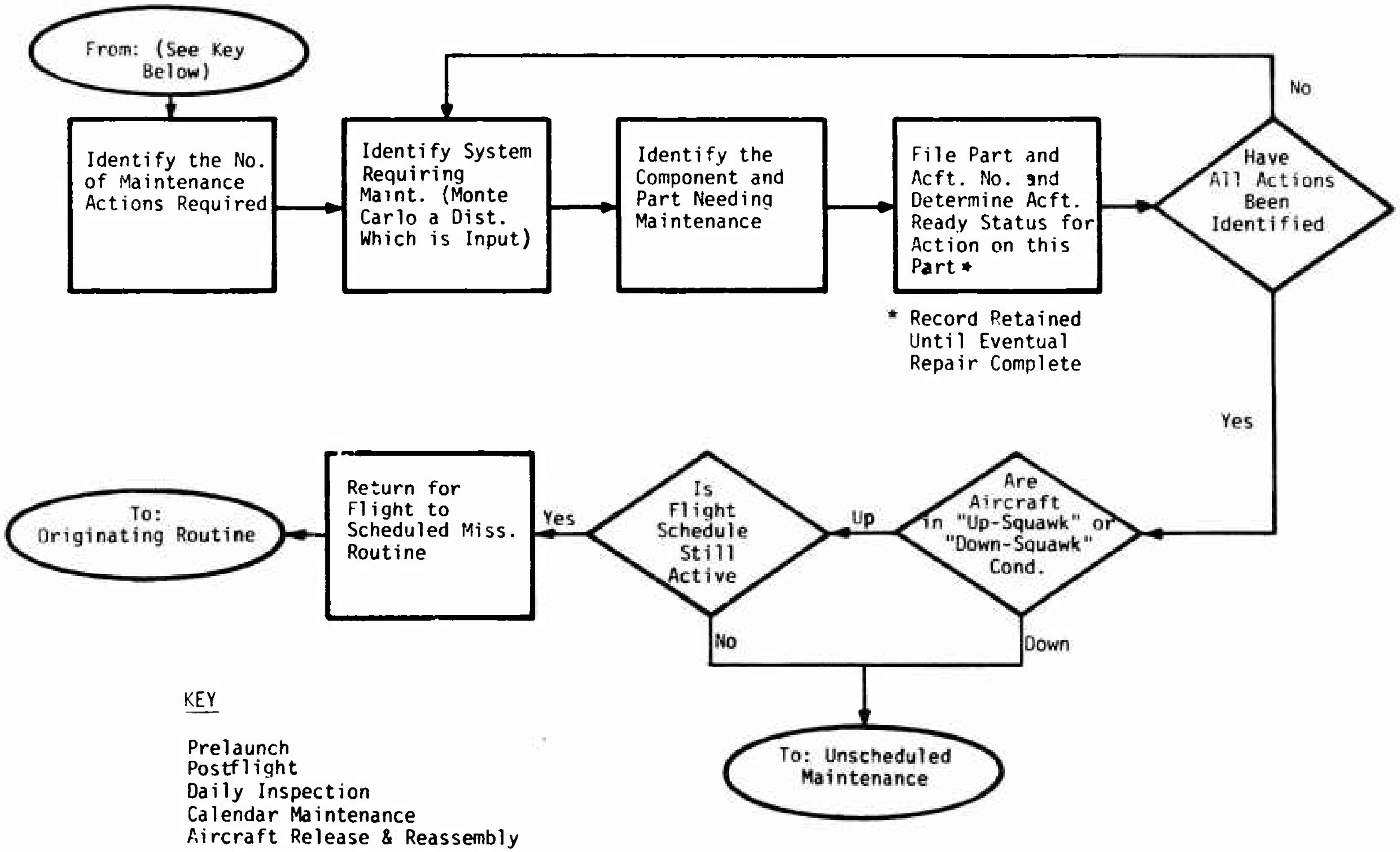


Figure 33. VALUE IV: Maintenance Determination Routine.

