AN IMPROVED SCHEDULING ALGORITHM
FOR EGLIN AFB TEST RANGES

THESIS

Jeffery Scott Antes
Captain, USAF

AFIT/GST/ENS/92M-01

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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The success of this new interactive scheduling algorithm is measured against a schedule produced by the current computer system, and against a schedule produced manually. The schedules that were produced using the new algorithm suggest improvement over the current computer system in terms of airborne test, task, and task-oriented training missions. Reimbursable costs were also improved. The new algorithm also produced a schedule comparable to one produced manually, and tends to suggest a small improvement. Improved mission throughput is one of the benefits that can be realized by incorporating the new algorithm as part of the current computer system.

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THESIS

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In Partial Fulfillment of the
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Jeffery Scott Antes, B.S.
Captain, USAF

March, 1992

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Co-advisor	Dr. James W. Chrissis/ENS	....
Co-advisor	Capt John J. Borsi/ENS	....

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Jeffery Scott Antes

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Abstract

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AN IMPROVED SCHEDULING ALGORITHM FOR EGLIN AFB TEST RANGES

I. Introduction

Background

The Department of Defense (DOD) uses test ranges across the United States to evaluate new research products, conduct operational tests and evaluations, and perform continuation training. The 3246th Test Wing (3246 TESTW) manages the Eglin Air Force Base range complex for the Air Force Development Test Center (AFDTC). In operating and maintaining over 86,500 square miles of water ranges, 725 square miles of land ranges, and a multitude of support facilities, the Wing tests and evaluates nonnuclear armaments, electronic combat systems, and navigation and guidance systems (4). The following discussion of the Eglin range facilities and scheduling process has been developed from information provided by the 3246 TESTW.

Several hundred test facilities are available at Eglin AFB. Examples of these facilities include:

1. Electronic countermeasures (ECM) threat sites for use with air- and ground-based electronic warfare systems.
2. A rocket sled track for controlled munitions effects testing.
3. A supersonic land range for high-speed flight.
4. A precision-measurement grid to measure how bomblets are dispersed.

5. Preflight Integration of Munitions and Electronic Systems (PRIMES) facility for ground simulation of electromagnetic flight environments.
6. Bombing ranges to test guided and unguided air-to-ground weapons.
7. Air ranges to test air-to-air weapons and conduct airborne training.
8. Explosive ordnance detonation (EOD) ranges for experimentation and training.
9. A climatic chamber to simulate various extreme weather conditions.

Approximately 500 different *profiles* or mission scenarios use one or more of the facilities. In addition to facilities, there are over 1000 equipment resources such as aircraft, radars, cameras, and antennas, used to support the tests(2). Some missions require specific equipment for specialized resource capabilities, while other missions can use one of many available resources. An operations and maintenance (O&M) contractor is responsible for many of the facility and equipment resources. Resource requirements relate directly to the test program development.

Early in the program development the program manager and an O&M representative discuss the range resources as they relate to each mission objective. The program manager writes a test directive which includes guidance concerning the program and information concerning resource requirements. Test engineers later use the test directive as a guide to develop test mission requests. A computerized scheduling tool, the Resource Scheduling and Operational Management System (RESOMS), is an integral part of submitting mission requests and scheduling test missions on the Eglin test ranges.

Test engineers enter two-part mission requests into RESOMS. *Mission Request Part A* contains resource requirements. *Mission Request Part B* shows aircraft load configuration, requested munitions, internal aircraft instrumentation, camera requirements, and any other special instructions. Appendix A provides a sample RESOMS mission request (3). Approximately 100 mission requests are submitted for each scheduling day.

Mission requests can be divided into general categories of training, test, task, and task-oriented training missions. Most training mission requests require a limited number of resources, providing a great deal of scheduling flexibility. Therefore, discussion of these mission requests is minimal in this research paper. The test missions, task missions, and a few task-oriented training mission requests require specialized or a considerable number of resources. As a result, further discussion focuses primarily on this group of mission requests.

To schedule the mission requests, RESOMS has three different modes of operation. The first mode schedules missions based on mission priority without any interaction from the user. If a resource conflict cannot be resolved by RESOMS the mission status is set to *NONSCHEDULED* and the system continues with the next highest priority mission. The second mode of operation is a semi-interactive mode that stops the scheduling process when a conflict cannot be resolved by RESOMS. The user periodically reenters the scheduling mode, identifies the mission and the resource conflict, and attempts to resolve the conflict if possible, or otherwise changes the mission status to *NONSCHEDULED.* The user then restarts RESOMS with the next highest priority mission and the process repeats. The third mode of operation is very user interactive. This single mission scheduling mode schedules each mission in RESOMS as directed by the user.

Currently, the semi-interactive and interactive modes are the only modes used for scheduling by the 3246 TESTW/DOS. The noninteractive mode is not used, since 3246 TESTW experience has found the schedules produced to be significantly inferior to ones produced by manual scheduling. The semi-interactive mode is used for scheduling training missions with few resource requirements. The flexibility of these training requests allows easy resolution of the occasional conflicts. This mode is not used to schedule the test and task missions since changing previously scheduled missions is cumbersome and time consuming due to the computer/user interface, especially if numerous missions must be altered or moved. This is further complicated by the fact that no prompt is available to tell the scheduler that RESOMS has stopped the scheduling process. Schedulers found RESOMS most useful for checking resource conflicts and scheduling missions previously plotted on a schedule by hand.

The Scheduling Process

The range scheduling division is responsible to the 3246th Test Wing/Deputy Commander for Operations (3246 TESTW/DO) for the complex process of determining how to sequence multi-resource mission requests for all missions using the Eglin facilities(1). A major change to the man-in-the-loop involvement occurred August 5, 1991, when the test wing changed from an eight- to a six-day scheduling cycle. This six-day scheduling cycle does not produce a six-day schedule, but rather a one-day schedule that takes six days to develop. The current scheduling process (shown in Figure 1.1) is described in the remainder of this section.

RUF		PLOT	FORECAST	HOTSEAT	EXECUTION
T-5	T-4	T-3	T-2	T-1	T-0
Final Get O&M contractor review Maintenance review Pre-plot begun	Pre-plot updated Schedule review meeting	Pre-plot = Plot Plot updated Schedule review meeting	Plot updated Operations Order printed No changes to Ops Order accepted	No changes to Ops Order accepted	No changes to Ops Order accepted

Figure 1.1. Six-Day Scheduling Process

Prior to the start of a cycle, a test engineer submits a mission request for a given test day (T). Some test organizations have presubmission reviews to eliminate conflicts between test programs within the organization. For example, the 3246 TESTW/Scheduling and Plans Branch(DOSP) must coordinate on requests submitted from within the test wing. Mission requests are entered into the RESOMS data base either directly or through the use of AFSC FORM 4024 for users without direct computer access. These mission submissions initiate the six-day cycle.

The *Ruf*, day T – 5, begins with the O&M contractor extracting a sorted printout of each mission request — the *Get.* RESOMS sorts the mission request inputs by mission priority. The 3246 Test Wing/Plans Division (XP) establishes a mission priority (1 – 999) for each test program using DOD and wing guidelines. After receiving the submissions, the contractor reviews them to ensure appropriate resources are requested to meet the planned mission objectives. A maintenance representative then ensures required aircraft availability and assigns appropriate additional aircraft. A scheduler then reviews 15 – 25 percent of the highest priority missions, to identify those requiring critical resources such as tanker aircraft, consolidated control facility (CCF), or frequency control and analysis(FCA) for the day being scheduled. This begins *Pre-plot*, the actual scheduling function.

The hand plotting of missions is a complex process since multiple resources are involved. The goal is to schedule as many of the requested missions as possible. For example, if two missions request the same aircraft to fly at the same time, schedulers must determine if alternative aircraft or times can be substituted. Schedulers often contact test engineers to request minor changes to missions in terms of a different number or type of resource than those listed as alternatives on the mission request, thus allowing additional missions to be flown. Once obvious conflicts are resolved, a manual entry is made on the *Pre-plot* schedule. A sample of this form is shown in Appendix B. The scheduler passes the mission request to an O&M contract employee who annotates O&M-operated resources scheduled for use. The mission request is then passed to another scheduler. This scheduler updates the mission request based on changes made by the first two people in the sequence and enters the mission into the RESOMS via single mission scheduling mode. RESOMS checks for aircraft, range support, range profiles, CCF, and two types of frequency utilization conflicts.

Minor conflicts are resolved and when no conflict exists the mission status is changed to *SCHEDULED.* When an unresolvable conflict exists, the mission with the higher priority is scheduled and the other is nonscheduled. This process continues until the scheduler processes all of the test, task, and task-oriented training mission requests.

Day T – 4 begins with a review of the previous day's flight activity. Frequently, numerous changes must be made to the *Pre-plot* schedule. One reason relates to backup missions which can be scheduled every second day following the originally scheduled date. For example, a successfully flown mission yesterday cancels backup missions previously scheduled for tomorrow and three days hence. Other reasons for cancellations include changing mission requirements, nonavailability or failure of test equipment, and aircraft maintenance, among others. Several possible scheduling opportunities exist for the openings created by canceled missions. Canceled missions may already have alternate missions waiting to take their places. Previously *NON-SCHEDULED* missions lacking a specific resource may plug into the slot, if the canceled mission releases the needed resource. After trying to schedule previously nonscheduled missions, the scheduler attempts to schedule any blackboard missions (blackboards). Blackboards are those mission requests submitted after 0800hrs on day T – 5. These late submissions have no mission priority over timely submittals. Canceled missions may cause resources to be unused that could only be used by rebuilding the entire schedule. The schedule is not rebuilt due to the labor involved and mission preparations already in progress. A mid-day meeting with operations and support agencies is held to review the schedule and discuss desired changes. Changes to the schedule are made due to resource conflicts (e.g., crew availability and special radio frequencies) undetected or unknown during the scheduling process.

Day T – 3, called *Plot*, begins with more changes to the schedule based on another day of flight activity and mission request changes. After changes and new blackboards are dealt with, the RESOMS semi-interactive scheduler is used to include the training mission requests in the schedule. Operations and support agencies attend another mid-day meeting to make a final review of the schedule. Changes continue throughout the day based on the latest flight activity.

Day T–2 is called *Forecast*. A new team of schedulers is dedicated to the schedule and work with it through execution (T – 0) to ensure continuity. Final revisions to the schedule are completed by 1200hrs and the Operations Order (Ops Order) is printed and distributed. The Ops Order is the official schedule. No mission changes affecting the schedule or maintenance operation are accepted. Mission cancellations made after this time have financial consequences for the using agency. Costs include the mission submission fee and any canceled resource costs.

Day T – 1 is called *Hot Seat*. Only minor changes to the schedule are allowed on this day(e.g., changes of radar resources due to needed repairs). These changes would not affect the overall mission or maintenance support requirements.

Day T – 0 is called *Execution*. An assigned staff and the dedicated scheduling team operate the Range Operations Control Center (ROCC). The group handles schedule problems that occur while the missions are airborne, or during final ground preparation. Problems occur for a variety of reasons including weather conditions or equipment malfunction.

RESOMS

RESOMS was conceptualized in 1979 and began operational use in 1983. The system is continually being updated to improve usability and capability. Small updates are often incorporated into daily maintenance tasks. Larger tasks are added to a list of program improvements. As of 1 November 1991, 25 requested enhancements to RESOMS have been identified. The list of requested improvements includes numerous computer/user interface recommendations, a formal feedback capability from schedulers to test engineers, and the need for alternate scheduling algorithms. Some suggestions to improve the scheduling algorithms include maximizing the number of missions scheduled to use the range and/or maximizing reimbursable budget authorization(RBA— money users pay Eglin AFB for O&M supported services). Maximizing the number of missions scheduled may also increase RBA, as well as customer satisfaction. Unfortunately, due to limited manpower, work on alternate scheduling algorithms for RESOMS has not been planned to date (5, 13).

Problem Statement

RESOMS can produce a schedule in the noninteractive mode; however, the RESOMS scheduling algorithm does not always produce an acceptable schedule in terms of number of test missions scheduled or maximum RBA. The algorithm performs only one pass for each mission request, preventing the system from reviewing previously-scheduled missions. In short, once scheduled, the resources are considered unavailable and RESOMS does not look at the mission request again. Missions may not be scheduled when alternate or sufficient resources exist but are not indicated on the mission request(e.g., radars and CCF). This results in more nonscheduled missions. The semi-interactive mode may force numerous missions to be unscheduled to resolve a conflict. Depending on the magnitude of changes, this can be very time consuming. Schedulers have found this mode as too inefficient for use in scheduling test, task, and task-oriented training missions. As a result, these missions are scheduled manually, prior to being entered into RESOMS using the single mission scheduling option.

The manual plotting of the schedule produces much better results in terms of number of test, task, and task-oriented training missions, 3246 TESTW/4485 Air Warfare Center(AWC) sorties, and RBA, but it is labor intensive. It also relies on the experience of the military schedulers in the range scheduling division, who are scheduled to leave in October 1992 when the scheduling process is turned over to the recipient of the new O&M contract. An improved scheduling algorithm could be incorporated as part of the recommended improvement to RESOMS and provide a systematic thought process that could be used in training new contract schedulers.

Purpose of the Research

The purpose of this research is to develop an algorithm that could be incorporated into RESOMS to improve the mission scheduling function. The algorithm interfaces with existing data and resource deconfliction subroutines currently in use or available through RESOMS. The algorithm is consistent with 3246 TESTW, USAF, and DOD guidelines currently in use at the Eglin test range. The primary objective of this research was to design an improved computerized scheduling aid. The measure of performance for this approach is the number of missions scheduled using this aid as compared to current Eglin capabilities. The research effort is limited to the *Pre-plot* schedule developed on day T-5. The *Plot, forecast, hot seat* and *execution* scheduling process is not included, since only modifications to the existing schedule are made during these phases. To accomplish the primary objective of successfully developing an effective algorithm, several prerequisites were accomplished and their discussion is included in subsequent chapters.

Overview of Subsequent Chapters

An understanding of general scheduling concepts and specific scheduling requirements is needed prior to working with any scheduling problem. Understanding of the Eglin test range scheduling was gained through the study of regulations, procedures, and directives, interviews/discussions with 3246 TESTW personnel associated with mission scheduling, as well as personal observation and interaction with the scheduling operation. An understanding of general scheduling concepts and appropriate solution approaches to the problem was gained through a review of the literature. Chapter II contains a discussion of the relationships between the theory and the specific problem, consideration of reasonable measures of effectiveness, and discussion of appropriate solution approaches.

Chapter III concerns the scheduling algorithms. The first portion of the chapter discusses assumptions and operating constraints used in the scheduling algorithm development. The later portions describe RESOMS, the manual scheduling method, and the new scheduling algorithm. The major differences between the scheduling methods are also discussed.