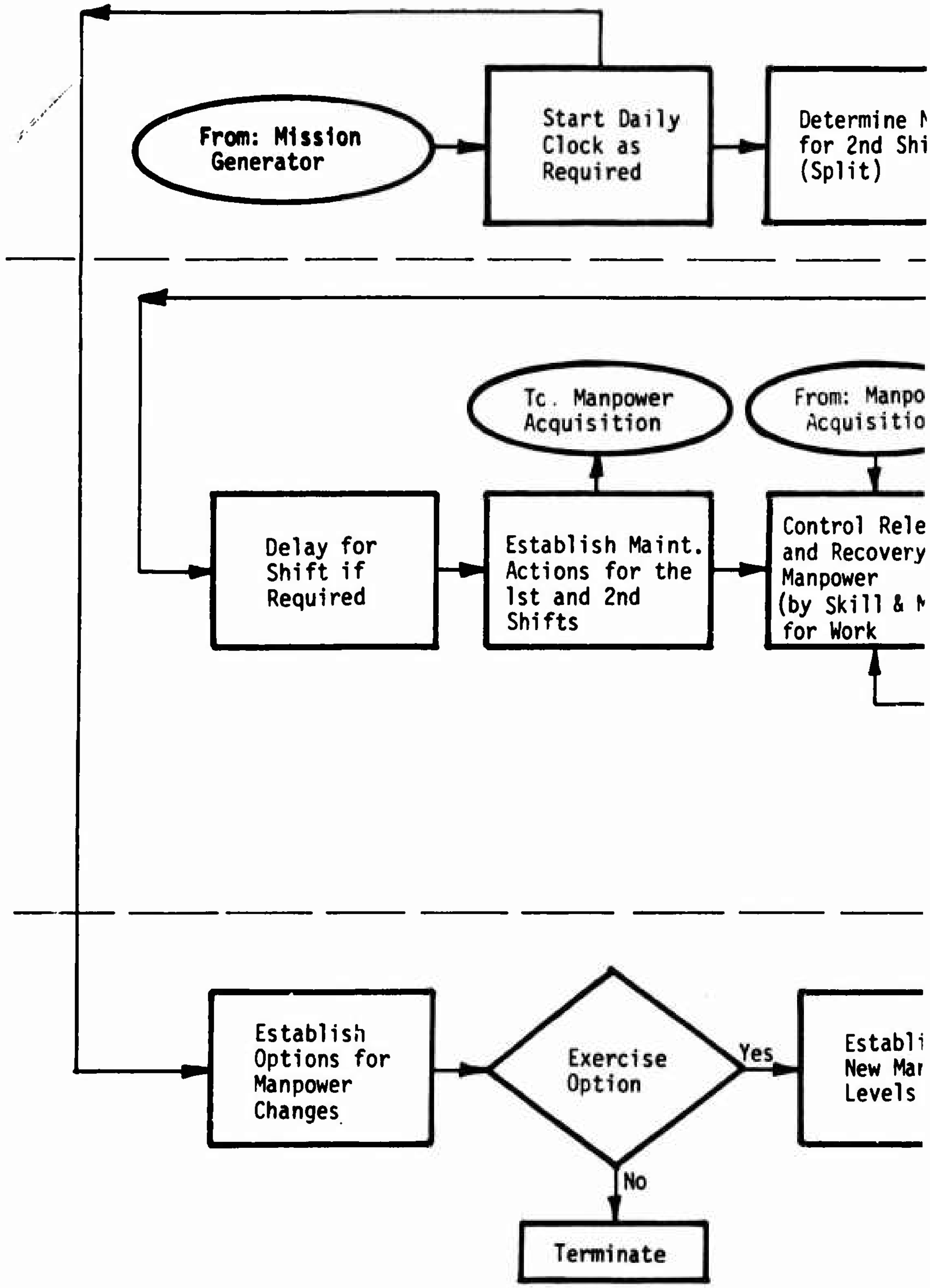
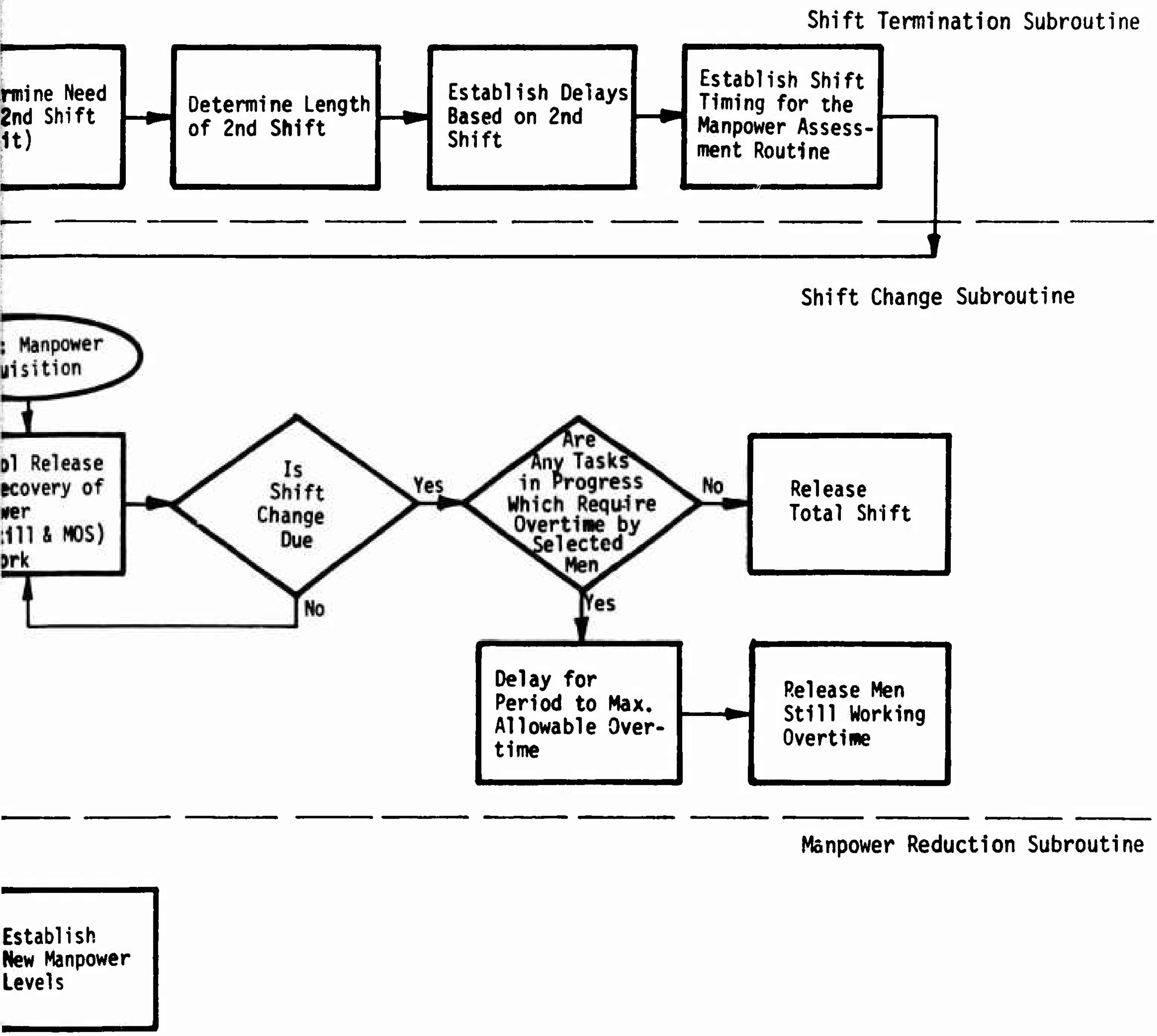


Figure 34. ARMS: Manpower Control Routine.