Chapter IV includes analysis schedules produced using three scheduling methods — RESOMS without user interaction, manually and the new interactive algorithm. A summary of the schedules as well as analysis of reasons why missions were scheduled by one method and not another is included.

Chapter V presents conclusions of the research and recommendations for further study.

II. Literature Review

The purpose of this chapter is to discuss some of the scheduling concepts contained in current literature. This includes a review of several measures of performance applicable to scheduling problems. Discussion focuses on resource-constrained scheduling with emphasis on heuristic rules relevant to range scheduling at Eglin AFB. Concerning scheduling problems, Baker states: "Traditionally, scheduling problems have been viewed as problems in optimization subject to constraints . . .(6:5)."

Optimization and Scheduling

In the attempt to find an optimal or near-optimal schedule for a given problem, some measure of performance or standard must be used to gauge success. Depending on the particular scheduling problem, the objective may be minimization or maximization of some standard. Weighted standards can be used to reflect multiple optimizations within a problem. Baker states the following concerning optimization and objective functions:

> Ideally, the objective function should consist of all costs in the system that depend on scheduling decisions. In practice, however, such costs are often difficult to measure, or even to identify. . . . Three types of decision-making goals seem to be prevalent in scheduling: efficient utilization of resources, rapid response to demands, and close conformance to prescribed deadlines. Frequently, an important cost-related measure of system performance (such as machine idle time, job waiting time, or job lateness) can be used as a substitute for total system cost. (6:5)

The complexity of Eglin range scheduling makes inclusion of all costs in the scheduling decision difficult, if not impossible. Examples of a number of the common cost-related measures of performance found in the literature include: throughput, idle time, overtime, opportunity cost, earliness, tardiness, and flowtime(6:9 – 23),(9:119), (20:32–39), (23:31–33), (28:65–66).

Although these measures of performance are typically related to a manufacturing process, a few of these are related to range scheduling. Numerous schedules are possible using one or more measures of performance. Weighted sums of these cost-related measures could be used, but they are dependent on the difficult task of determining weighting or utility factors (17:3), (23:30), (26:70). Based on experience, Eglin range scheduling uses maximum throughput, in terms of the number of missions scheduled, as its measure of performance. The other measures of performance discussed are possible alternatives, although for this research are considered only as scheduling constraints.

Throughput. Throughput is a cost-related measure frequently used to support decision making goals. Improved equipment, materials, and/or manufacturing processes can often increase production output. Eglin range scheduling is no exception. The number of missions scheduled reflects the throughput of the Eglin scheduling process. With forthcoming budget cuts, and with range resources not expected to increase, scheduling procedures provide the best opportunity for improving the number of missions scheduled. If more missions can be scheduled, customers can complete their test programs with less delay. Maximizing throughput may or may not increase the number of resources in use or the amount of reimbursable funds to the 3246 TESTW. However, it is no unreasonable to expect that the level of reimbursement (RBA) would increase with better throughput.

Idletime, Overtime, and Lost Opportunity. Several cost-related measures of performance concern efficient utilization of resources. Idletime, overtime, and lost opportunity relate directly to decision-making goals for many companies. These measures of performance are also an appropriate topic of discussion for Eglin test range scheduling.

The minimization of idle time relates to efficient utilization of resources. If a resource has no idle time, maximum value of the resource has been obtained (6:13-14), (22:1208). This is true, to a limited degree, for Eglin test range scheduling. The 3246 TESTW has identified several test range resources in very limited supply. For example: most FCA codes can be used by only one mission at a time; CCF capacity can be reached when only a couple missions require extensive data; and usually, only one tanker aircraft is available on a given day. Some of these resources are operated through an O&M contract with portions of the cost reimbursed by the using test program. Eglin range schedulers attempt to keep idle time of these resources at a minimum. 3246 TESTW/DOS experience indicates that scheduling missions using a large portion of these critical resources before missions needing few resources minimizes idletime and maximizes throughput. While using this approach, schedulers must also consider utilization of other range resources and ensure mission priority constraints are not violated (14, 18, 19). In addition to minimizing idletime, minimizing overtime is also a consideration for efficient utilization of resources and the maximization of throughput.

Overtime may be a useful measure of performance if overtime operating costs are high. In industry, overtime may become a factor if demand exceeds production capability. Personnel costs are often a major contributor to overtime costs. The O&M contract employees are the primary personnel involved in an overtime situation. Evaluating the need for overtime reveals common-sense insights potentially beneficial during Eglin range scheduling. First, scheduling jobs closer together minimizes idle time, which results in the need for less overtime. Second, scheduling missions within the O&M employee workday reduces overtime before and/or after their scheduled day.

Another factor related to maximizing throughput is lost opportunity. Efficient resource utilization can reduce lost opportunity. In industry, lost opportunity might be associated with the lost profit from not having enough production capability or inventory to meet demand. This can be easily related to Eglin test range scheduling in terms of failing to schedule a mission during an available opportunity. For example, this may occur if only one mission requiring tanker support is scheduled when a second mission could have been scheduled at the same time. This is directly related to the capability of the available scheduling methods to find available scheduling opportunities.

Use of the concepts contained in discussion of idletime, overtime, and lost opportunity can improve the scheduling process and increase throughput. Details of the implementation of these concepts as constraints to improve the scheduling process are included in Chapter 3.

Constraints

Constraints are frequently encountered in scheduling problems. Two feasibility constraints associated with Eglin range scheduling concern resource allocation and mission scheduling. Both types of constraints are discussed separately below, with respect to Eglin range scheduling.

Resource Allocation. In the development of a schedule, allocation constraints relate to which resources are allocated to perform each task (6:5). This is no small concern for the Eglin test ranges. As of mid-November 1991, over 1000 resource codes were listed in AFDTC Pamphlet 55-12. Some scheduling constraints are developed with the test program. Some constraints may restrict testing of a system to specific resources. For example, a test may require one particular F-15 aircraft using one particular bomb range. This restriction may be caused by the existence of only one system or essential test equipment being available from only one source. Other constraints provide more flexibility during scheduling. For example, some tests allow a choice of any of a particular type of aircraft (e.g., F-15) or radar (e.g., A-20). The most flexible constraints allow any aircraft to be used as a chase ship or any airspace block to be used. The inability to satisfy any of these constraints would prevent the mission from being performed.

Other interacting resource constraints exist, based on safety criteria. A range resource may not be in use, but still restricted from use due to another operation in another area. For example, numerous ground test areas cannot be used while an aircraft with live ordnance flies overhead. This conflict may cause a mission to be nonscheduled. In many cases RESOMS can determine nonfeasibility when a resource conflict exists. Possible alternative resources listed on the mission request are considered for the mission being scheduled; however, selecting alternate resources on missions already scheduled is not performed by the current RESOMS algorithm. Including this capability would be an improvement to the scheduling algorithm. Assumptions concerning Eglin test range resource constraints are discussed in Chapter 3.

Mission Scheduling. Constraints associated with mission scheduling concern when missions are performed. Discussion concerning idle time, overtime, and lost opportunity in Chapter II highlighted the importance of scheduling missions close together within the day. The current RESOMS scheduling algorithm uses the requested start/stop time as input for when a mission can be flown. In some cases this is important, as it may be a *hard* constraint that if not met results in the mission being nonscheduled. For example, when satellite coverage limits the test mission acceptable time block, even a small deviation from the given start/stop time may be unacceptable. For other missions, the requested resource may be based on some *soft* resource constraint which has flexibility beyond the desired request. Scheduling using the requested start/stop times can produce idle time between operations. An improvement to this method would be to adjust mission start times to begin as soon as possible after the previous mission. This would also help reduce overtime requirements as long as the solid block of use time was not different than scheduled duty hours. Idle time may still exist, since resources have various turn times (time required prior to reuse). One example of this is that an aircraft may have a four-hour turn time whereas a radar may have only 30 minutes of required turn time. This idle time may not be lost, as other missions may not require the aircraft and can utilize the radar. The assumptions concerning scheduling constraints that would improve the current RESOMS scheduling algorithm are explained in the next chapter, during discussion of the assumptions and operating constraints.

Resource-Constrained Scheduling Problems

Problems can be classified by how much time a solution could take. The worst case *time complexity function* for an algorithm expresses its time requirements by giving, for each possible input length, the largest amount of time needed by the algorithm to solve a problem of that size. A *polynomial time algorithm* is one whose time complexity function is polynomial for a given input length n. Resource-constrained scheduling problems(RCSP) are classified as NP-complete for which no known worst-case polynomial time algorithms exist. The only known solution approaches for NP-complete problems can take, in the worst case, an exponential amount of time. Heuristic approaches which cannot guarantee optimal solutions are commonly used when the size of the problem indicates that the computational time requirements become infeasible (9:131), (10:72), (12:323), (17:3–5), (23:30), (24:3–8), (25:83),(26:65), (28:66), (29:412), (11:6). Since the Eglin test range problem is a large RCSP, this provides the motivation for the use of heuristic approaches in this situation. The following sections discuss heuristics in general, and then highlight several appropriate techniques.

Heuristics

Heuristic approaches to scheduling often consist of "fairly simple scheduling rules capable of producing reasonably good suboptimal schedules (6:279);" or more simply as *rule-of-thumb* scheduling (17:5), (8:9b). Many times these heuristics are tailored to fit the specific problem under consideration. Since a heuristic approach cannot guarantee an optimal result, it can be difficult to determine the effectiveness of any one solution approach. Many times, comparisons can be made only with other heuristic approaches on specific problems(6:285), (12:323–324).

Optimization methods are often used in conjunction with heuristics. A mathematical program may be used to optimize a portion of the overall problem. Other times, a heuristic approach is used to provide a starting point for an optimal solution. Examples of mathematical approaches included in the literature are branch-and-bound (22), critical path methods (22), linear programming (12) and integer programming (29). For a more complete listing of examples of heuristic applications, the reader can reference a survey of heuristic methods and applications that categorizes 442 articles into 12 classes of heuristic approaches and 144 areas of application (30). Details of the optimization techniques are included in related textbooks (7, 15, 16, 21, 27).

Priority Rules

The literature includes many discussions of rules used for assignment priority. Some of these assign priority to jobs with the least slack, shortest processing time (SPT), first-come-first-served(FCFS), or are based on the critical path of a job (6:279), (22:1208), (23:35), (26:66). The following are several priority rules that may be applicable to Eglin range scheduling.

1. Select missions to enter the scheduling process based only on mission priority. This always ensures DOD and Eglin priority constraints are not violated.
2. Select missions based on a set of critical resources. As discussed earlier, experience indicates tanker aircraft, CCF, and FCA resources are critical resources since they are in very limited supply and create the most obvious bottlenecks to the scheduling process.

Scheduling algorithms use priority rules with constructive and/or improvement heuristics.

> Construction algorithms generate a solution by adding individual components .... one at a time until a feasible solution is obtained. 'Greedy' algorithms, seeking to maximize improvement at each step, comprise a large class of construction heuristics. .... Improvement heuristics begin with a feasible solution and successively improve it by a sequence of exchanges or mergers in a local search.(30:89)

The current RESOMS scheduling algorithm is a Greedy type constructive algorithm. In the noninteractive mode, missions are scheduled and not considered in any other scheduling action as the schedule develops. Only manual changes by a scheduler are possible for previously-scheduled missions. This RESOMS liability limits throughput of the schedule. A more detailed description of the RESOMS algorithm is included in Chapter III.

A new interactive scheduling algorithm is developed in the next chapter using a constructive heuristic. The algorithm selects critical resource groups and then schedules by mission priority within critical resource group. This interactive algorithm allows changes to previously scheduled missions to improve the number of missions scheduled.

III. Scheduling Algorithm Development

This chapter presents scheduling algorithms for use with the Eglin test ranges. A discussion of assumptions and operating constraints used in the algorithmic development is followed by a description of the current RESOMS scheduling algorithm. Also included is a discussion of the manual scheduling method and description of a proposed algorithm. The final portion discusses major differences between the scheduling methods.

Assumptions and Operating Constraints

During the process of developing the new interactive algorithm, several areas were identified that could produce different results based on mission request information. Several assumptions and operating constraints related to this mission request data were developed to ensure a common basis for schedule comparisons in Chapter IV:

1. Only mission requests with a mission type of *TEST, TASK,* and *TASK-ORIENTED TRAINING* are included in the algorithm study. The other training missions are not included since they are scheduled on day T-3 due to their scheduling flexibility.
2. A scheduler has screened the mission requests to ensure *OVERALL ACCEPTABLE TIME BLOCK* information will allow RESOMS to have the same time blocks to schedule missions as the new interactive algorithm. This allows the RESOMS scheduling algorithm to use available time previously restricted by convenience while not exceeding duty-day limits. Convenience constraints refer to user requests for a time block (e.g., 0930 – 1530) which ensure that duty hours are not "unreasonable". Acceptable time blocks related to other mission requirements such as sun angle, daylight or darkness were not altered.

3. A scheduler has screened the mission requests to ensure mission category information is accurate. Corrections are made as necessary. This ensures proper sequencing when scheduling missions.

4. An O&M contractor has reviewed and adjusted range support resources on the mission request to ensure only operational equipment is considered available to the user.

5. A maintenance scheduler has reviewed aircraft requirements, assigned appropriate aircraft, and entered actual pre/post maintenance time requirements on the mission request.

6. A mission being scheduled under *management emphasis* is given the same artificial mission priority for use with RESOMS and the new algorithm.

The RESOMS Scheduling Algorithm

The current RESOMS scheduling algorithm in the non-interactive mode is a constructive heuristic that builds a schedule one mission at a time based on mission priority. Once a mission is scheduled, the timing of this mission and its assigned resources are not changed. If a mission is unable to be scheduled with information provided on the mission request, the mission status is changed to *NONSCHEDULED*. The next-highest priority mission is selected and the scheduling cycle continues. Figure 3.1 shows a more detailed overview of the algorithm. The algorithm flow is divided into blocks and labeled. Description of each block includes additional details of the scheduling algorithm performed by the computer.

Block a This block selects the highest priority mission waiting to be scheduled in RESOMS. This mission is referred to as the *active* mission.

Block b RESOMS checks the active mission in all possible mission start/stop times for conflicts in the following resource groups: aircraft, range support, range profiles, consolidated control facility (CCF), and two types of frequency utilization.

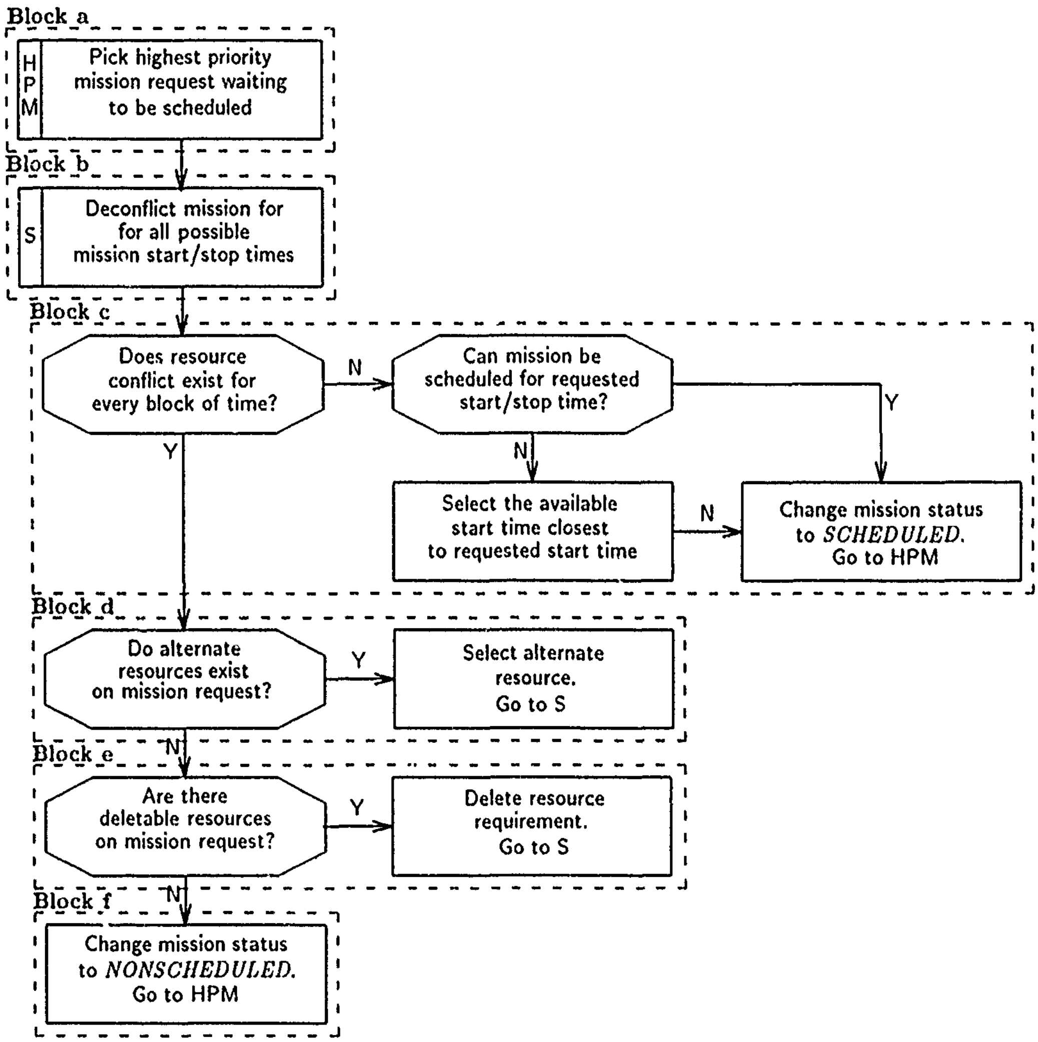


Figure 3.1. Overview of RESOMS Algorithm

Block c If there is a time in which no conflict exists, RESOMS first tries to schedule the mission during the requested mission start/stop times. If this is possible the mission status is changed to *SCHEDULED* and RESOMS begins the cycle again (**Block a**). If the mission cannot be scheduled at the requested time RESOMS schedules the mission at a time closest to the requested start/stop time prior to changing the mission status and restarting the cycle.

Block d If a conflict exists in every possible start/stop time block, RESOMS determines if alternate choices exist within the conflicting resource group for the active mission. If an alternative resource exists in the conflicting resource group, the next alternative resource choice is selected and the search for available start/stop time block begins again (**Block b**).

Block e If no alternative resource exists in the conflicting resource group, RESOMS checks to determine if any resources are deletable for the active mission. If a resource requirement can be deleted, the resource is deleted and the search for available start/stop time block begins again (**Block b**).

Block f If a resource requirement cannot be deleted, the mission status changes to **NONSCHEDULED** and the cycle begins again (**Block a**).

New Interactive Scheduling Algorithm

The new interactive scheduling algorithm presented in this section requires a man-in-the-loop to operate. The new algorithm is designed for integration in RESOMS to systematically perform many steps of the algorithm. These steps include determining what mission to schedule, selecting missions within the critical resource groups, and attempting to individually schedule missions at a designated time. However, the algorithm also relies on scheduler input to resolve conflicts. The algorithm is not intended to replace RESOMS, but rather to enhance the capabilities of RESOMS by modifying the scheduling algorithm. The development of the algorithm is based on the following:

1. A complete cycle of the algorithm consists of four parts. This four-part cycle schedules missions based on identified critical bottleneck resources as discussed in Chapter 2. The first part attempts to schedule missions requiring a tanker for refueling, CCF, and FCA resources. Missions with these resource requirements are viewed as the most difficult to schedule. The second part of the algorithm attempts to schedule missions requiring a subset of these three resources — CCF and FCA, and the third part attempts to schedule missions requiring a tanker resource. The fourth part attempts to schedule remaining missions. Within each part of the cycle, missions are scheduled by mission priority. The algorithm ensures higher-priority missions are scheduled in place of previously scheduled lower-priority missions from another cycle if possible. The algorithm four-part cycle is depicted in Figure 3.2.

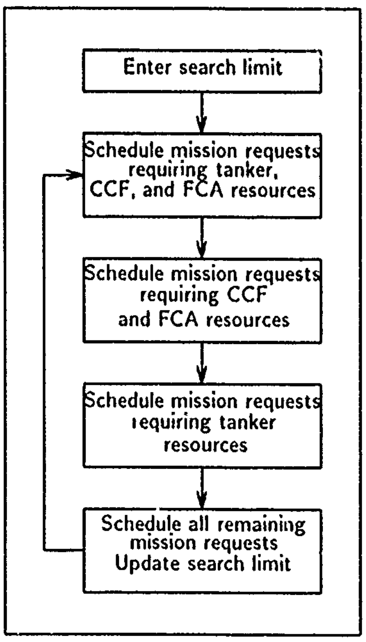


Figure 3.2. The Scheduling Algorithm Cycle

2. The scheduler enters an initial search limit. The search limit is a subjective value (e.g., 20) determined by the scheduler based on the total number of

missions to be scheduled. This allows the scheduler to consider the number of missions he expects to schedule in the first iteration. Selecting a large number results in more lower-priority missions being unscheduled because of a higher-priority mission. Selecting a low number results in missions requiring the three critical resources being nonscheduled more often. The step size increases the search limit for subsequent iterations of the cycle. A value of 15 for the step size was also subjectively determined based on the number of missions considered during this study.

3. Missions are selected for scheduling based on priority rank. Priority rank is a sequential ordering from 1 to n where n is the number of missions to be scheduled and rank can be based on the lowest mission priority number or highest RBA. Mission priority ranking is used for this study since scheduling based on RBA may violate current DOD and 3246 TESTW mission priority rules.

4. The RESOMS individual mission scheduler is used to schedule missions and identify conflicts. The capability for RESOMS to select start/stop time windows for a mission is not used. This allows the new interactive algorithm to use some of the RESOMS deconfliction capabilities while allowing all start/stop times to be directed by the new algorithm.

5. Missions requiring tanker support are scheduled to start at 0700 or 1300. Unlike RESOMS, more than one mission may use the tanker in the same time block. When a tanker resource conflict occurs, the scheduler confirms that offload requirements can be met, overrides the conflict, and schedules the mission, whereas RESOMS would nonschedule the mission. The assigned takeoff time structure also allows the tanker to fly two missions a day while providing required tanker aircraft maintenance turn time. RESOMS will allow two tanker missions to be scheduled following each other since it does not consider tanker turn time.

6. Threat missions using CCF and FCA resources have an overall acceptable time block of 1000 — 1800 unless daylight requirements require a specific mission to use an earlier stop time. This minimizes the amount of overtime required to support the required resources.

7. The overall acceptable time for remaining missions is 0700 — 1700. Mission requests with special time block requirements based on daylight or satellite coverage are not altered. This constraint is included to keep the majority of the missions within a standard maintenance and crew duty-day.

Figures 3.3 through 3.6 show a more detailed overview of the four part cycle. The algorithm flow for each part is divided into blocks and labeled. The description of each block includes additional details of the scheduling algorithm. If used as designed, many algorithm actions would be accomplished by the computer. Part 1 of the algorithm, depicted in Figure 3.3, attempts to schedule missions requiring tanker, CCF, and FCA resources. The user begins the algorithm by entering the search limit.

Block A The algorithm selects the highest priority mission requiring tanker, CCF, and FCA resources waiting to be scheduled. Only missions with a mission status of *SCHEDULING* are considered. If an alternate mission is selected, the algorithm checks the mission status of the primary mission. If the primary mission has a mission status of *SCHEDULING*, the algorithm reverses the priority rank and considers the primary mission first.

Block B The mission start time is 0700 if possible, otherwise 1300.

Block C The RESOMS scheduler attempts to schedule the mission. If this is possible the mission status changes to *SCHEDULED* and the algorithm continues in Block F.

Block D If a resource conflict could not be resolved by RESOMS, the user is prompted to determine if any alternate or deletable resources exist that were

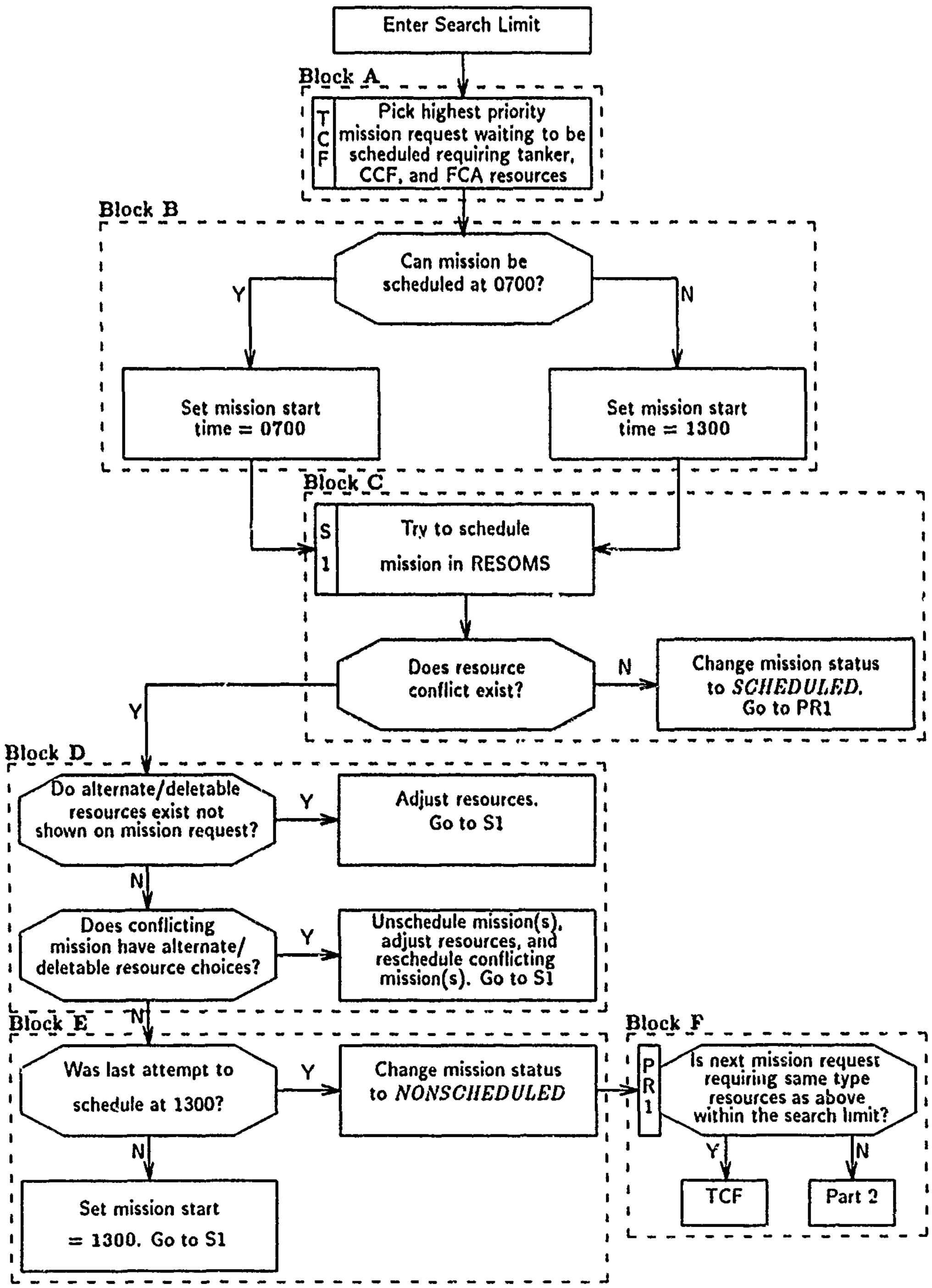


Figure 3.3. Overview of New Scheduling Algorithm - Part 1

not shown on the mission request. If changes can be made, the mission returns to **Block C**) to be scheduled after resource adjustments are complete. If changes are not possible for the active mission, the user determines if resource adjustments can be made for the conflicting mission. If changes can be made, the user unschedules the conflicting mission, makes the change, and reschedules. Scheduling of the active mission restarts in **Block C**.

Block E If the conflict cannot be resolved for a mission start time of 0700, the scheduling process begins again with a start time of 1300 in **Block C**. If the conflict cannot be resolved for a mission start time of 1300, the mission status changes to *NONSCHEDULED*.

Block F If more missions require the same resources within the search limit, the cycle restarts at **Block A**, otherwise the algorithm proceeds with Part 2.

Part 2 of the algorithm, depicted in Figure 3.4, attempts to schedule missions waiting to be scheduled which require CCF and FCA resources.

Block G The same logic as **Block A** except missions requiring CCF and FCA resources are selected.

Block H The mission start time is 0700 if possible, otherwise 1000.

Block I The same logic as **Block C** except the algorithm continues in **Block M**.

Block J The same logic as **Block D** except the algorithm returns to **Block I**.

Block K If the conflict cannot be resolved, the mission start time is slipped to the earliest available time based on turn time. As long as the stop time is within the acceptable time block, the algorithm attempts to schedule the mission using **Block I**.