Shift Termination Subroutine
rmine Need
2nd Shift
it)
Determine Length of 2nd Shift
Establish Delays Based on 2nd Shift
Establish Shift Timing for the Manpower Assessment Routine
Shift Change Subroutine
: Manpower
uisition
ol Release
ecovery of
wer
:ill & MOS)
ork
Is Shift Change Due
Yes
No
Are Any Tasks in Progress Which Require Overtime by Selected Men
No
Yes
Release Total Shift
Delay for Period to Max. Allowable Overtime
Release Men Still Working Overtime
Manpower Reduction Subroutine
Establish New Manpower Levels

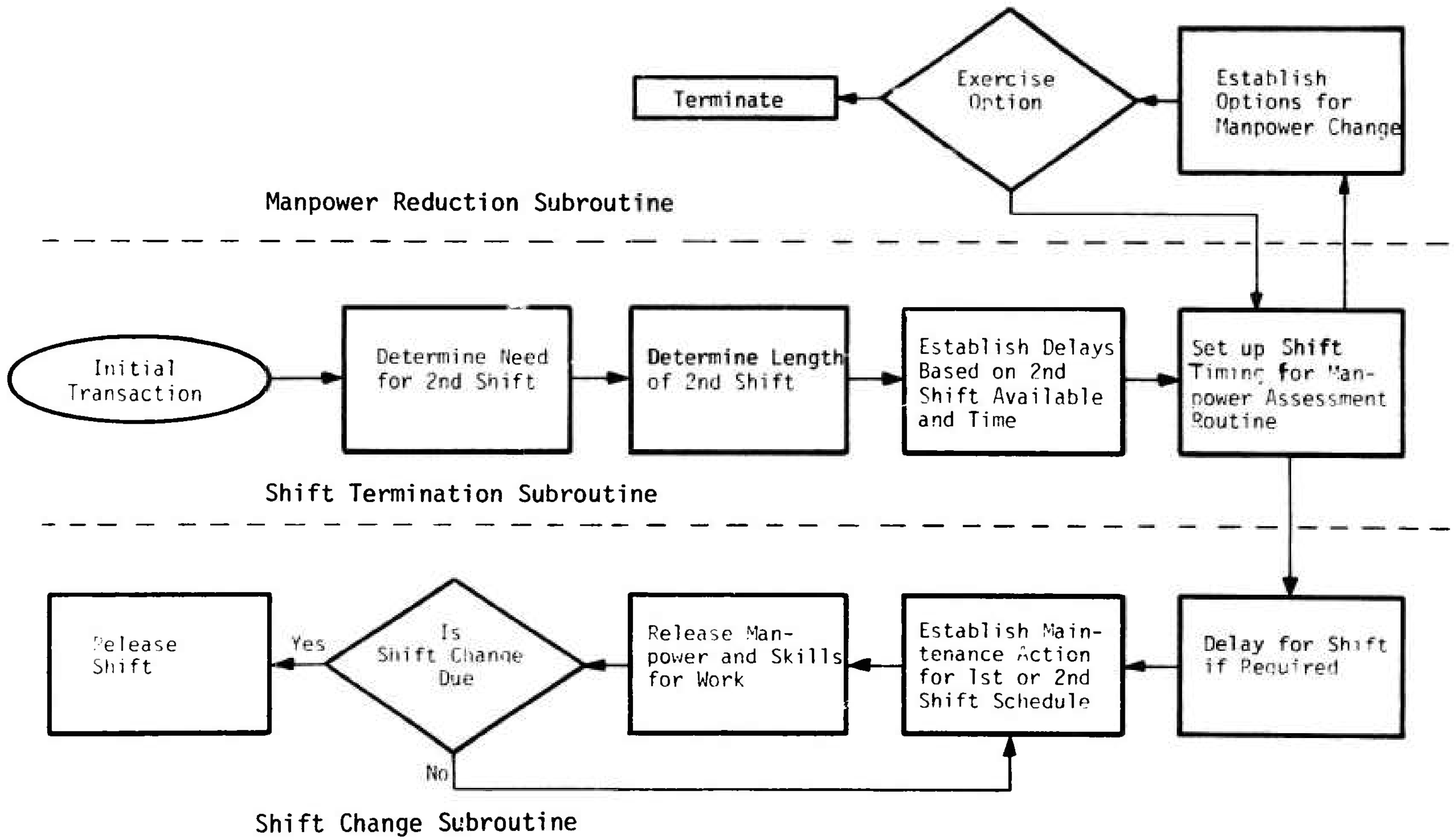


Figure 35. VALUE IV: Manpower Control Routine.