Block L If the mission cannot be scheduled in the acceptable time block, the algorithm attempts to schedule the mission by bumping the lower-priority missions. Bumping occurs when a lower-priority mission is at least temporarily displaced.

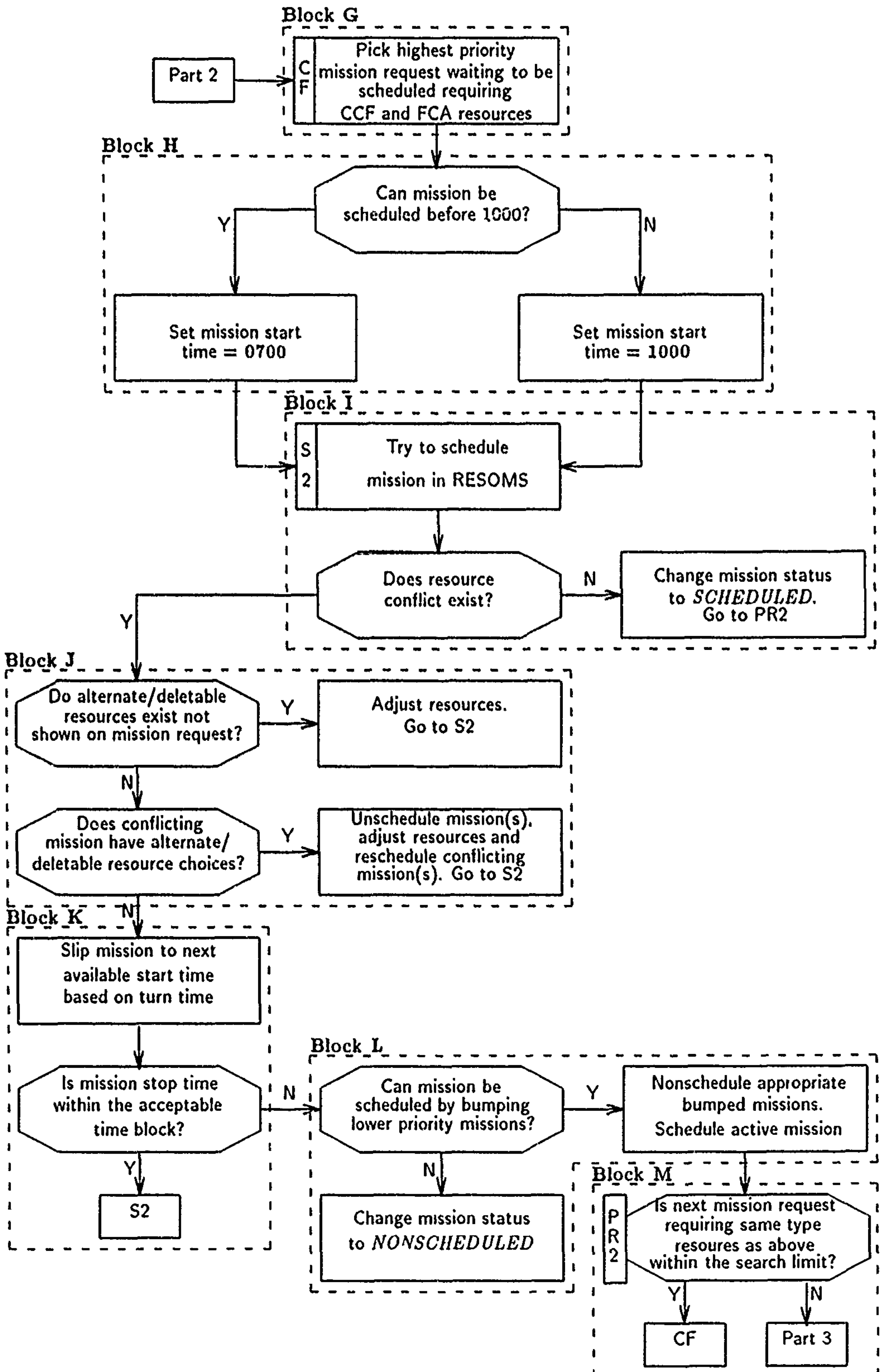


Figure 3.4. Overview of New Scheduling Algorithm – Part 2

The bumping process is accomplished by unscheduling one mission at a time until the active mission is scheduled, or no lower-priority missions remain. If scheduling the active mission is not possible, the mission status changes to *NONSCHEDULED*. An attempt is then made to reschedule bumped missions, highest priority first. Rescheduling missions in this order guards against a lower-priority mission using resources needed by a higher-priority mission. During rescheduling, the user is prompted to resolve conflicts if possible.

<u>Block M</u> If more missions require the same resources within the search limit, the cycle restarts at **Block G**, otherwise the algorithm continues with Part 3.

Part 3 of the algorithm, depicted in Figure 3.5, attempts to schedule missions waiting to be scheduled which require a tanker resource.

<u>Block N</u> The same logic as **Block A** except missions requiring tanker resources are selected.

<u>Block O</u> The same logic as **Block B**.

<u>Block P</u> The same logic as **Block C** except the algorithm continues in **Block S**.

<u>Block Q</u> The same logic as **Block D** except the algorithm returns to **Block P**.

<u>Block R</u> If the conflict cannot be resolved for a mission start time of 0700, the scheduling process begins again with a start time of 1300 in **Block P**. If the conflict cannot be resolved for a mission start time of 1300, the algorithm attempts to schedule the mission by bumping lower-priority missions as described in **Block L**. If this is not possible, the mission status changes to *NONSCHEDULED*. An attempt is made to reschedule bumped missions.

<u>Block S</u> If more missions require the same resource within the search limit, the cycle restarts at **Block N**, otherwise the algorithm continues with Part 4.

Part 4 of the algorithm, depicted in Figure 3.6, attempts to schedule all remaining missions.

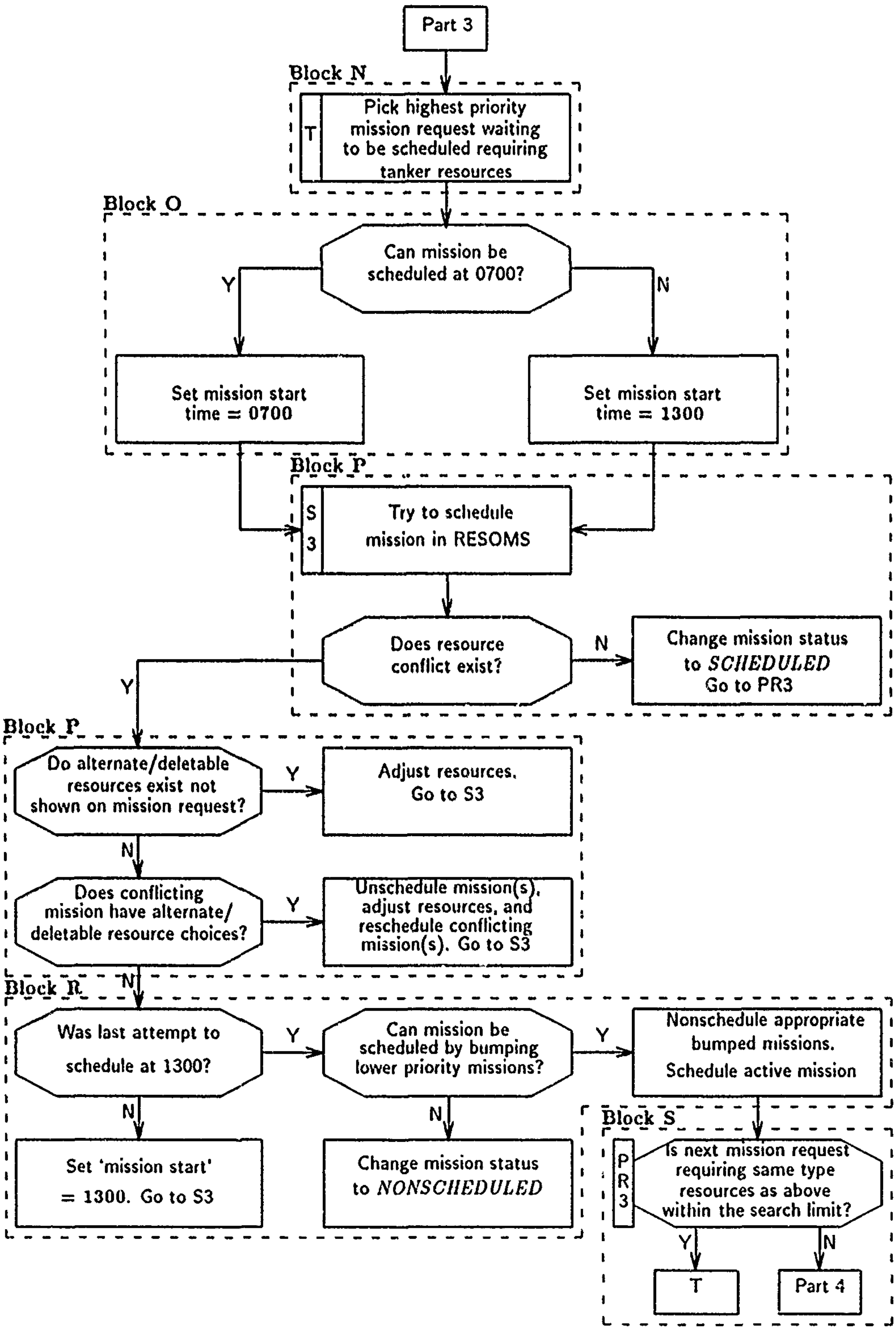


Figure 3.5. Overview of New Scheduling Algorithm – Part 3

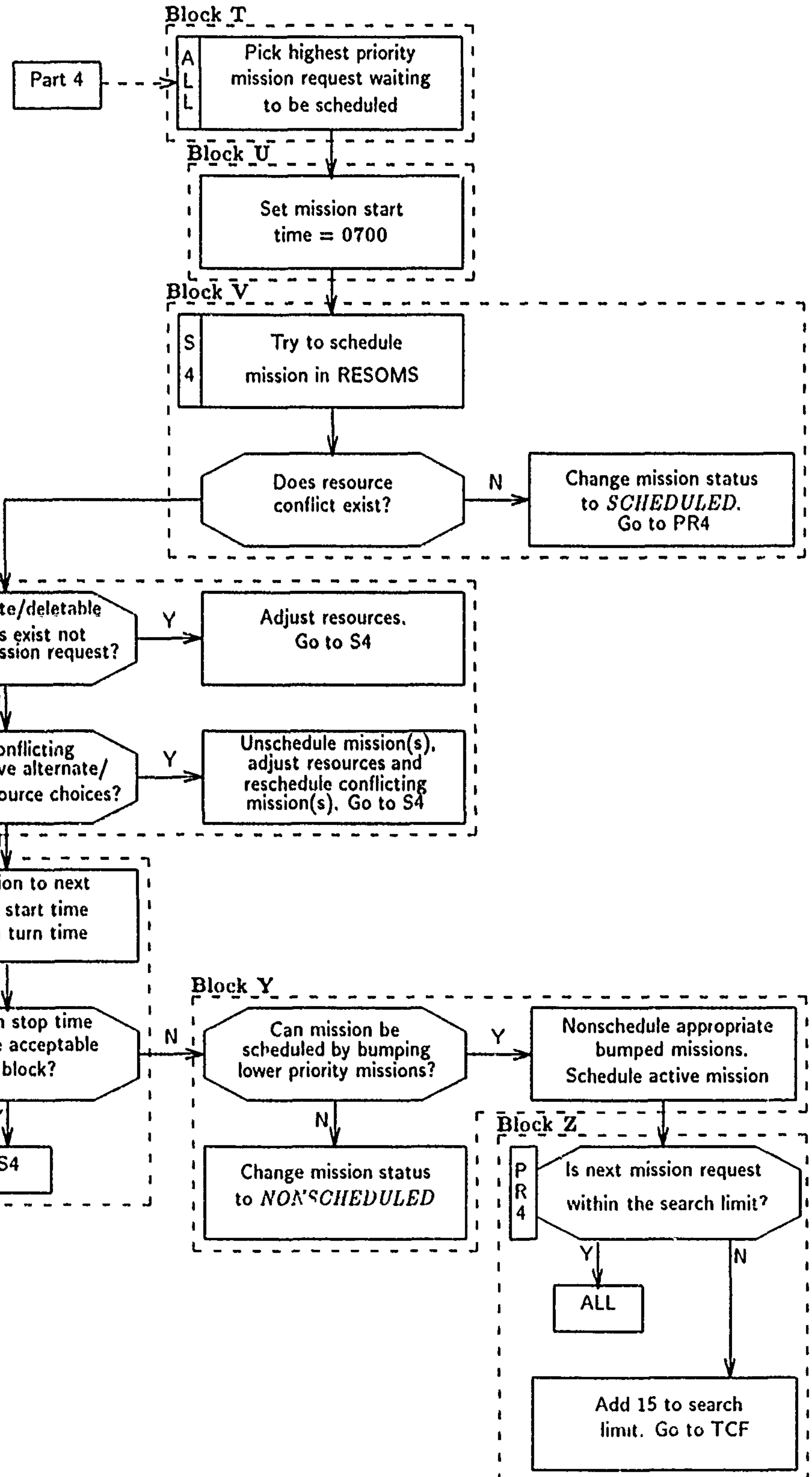


Figure 3.6. Overview of New Scheduling Algorithm – Part 4

Block T The same logic as **Block A** except resource requirements are not considered, therefore allowing all remaining missions to be considered for scheduling.

Block U Initial mission start time is 0700.

Block V The same logic as **Block C** except the algorithm continues in **Block Z**.

Block W The same logic as **Block D** except the algorithm returns to **Block V**.

Block X The same logic as **Block K** except the algorithm returns to **Block V**.

Block Y The same logic as **Block L**.

Block Z If more missions exist within the search limit, the cycle restarts at **Block T**, otherwise add 15 to the search limit and continue the algorithm with **Block A**.

For a step-by-step detail of the new scheduling algorithm see Appendix C.

Algorithm Differences

Although the algorithms attempt to schedule as many missions as possible, there are numerous noteworthy differences between the RESOMS noninteractive algorithm, the manual scheduling method, and the new scheduling algorithm. The significant differences are contained in the following list.

1. The RESOMS scheduling algorithm is a constructive algorithm that does not change a mission or its resources once scheduled. The new scheduling algorithm is also a constructive algorithm, but allows for changes to, or removal of, previously scheduled missions.

2. The RESOMS algorithm selects the next mission to be scheduled strictly by mission priority. The new interactive algorithm bases scheduling activity on critical resource groups and priority rank within each of the four cycles.

3. The RESOMS algorithm allows only alternate/deletable resources listed on the mission request to be considered. The new algorithm, like the manual

scheduling method, solicits information from the mission request submitter to determine if unlisted options exist.

4. The manual method is highly dependent on scheduler skill and experience and therefore is not as systematic as the computer-based new algorithm or RESOMS.

All three scheduling methods are capable of producing a schedule. To compare the effectiveness of each method, each method has been exercised using the same mission request information. The results and analysis of these schedules are included in Chapter IV.

IV. Algorithm Testing and Analysis

In order to test the effectiveness of the new interactive algorithm, schedules were built using actual mission requests for three typical scheduling days. The three days were selected by 3246 TESTW/DOSO and are considered as representative samples and not as extreme cases. The schedules produced for the three days by the new interactive algorithm, can be compared to the schedules produced by the noninteractive RESOMS mode and to schedules produced manually. The schedules produced with the RESOMS algorithm and the new algorithm were extracted from products generated using the training mode in RESOMS. The training mode operates essentially the same as the functional mode without affecting the actual schedule. The manual schedules were extracted from initial RESOMS output of the *Pre-plot*. This chapter presents the schedules, scheduling activity summaries, and analysis of reasons why missions were scheduled by one method and not another. The schedule from each method shows the scheduling day as a timeline with the hours of the day shown across the top of the table. Mission numbers in highest-priority to lowest-priority order are shown in the second column of the table. The rectangular areas in the main table indicate mission times. A rectangular area in the column to the left of the mission numbers *(NS)* indicates the mission status is *NONSCHEDULED*. Other information extracted from the RESOMS output is used for the scheduling activity summary and analysis of the nonscheduled missions.

The scheduling activity summary includes information concerning sorties, missions and RBA for all three scheduling methods. The 3246 TESTW computes and/or monitors this information for internal analysis. Total missions scheduled and total missions nonscheduled combine to equal the total missions considered. Total TESTW/AWC sorties are only those flights flown using the 3246 TESTW and the 4485 AWC aircraft. Total air test/task missions is simply the total number of airborne test and task missions flown. Since missions may have one or several aircraft sorties involved, the number of missions may be less than the number of sorties. RBA was not considered during schedule construction, although a change in RBA may be a side effect of the number and/or priority of missions scheduled.

In addition to numerical information concerning the schedules, analysis of differing results from the scheduling methods is also important. All three scheduling methods were able to schedule a certain portion of the mission requests. Some missions were scheduled at different times of the day or shortened as a result of the particular scheduling method.

Each schedule contains nonscheduled missions resulting from resource conflicts with higher-priority missions. Some resource conflicts resulted in nonscheduled missions using all three methods and indicates resource demand exceeded availability. Of particular interest are nonscheduled missions that were scheduled by at least one of the other scheduling methods. A summary of the reasons nonscheduled missions were able to be scheduled by at least one other method is included for each day. A more detailed explanation including mission numbers, conflicting resources, and explanation of how other methods were able to schedule the mission can be found in Appendix D.

The schedules, schedule activity summary, and analysis of nonscheduled missions for each day are presented in the following sections.

Day 1

A total of 50 mission requests were considered for Day 1 of the algorithm testing. The schedule produced using RESOMS in the noninteractive mode is shown in Figure 4.1 with 31 missions scheduled and 19 missions nonscheduled. Figure 4.2 presents the schedule produced manually with 37 missions scheduled and 13 missions nonscheduled. The new interactive scheduling algorithm produced a schedule with 37 missions scheduled and 13 missions nonscheduled. Figure 4.3 illustrates this schedule. Several missions on the schedule produced with the new algorithm do not begin at 0700 as the algorithm would suggest as they were scheduled based on more restrictive time window constraints.

The summary of scheduling activity for Day 1 is shown in Table 4.1. Review of the information included in the table indicates some general differences between the schedules for this particular day. The manual method and the interactive algorithm increased the number of airborne test and task missions by scheduling over 50% more missions than were scheduled using RESOMS. The 6 nonscheduled missions resulted in 13 fewer 3246 TESTW/4485 AWC sorties flown. Flying only half the number of sorties with the RESOMS schedule indicates considerable reduction in aircraft and aircrew usage. Based on the schedules developed by the different methods, the schedule produced by the new algorithm recoups $1,275 more than the manual scheduling method, while earning $18,095 more than the RESOMS schedule. Since the selection of missions is not RBA-based, one cannot with certainty, attribute the increased RBA to the algorithm

Table 4.1. Day 1 Scheduling Activity Summary

TOTALS	RESOMS	MANUAL	ALGORITHM
MISSIONS CONSIDERED	50	50	50
MISSIONS SCHEDULED	31	37	37
MISSIONS NONSCHEDULED	19	13	13
AIR TEST/TASK MISSIONS	11	17	17
TESTW/AWC SORTIES SCHEDULED	13	26	26
RBA($)	35,293	53,388	54,663