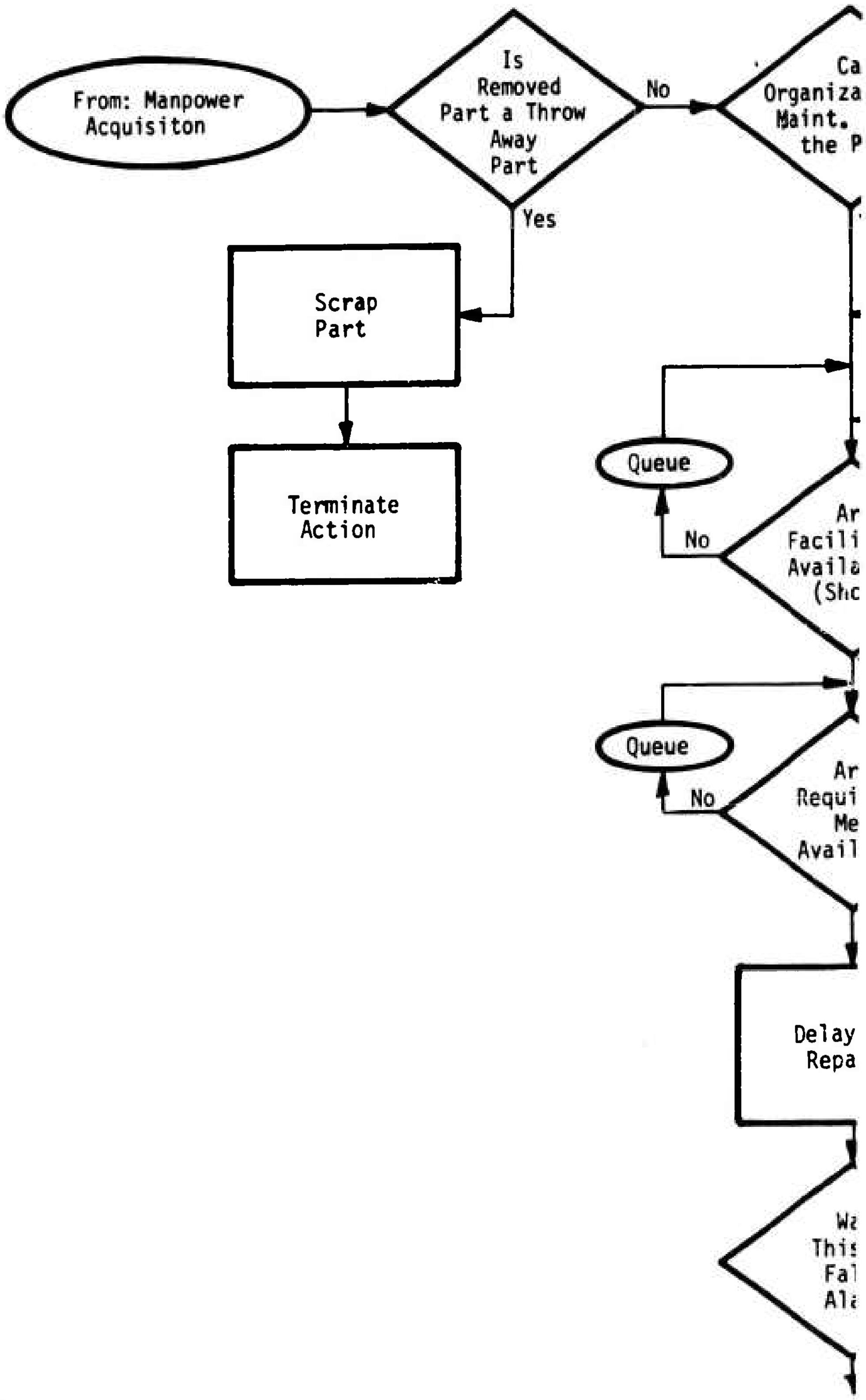
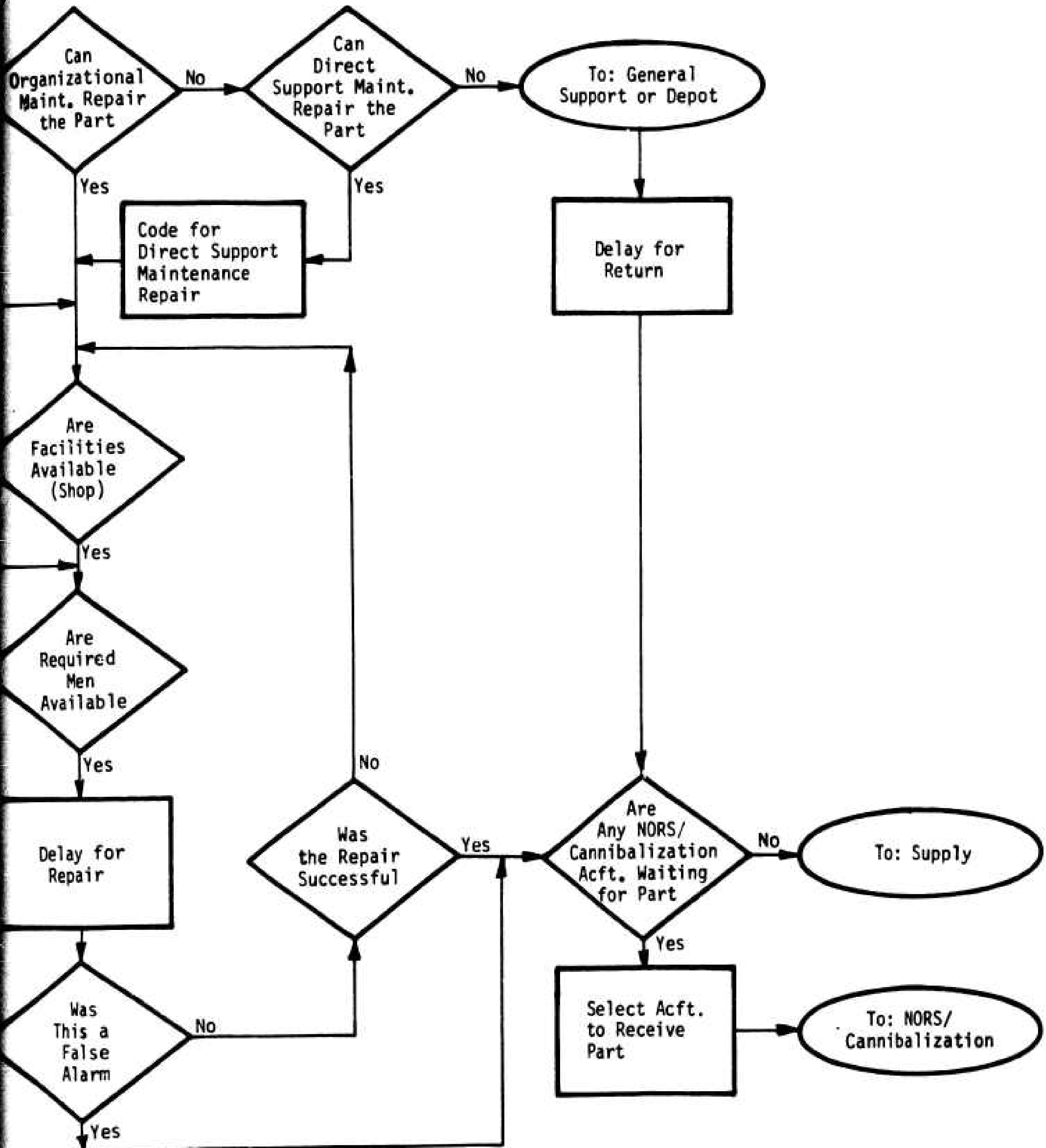


Figure 36. ARMS: Organizational and Direct Support Parts Repair Routine.