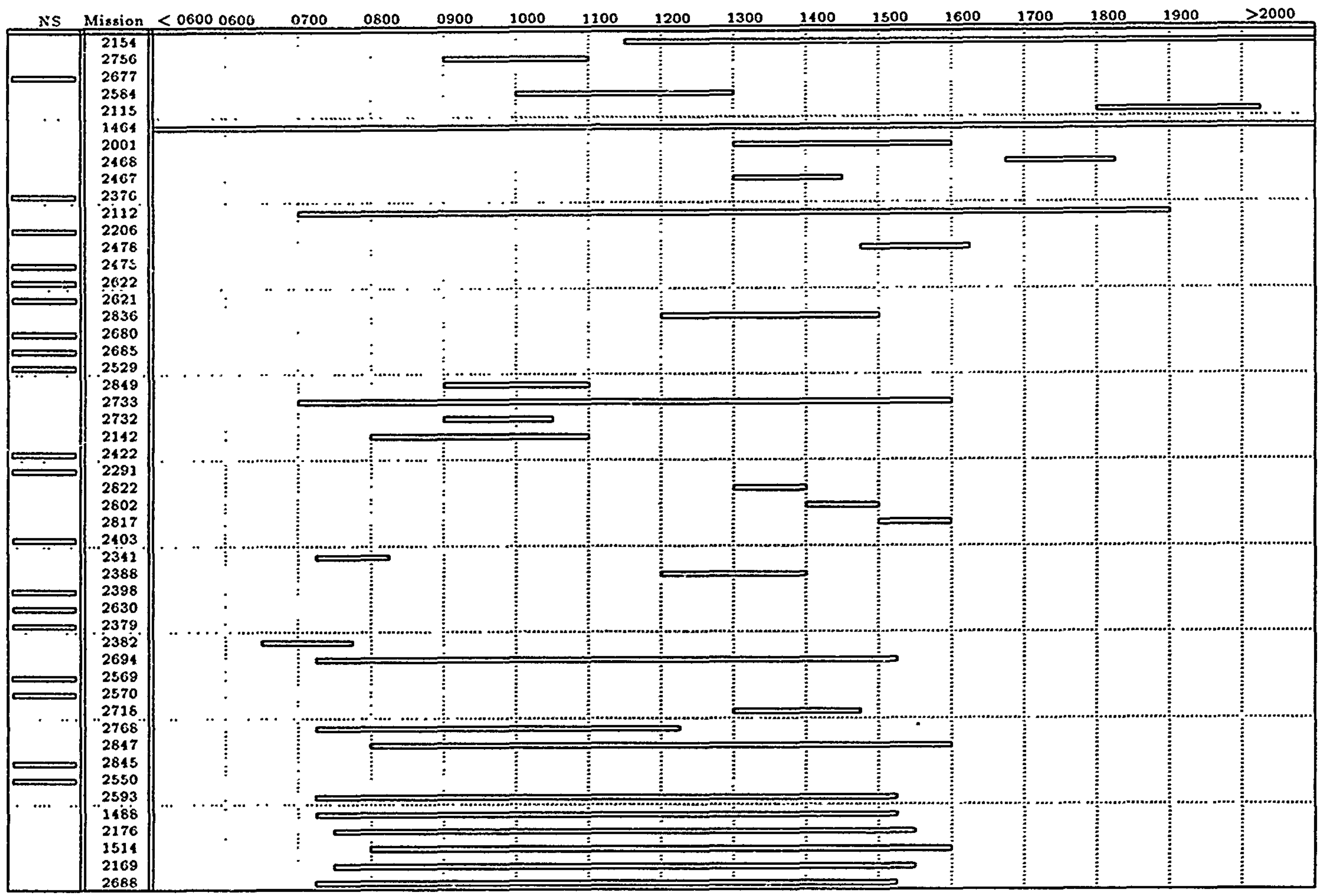


Figure 4.1. Day 1 Schedule Using the RESOMS Noninteractive Scheduling Mode

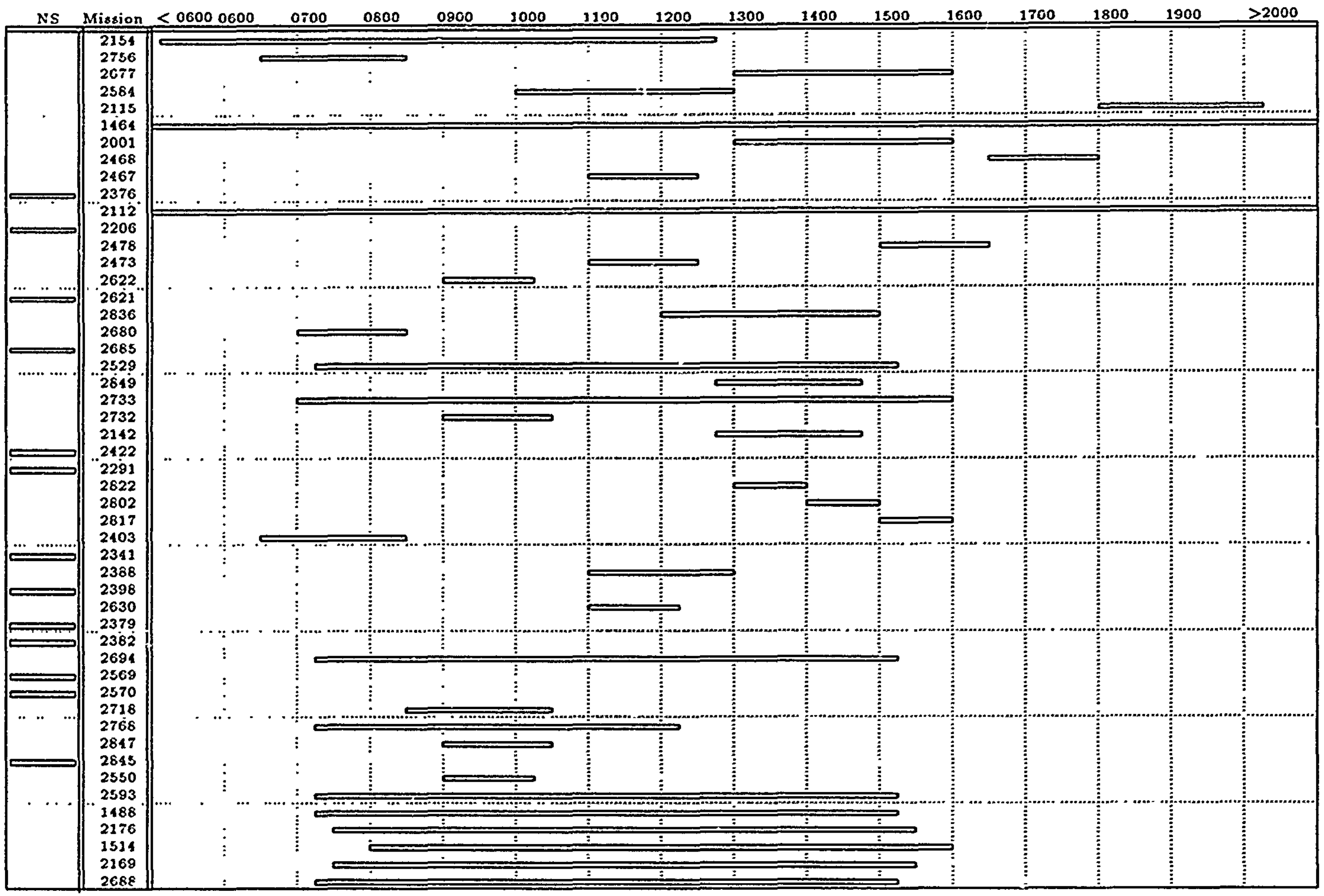


Figure 4.2. Day 1 Manually Plotted Schedule

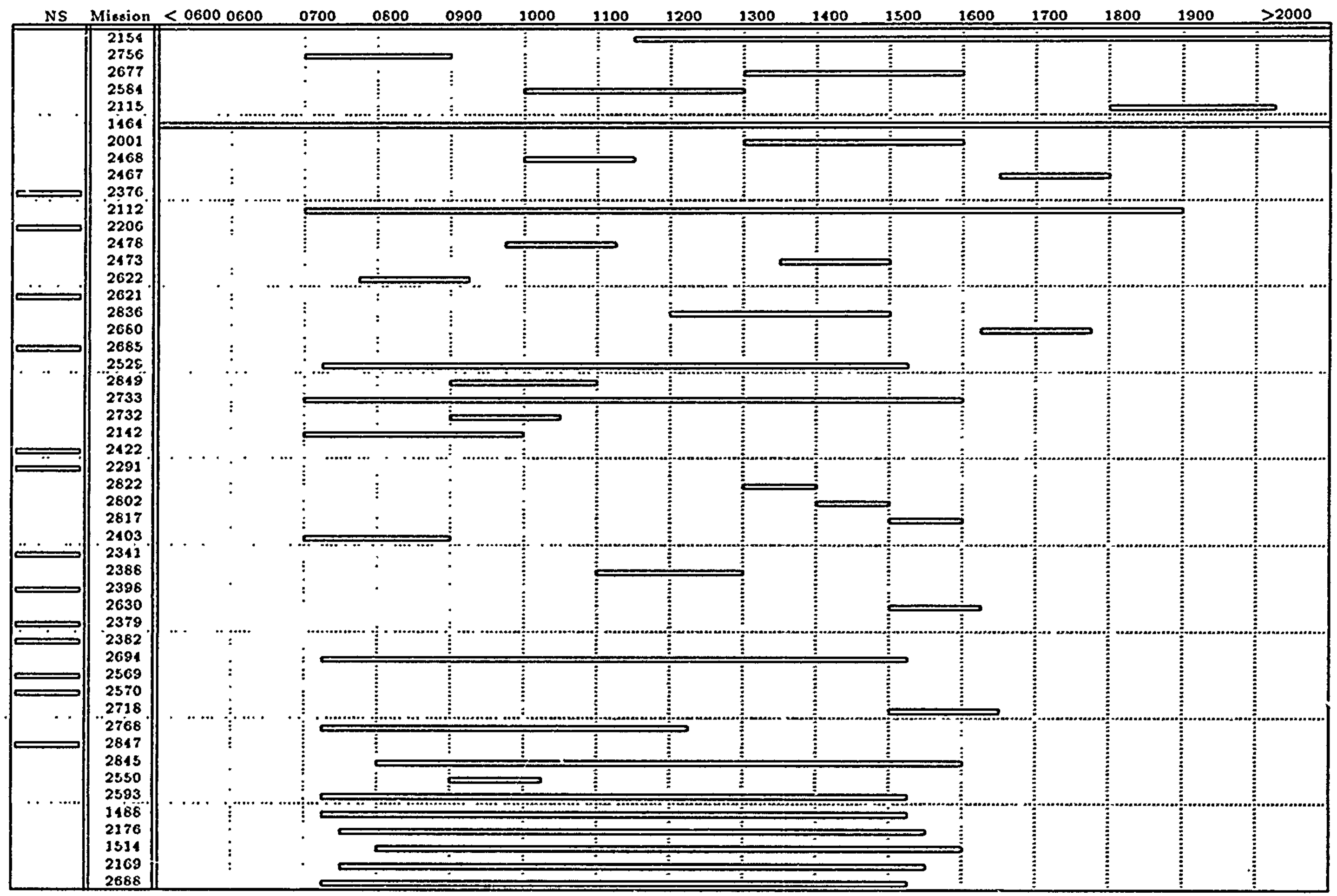


Figure 4.3. Day 1 Schedule Using the New Interactive Scheduling Algorithm

To find the causes of the differences in these schedules, reasons why nonscheduled missions were able to be scheduled by at least one other mode must be reviewed. The RESOMS schedule had nine missions that were scheduled by at least one other scheduling method. Three missions were nonscheduled because the conflicting mission was scheduled for a requested time in the middle of the morning, and did not allow sufficient resource turn time for another mission. The scheduler and interactive algorithm scheduled missions in such a way that allowed the three missions to be scheduled. Three missions were nonscheduled because RESOMS computed that a CCF resource conflict existed when in reality sufficient resources were available. This pseudo-conflict (false identification of a conflict) was avoided by the other scheduling methods through scheduler interaction. Scheduler interaction was key in other missions being scheduled by the schedulers and the interactive algorithm. One mission was nonscheduled because RESOMS is not capable of telling missions to coordinate with each other and share a resource. Two missions were nonscheduled because RESOMS is unable to pick a resource not listed on the mission request.

The manually-constructed schedule and new interactive scheduling algorithm contained three nonscheduled missions that were scheduled by another method. The conflicting resource was available for RESOMS to schedule two of the missions because it did not schedule a higher-priority mission using the resource. The other mission nonscheduled on the manual schedule resulted from an oversight of a deletable resource The interactive algorithm prompted the scheduler to determine if the resource could be deleted. As a result the manual method scheduled the alternate of a mission that did not require the resource. It is possible that oversight of this type could also occur with the interactive algorithm since it relies on scheduler input.

Day 2

A total of 38 mission requests were considered for Day 2 of the algorithm testing. The schedule produced using RESOMS in the noninteractive mode is shown in Figure 4.4 with 27 missions scheduled and 11 missions nonscheduled. Figure 4.5 presents the schedule produced manually with 30 missions scheduled and 8 missions nonscheduled. The new interactive scheduling algorithm produced a schedule with 31 missions scheduled and 7 missions nonscheduled. Figure 4.6 illustrates this schedule. Several missions on the schedule produced with the new algorithm do not begin at 0700 as the algorithm would suggest as they were scheduled based on more restrictive time window constraints.

The summary of activity for Day 2 is shown in Table 4.2. Review of the information included in the table indicates some general differences between the schedules for this particular day. The manual method and the new algorithm increased the number of airborne test and task missions above RESOMS results by 33% and 45%, respectively. The new algorithm scheduled one more mission than the manual method, but flew one less sortie. The additional sortie resulted when the manual schedule used an extra chase aircraft rather than refueling support as done by the interactive algorithm. The manual method and the new algorithm flew 70% and 60% more sorties than RESOMS scheduled, respectively. Based on the schedules developed by the different methods, the new algorithm schedule recoups $1,065 more than the manual scheduling method, while earning $6,931 more than the RESOMS schedule. Since the selection of missions is not RBA-based, one cannot with certainty, attribute the increased RBA to the algorithm.

To find the causes for the differences in these schedules, nonscheduled missions must be reviewed. The RESOMS schedule had seven missions that were scheduled by at least one other scheduling method. The reasons are very similar to those from Day 1. Three missions were nonscheduled because the conflicting mission was scheduled for a requested time in the middle of the morning, and did not allow sufficient resource turn time for another mission.

Table 4.2. Day 2 Scheduling Activity Summary

TOTALS	RESOMS	MANUAL	ALGORITHM
MISSIONS CONSIDERED	38	38	38
MISSIONS SCHEDULED	27	30	31
MISSIONS NONSCHEDULED	11	8	7
AIR TEST/TASK MISSIONS	9	12	13
TESTW/AWC SORTIES SCHEDULED	10	17	16
RBA($)	35,723	41,589	42,654

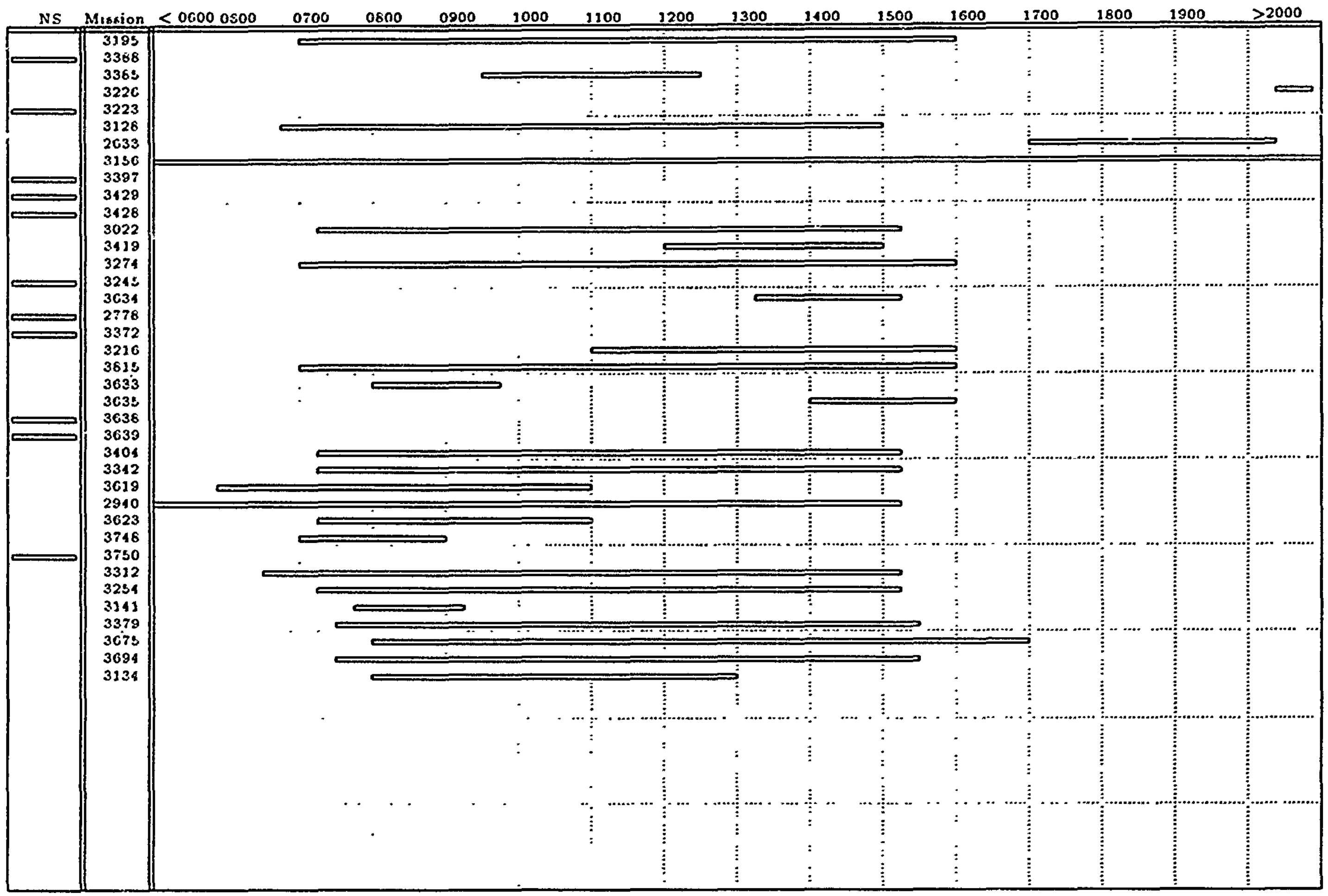


Figure 4.4. Day 2 Schedule Using the RESOMS Noninteractive Scheduling Mode

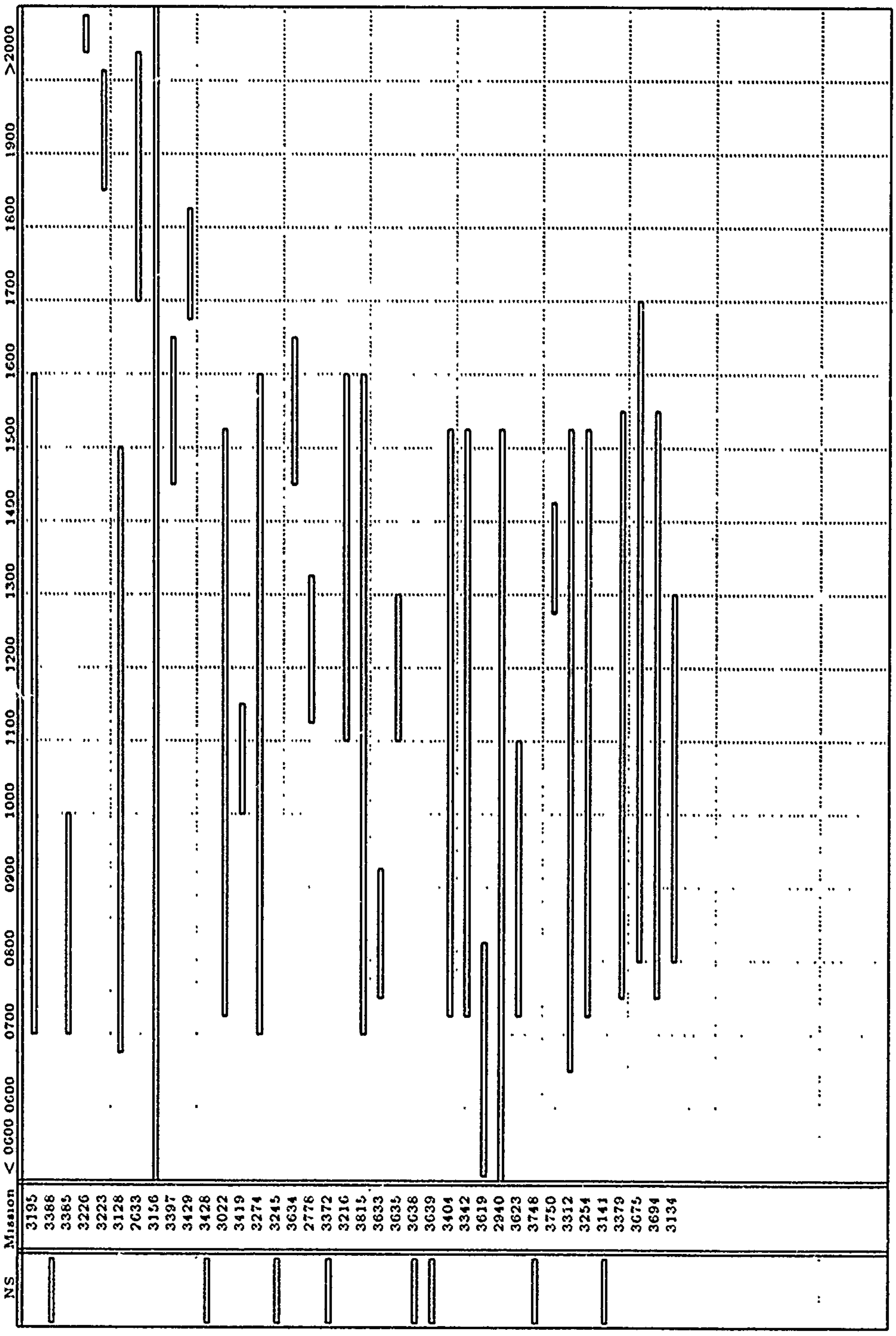


Figure 4.5. Day 2 Manually Plotted Schedule

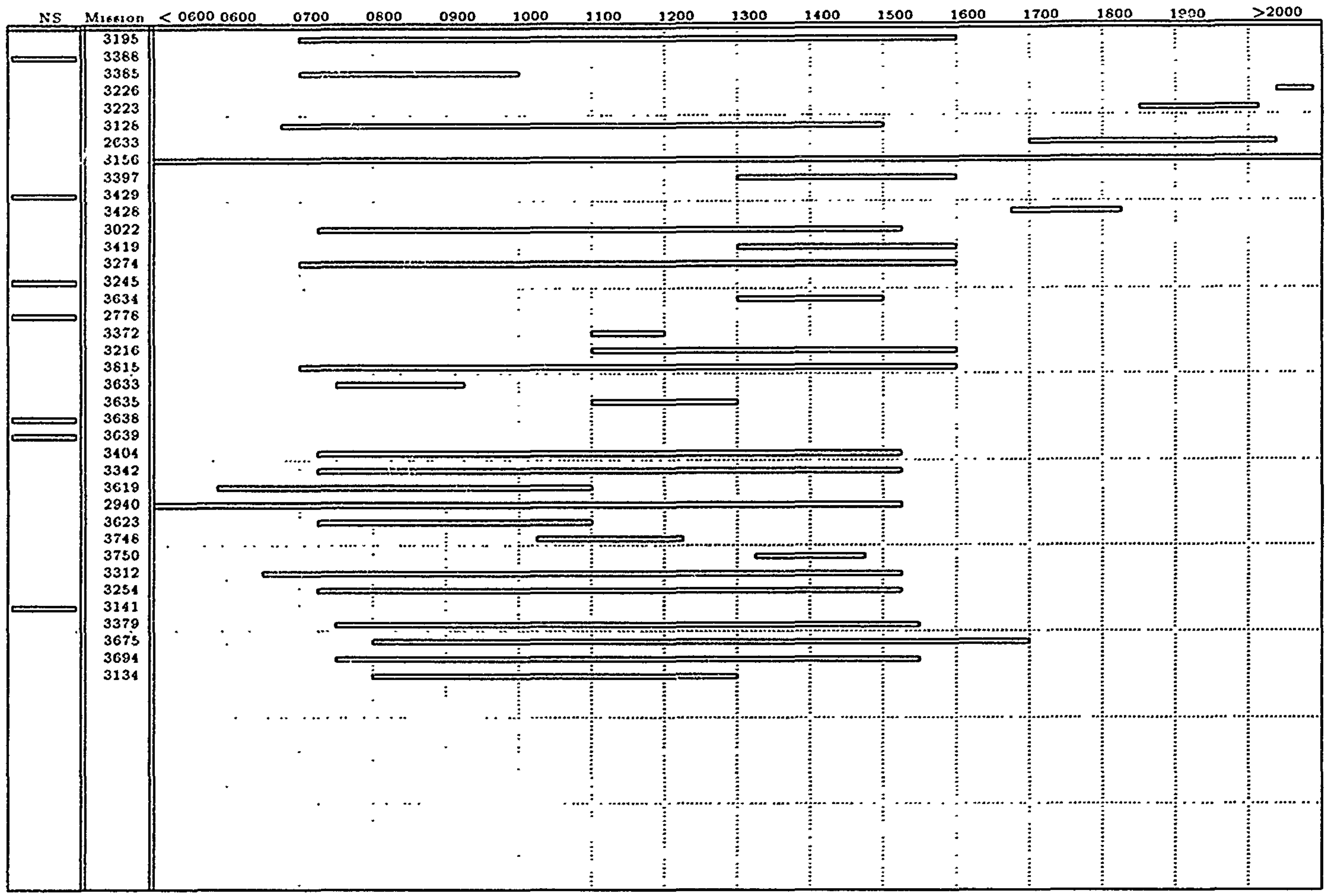


Figure 4.6. Day 2 Schedule Using the New Interactive Scheduling Algorithm

The scheduler and interactive algorithm scheduled missions in such a way that allowed the missions to be scheduled. Scheduler interaction was again key in other missions being scheduled by the schedulers and the interactive algorithm. One mission was nonscheduled by RESOMS pseudo-conflict for CCF resources. Another mission was nonscheduled because RESOMS can not recognize similar missions that can operate with shortened turn time. Two of the missions that were nonscheduled were very similar or identical to other nonscheduled missions. While RESOMS did not schedule either of the missions, the manual method and the interactive algorithm selected opposite missions from the similar pairs.

The manually-constructed schedule contained four nonscheduled missions that were scheduled by at least one other method. A resource was available for RESOMS to schedule two of the missions because it did not schedule a higher-priority mission. The interactive algorithm scheduled one of the missions by selecting a resource overlooked by the scheduler. It is possible that oversight of this type could also occur with the interactive algorithm since it relies on scheduler input. Two of the missions that were nonscheduled were very similar or identical to other nonscheduled missions. The interactive algorithm picked the other mission in the pair. The other mission nonscheduled on the manual schedule resulted from an oversight of a deletable resource. The interactive algorithm prompted the scheduler to determine if the resource could be deleted. As a result the manual method scheduled the alternate of a mission that did not require the resource.

The schedule constructed by the new interactive algorithm contained three missions that were scheduled by at least one other method. A resource was available for RESOMS to schedule one of the missions because it did not schedule a higher-priority mission. Two of the missions that were nonscheduled were very similar or identical to other nonscheduled missions. The scheduler picked the other mission in the pair when building the manual schedule.

Day 3

A total of 54 mission requests were considered for Day 3 of the algorithm testing. The schedule produced using RESOMS in the noninteractive mode is shown in Figure 4.7 with 34 missions scheduled and 20 missions nonscheduled. Figure 4.8 presents the schedule produced manually with 34 missions scheduled and 20 missions nonscheduled. The new interactive scheduling algorithm produced a schedule with 35 missions scheduled and 19 missions nonscheduled. Figure 4.9 illustrates this schedule. Several missions on the schedule produced with the new algorithm do not begin at 0700 as the algorithm would suggest as they were scheduled based on more restrictive time window constraints.

The summary of activity for Day 3 is shown in Table 4.3. Review of the information included in the table indicates some general differences between the schedules for this particular day. The manual method and the new algorithm increased throughput of airborne test and task missions above RESOMS results by approximately 15% and 25%, respectively. The new algorithm scheduled one more mission and sortie than the manual method. The difference between RESOMS and the other scheduling methods is not as great in this test sample.

A notable flaw in the RESOMS schedule exists. Mission 3179 is scheduled to immediately follow mission 3868 and allows no time for the tanker aircraft to land, refuel, and takeoff again. Flight time and offload requirements would not allow a single mission to remain airborne for the entire duration. Although the number of missions scheduled does not vary greatly, there is a considerable difference in RBA. Based on the schedules developed by the different methods, the new algorithm schedule recoups $7,980 more than the manual scheduling method, while earning $26,037 more than the RESOMS schedule. Since the selection of missions is not RBA-based, one cannot with certainty, attribute the increased RBA to the algorithm.

To find the causes for the differences in these schedules, nonscheduled missions must be reviewed. The RESOMS schedule had six missions that were scheduled

Table 4.3. Day 3 Scheduling Activity Summary

TOTALS	RESOMS	MANUAL	ALGORITHM
MISSIONS CONSIDERED	54	54	54
MISSIONS SCHEDULED	34	34	35
MISSIONS NONSCHEDULED	20	20	19
AIR TEST/TASK MISSIONS	13	15	16
TESTW/AWC SORTIES SCHEDULED	16	18	19
RBA($)	43,305	61,362	69,342

by at least one other scheduling method. The reasons are again similar to the first two days. Four missions were nonscheduled because RESOMS did not allow the sharing of resources. The scheduler and interactive algorithm scheduled the two missions needing a tanker at the same time thus allowing the other four missions to be scheduled. One mission was nonscheduled by RESOMS pseudo-conflict for CCF resources. In another instance RESOMS scheduled an alternate mission rather than the primary mission. The new scheduling algorithm includes logic to prevent an alternate from being scheduled prior to the primary mission.

The manually-constructed schedule contained six nonscheduled missions that were scheduled by at least one other method. A resource was available for RESOMS to schedule four of the missions because it did not schedule a higher-priority mission. The interactive algorithm scheduled one of these missions and another nonscheduled mission by scheduling missions closer together. The other nonscheduled mission was the alternate mission scheduled by RESOMS.