Can Organizational Maint. Repair the Part
No
Can Direct Support Maint. Repair the Part
No
To: General Support or Depot
Yes
Yes
Code for Direct Support Maintenance Repair
Delay for Return
Are Facilities Available (Shop)
Yes
Are Required Men Available
Yes
Delay for Repair
No
Was the Repair Successful
Yes
Are Any NORS/ Cannibalization Acft. Waiting for Part
No
To: Supply
Yes
Select Acft. to Receive Part
To: NORS/ Cannibalization
Was This a False Alarm
No
Yes

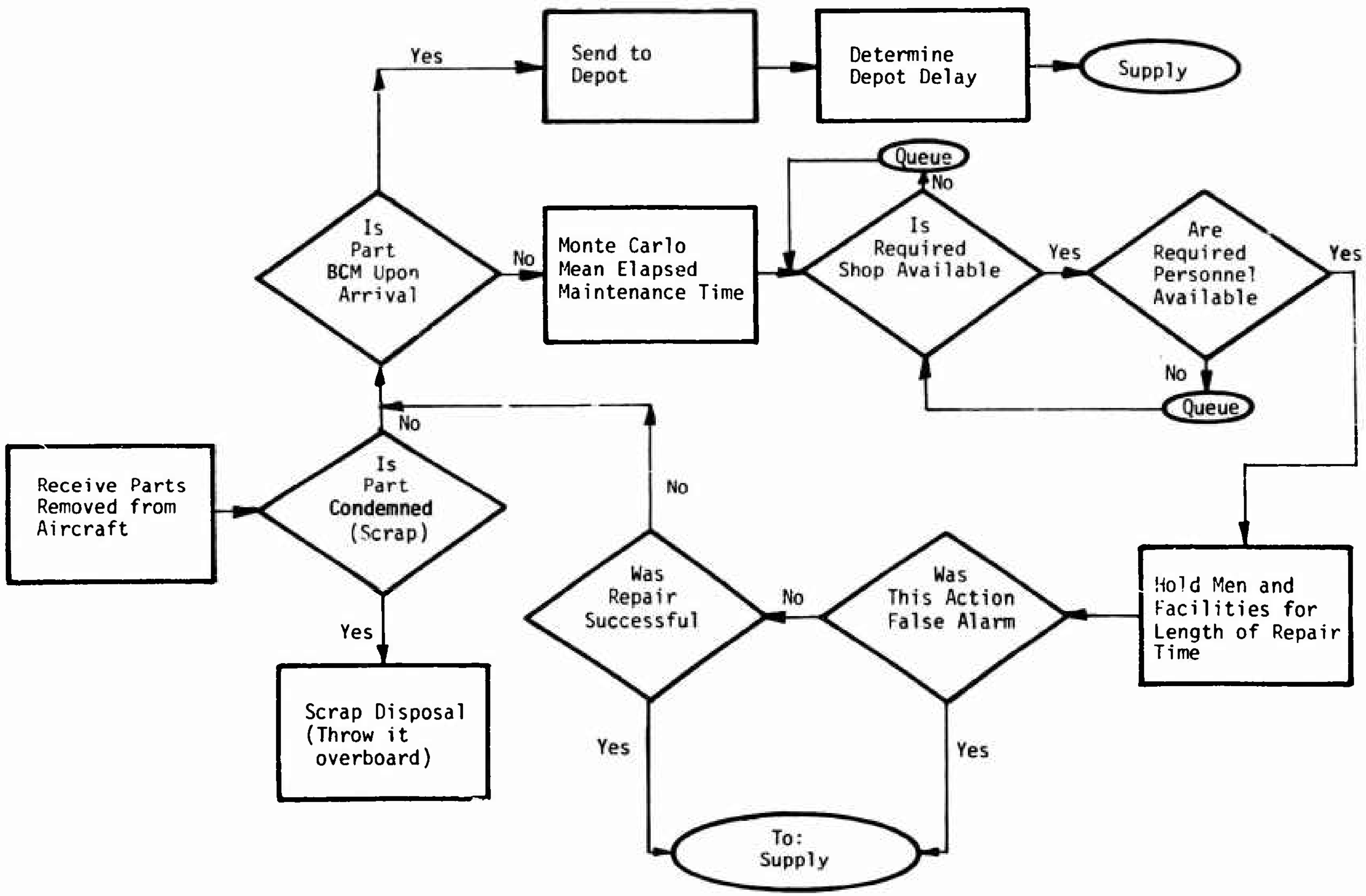


Figure 37. VALUE IV: Intermediate Maintenance Routine.

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