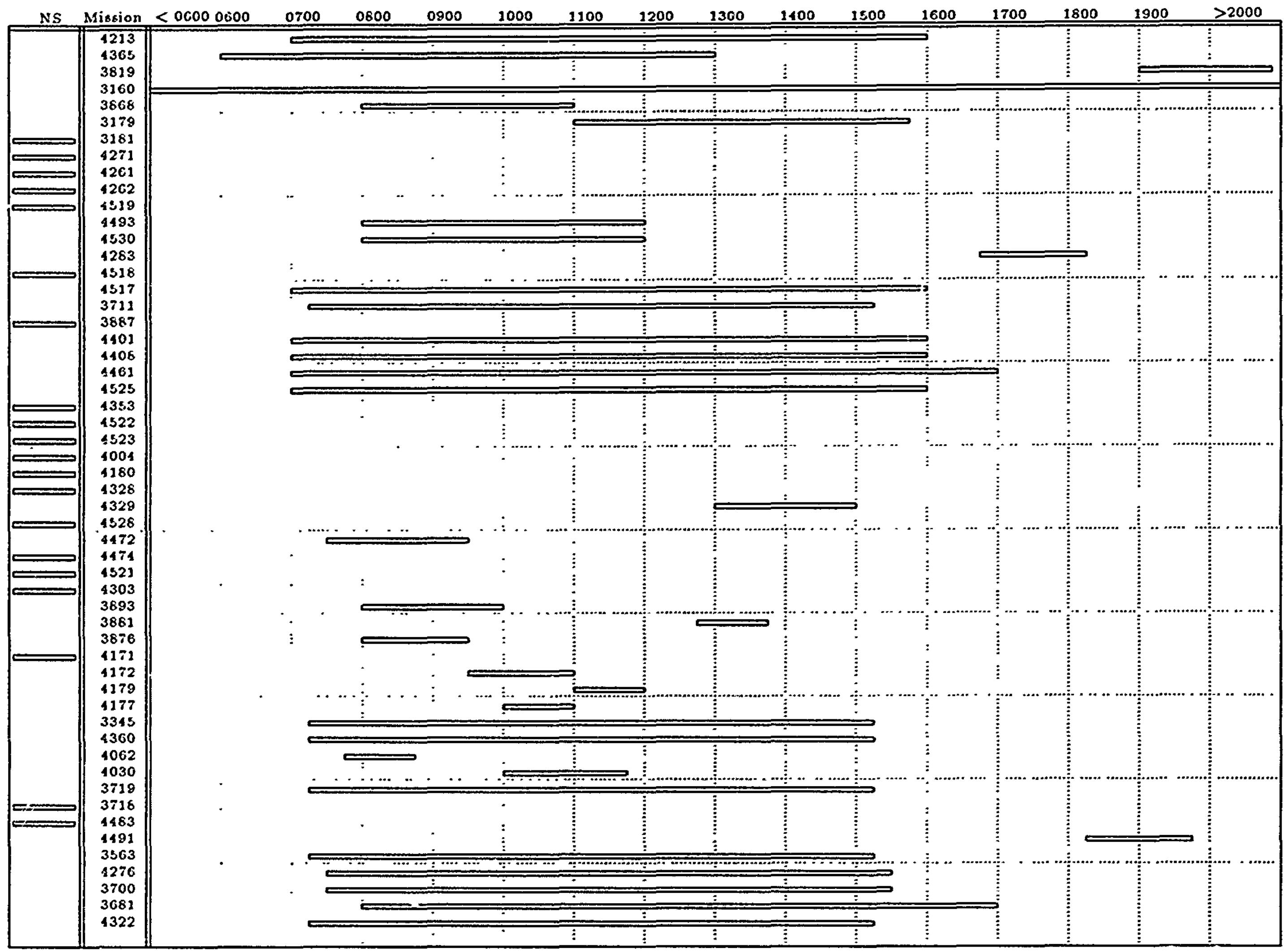


Figure 4.7. Day 3 Schedule Using the RESOMS Noninteractive Scheduling Mode

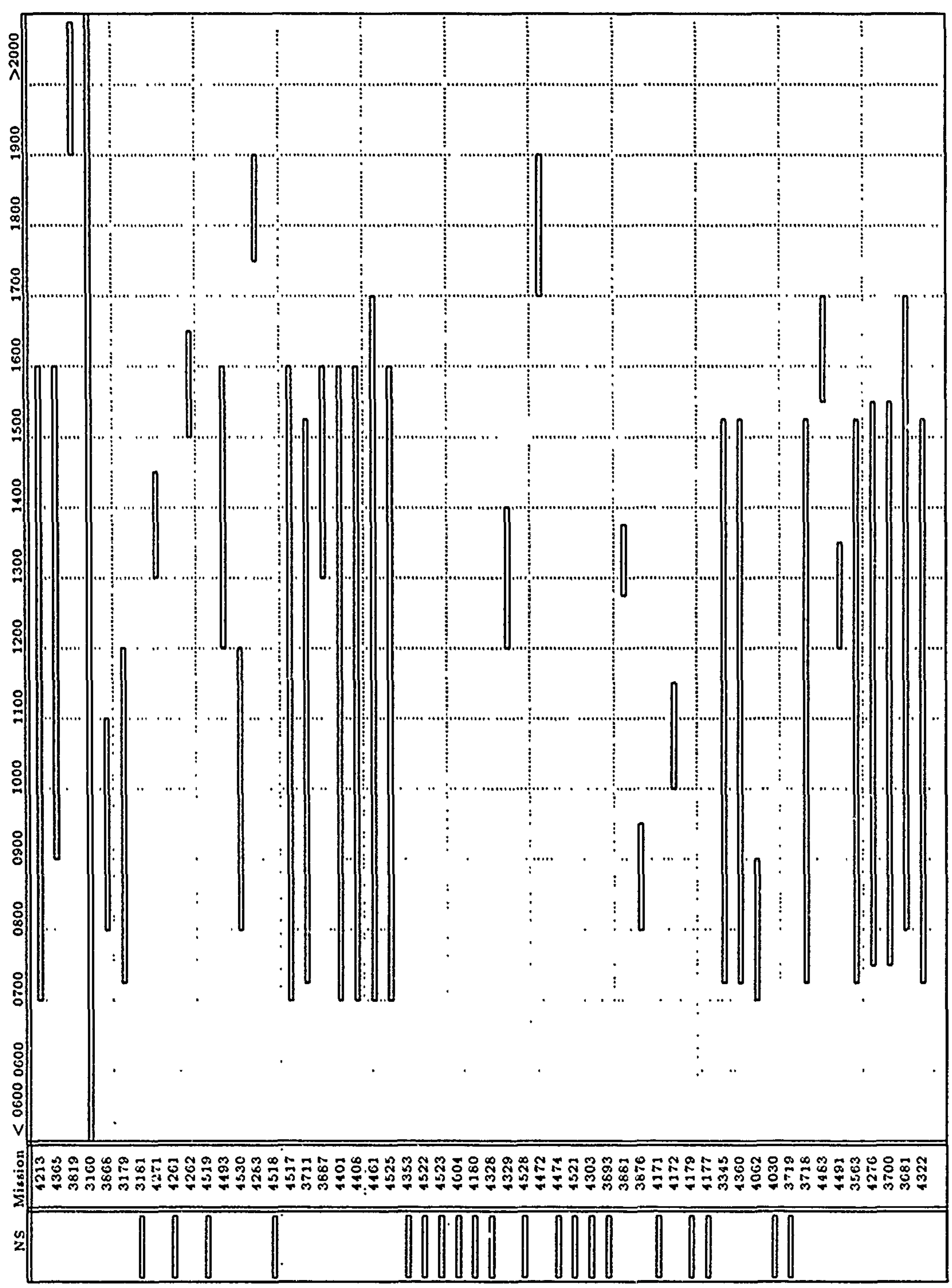


Figure 4.8. Day 3 Manually Plotted Schedule

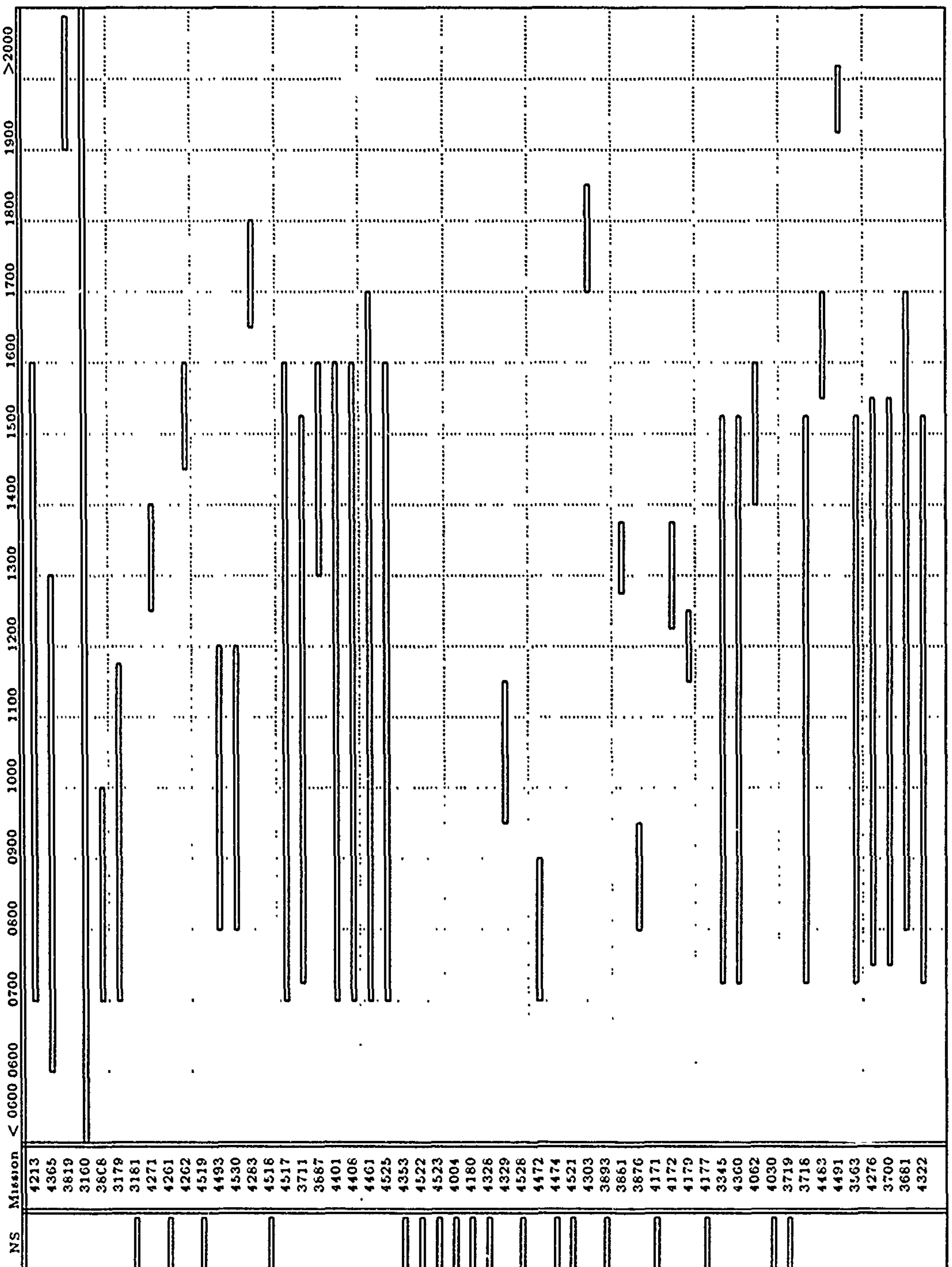


Figure 4.9. Day 3 Schedule Using the New Interactive Scheduling Algorithm

The schedule constructed by the new interactive algorithm contained four missions that were scheduled by at least one other method. A resource was available for RESOMS to schedule three of the missions because it did not schedule a higher-priority mission. The other nonscheduled mission was the alternate mission scheduled by RESOMS.

Analysis Summary

The three days of schedules developed using the three methods provide an estimate of the capability of each scheduling method. No detailed statistical comparison was performed on this limited number of samples since results would not provide any conclusive information. However, general observations are made with respect to the schedule activity summaries and the analysis of nonscheduled missions. In addition, 3246 TESTW/ADO impressions of the schedules produced by the new algorithm are included. The activity summaries for the three days of data allow several general characterizations concerning the different scheduling methods.

The nonscheduled missions provide considerable insight to the activity summaries. The majority of interest concerns results obtained from airborne test, task, and task-oriented training missions. In terms of the number of missions and 3246 TESTW/4485 AWC sorties flown, the manual scheduling method and the new scheduling algorithm produce fairly similar schedules. On two of the test days the new algorithm did schedule an additional mission. This systematic computer-aided approach to scheduling seems to help avoid scheduler oversights. The manual method and the new algorithm outperformed the RESOMS scheduling method in terms of airborne test, task, and task-oriented training missions, total missions, and sorties scheduled.

The fact that the other methods outperformed RESOMS was not unreasonable to expect. Previous experience within the 3246 TESTW determined that the manual method surpassed RESOMS in throughput. Although the number of test cases are limited, the results do not contradict these previous findings. The new algorithm contains concepts for scheduling critical resources currently used by the schedulers and attempts to make improvements to the schedule during construction of the schedule. The RESOMS algorithm uses only a "Greedy" heuristic to build the schedule. RESOMS occasionally scheduled missions not scheduled by the manual method or the new scheduling algorithm, but at the expense of a higher-priority mission.

The capability for a scheduler to make an input during the scheduling process resulted in several higher-priority missions being scheduled that were not scheduled by RESOMS(e.g., using a tanker for two missions at the same time, resolving CCF pseudo-conflicts). The quality of the manual schedules probably varies considerably with the level of experience of the scheduler. The systematic approach used by the algorithm should make the scheduling process less dependent on individual expertise and while any single individual may be able to beat the new algorithm, the interactive approach of the algorithm doesn't preclude using scheduler's insights.

The difference between schedules in terms of the number of missions scheduled and the priority of the missions scheduled appear to relate to RBA. The interactive algorithm consistently scheduled more and higher priority missions than RESOMS and an increased RBA was also noted. The RBA of the new algorithm was considerably better than the manual method on only one of the days, and slightly better on the other two days. This tends to indicate a possible improvement in RBA by the new scheduling algorithm, although the small number of data points does not provide rigorous statistical conclusions.

In addition to the above comparisons of the schedules, the schedules and activity summaries were provided to the 3246 TESTW/ADO for review. The 3246 TESTW/ADO expressed that he was "very pleased with the schedules" produced by the new algorithm. He was also pleased that the algorithm was developed using concepts based on Eglin scheduler expertise and is designed to interact with schedulers during use. The ADO also envisioned reduced scheduler manpower costs if the algorithm is implemented in RESOMS, since fewer people and less experience would be required to develop a schedule.

Conclusions based on this research and recommendations for further study are presented in Chapter V.

V. *Conclusions and Recommendations*

This chapter provides a summary of the research and presents ideas for future research or improvement to the Eglin test range scheduling system.

Conclusions

The need exists for an algorithm that improves mission scheduling, integrates into RESOMS, and utilizes many of RESOMS current capabilities. The primary objective of this research was to design an improved computerized scheduling aid. The measure of performance for this approach is the number of missions scheduled using this aid as compared to current Eglin capabilities. Constructive heuristics are integrated in the algorithm to schedule missions according to critical resource groups while ensuring mission priority is not violated. The success of this newly-developed scheduling algorithm has been measured against the schedule produced using RESOMS without interaction, and the manually-plotted schedule.

The schedules that were produced using the new algorithm demonstrated, at least for a small number of cases tested, improvement over RESOMS in the noninteractive mode in terms of airborne test, task, and task-oriented training missions and sorties, as well as RBA. In testing the new algorithm also produced schedules at least as good as those produced manually, with, in most cases a small improvement in the number of missions scheduled. This improvement is possible due to a more systematic approach to scheduling which helps control lost opportunities caused by oversight. Improved mission throughput is one of the benefits that may be realized by incorporating the new algorithm as part of RESOMS.

Another benefit of incorporating the new algorithm in RESOMS is that one scheduler can create the schedule without the assistance of others since the scheduler would interact directly with the computer rather than using the current multi-person process.

The systematic approach to scheduling is beneficial to schedulers with less experience since the algorithm would help build the schedule in addition to identifying conflicts.

Eglin test ranges operate under very dynamic conditions. The new algorithm presented in this research uses constructive heuristics to develop a schedule that demonstrated for a small number of tests considerable improvement over the current RESOMS algorithm. The algorithm also provides a method to combine computer capabilities and existing scheduler experience. Based on initial indications, additional testing of the new interactive scheduling algorithm is warranted. This testing would be most effective if performed as a trial implementation within RESOMS to allow analysis of schedules, as well as scheduling time and manpower requirements.

Recommendations

During the course of working with the scheduling system and developing the new scheduling algorithm we have noted that improvement heuristics have the potential to further improve the scheduling process. Improvement heuristics should be investigated to determine their value in improving existing schedules constructed by any other method.

Appendix A. *Sample Mission Request*

```
Menu Item: MX/GB as of 91-10-17 at 08:46. Scheduling date: MON 911021  Page    1
                                                   As of: 17-OCT-1991 at 08:45
 MISSION  REQUEST:  6648                  (LNCH HOT ADP-2       )      SCHEDULED
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
 MISSION: 6648                                           SUBMITTER: TZ.BROLLEY
 TITLE: ADP AMRAAM SEPARATIONS/GUIDED LAUNCHES
 JON: 2185UA36      JON PHASE: ACTIVE          PRIORITY: 0107
 RESPONSIBLE TEST ENGINEERS:
SUB: TZ.BROLLEY        3246TW/DOMT               (904)882-4873  (904)939-1402
ALT: TZ.HUBERAP        3246TW/DOMT               (904)882-4873  (904)651-2446
ALT: TZ.WAYNE          3246TW/DOMT               (904)882-4873

MISSION INFORMATION
--------------------------------------------------------------------------------
 MISSION DATE(YYMMDD): 91-10-21 (MON)  OVERALL ACCEPTABLE TIME BLOCK: 0700-0900
 MISSION START-STOP:  0700-0900        ALLOWABLE TIME REDUCTION: 000
 HAVE HEMP CODES: D E F                NOTAMS NEEDED: Y
 MISSION TYPE:          TD  - TEST       AIR ARMAMENT
 MISSION CONDITION:     HS  - REST    SUPERSONIC / OTHER
 MISSION LOCATION:      AW  - AIR        WATER PROFILE
 MISSION ACTIVITY:      AA  - AIR-AIR GUIDED MUNITIONS, POWERED, HOT
 REQUESTING AGENCY:     V   - 3246 TESTW/TZM
 MISSION OBJECTIVE:  ADP HOT LAUNCH, A LOAD, PROFILE ADP-2
 MISSION CATEGORY: BACKUP                RELATED MISSION NUMBER: 6646
  THIS MISSION REQUIRED IF MISSION 6646 IS NOT SUCCESSFUL
 IS THIS A BLACKBOARD MSN ? N

CURRENT MISSION STATUS - SCHEDULED
--------------------------------------------------------------------------------
 SCHEDULED BY RUN 009
 STATUS LAST CHANGED BY SCHEDULER        12:26 ON 911011
 TIME / DATE SUBMITTED BY REQUESTOR      11:00 ON 911009
 TIME / DATE SUBMITTED BY ORGANIZATION   13:42 ON 911010

   AIRCRAFT                  GP CN DEL  START-STOP PRE POST MNT P/P FC  J PG A C S
--------------------------------------------------------------------------------
F16A     761     TW          [illegible] [illegible] N   0700-0900  240 030  120 000 62  N 1      S
                                  ...TING FROM: HOT GUN LINE
                             A/... ...QUIRES REFUELING
F16B      37     TW          0  [illegible] N   0700-0900  000 000  120 000 61  N 1      S
                             OPERATING FROM: RAMP
                             A/C REQUIRES REFUELING
KC10     ANY     OTHER       0  1  N    0700-0900  000 000  000 000 ANY N 1    U S
                             OPERATING FROM: RAMP
                             NUMBER OF A/C OF THIS TYPE TO BE UTILIZED:  1
     FREQUENCY: OTH  394.800 MHZ   ALTITUDE: 20 (K FT)   REFUEL TIME: 0015
   OFFLOAD MIN: 000 (K LBS)     OFFLOAD MAX: 035 (K LBS)

   PROFILES                  GP CN DEL  START-STOP      HOT  SUPER           A C S
--------------------------------------------------------------------------------
STANDARD-EWTA2.W01           0  1  N    0700-0900        Y     Y               S
    ALTITUDE: MIN =      .0 (K FT)     MAX =  50.0 (K FT)
    EWTA2 (000-000)
STANDARD-EWTA3.W01           0  1  N    0700-0900        Y     Y               S
    ALTITUDE: MIN =      .0 (K FT)     MAX =  50.0 (K FT)
    EWTA3 (000-000)
STANDARD-W151.W01            1  1  N    0700-0900        Y     Y               S
    ALTITUDE: MIN =      .0 (K FT)     MAX =  50.0 (K FT)
    W151 (000-000)

   RANGE SUPPORT             GP CN DEL  START-STOP PRE POST TURN             A C S
--------------------------------------------------------------------------------
A20AUXGEN1                   0  1  N    0700-0900  000 000  000                U S
A20FPS16-31     CCF          0  1  N    0700-0900  000 000  015                  S
A20FPS16-32     CCF          0  1  N    0700-0900  000 000  015                  S
A3AUXGEN                     0  1  N    0700-0900  000 000  000                U S
A3FRW2                       0  1  N    0700-0900  090 000  015                  S
A3MPS19-161     CCF          0  1  N    0700-0900  000 000  015                  S
A6FCA           CX10         0  1  N    0700-0900  090 000  015                  S
A6FCA           CX3          0  1  N    0700-0900  090 000  015                  S
A6FCA           CX5          0  1  N    0700-0900  090 000  015                  S
B4A303                       0  1  N    0700-0900  030 000  015                  S
D3AUXGEN1                    0  1  N    0700-0900  030 000  000                U S
D3FCA                        0  1  N    0700-0900  090 000  015                  S
D3FPS16-27      CCF          0  1  N    0700-0900  000 000  015                  S
D3FRW2                       0  1  N    0700-0900  090 000  015                  S
D3TH105                      0  1  N    0700-0900  000 000  015                  S
EOD                          0  1  N    0700-0900  000 000  000                U S
FLFAC105                     0  1  N    0700-0715  060 000  015                  S
FLT OPS OPEN                 0  1  N    0700-0900  120 120  000                U S
MICROWAVE-BLD44              0  1  N    0700-0900  030 000  000                U S
FE OPEN                      0  1  N    0700-0900  045 060  000                U S
SAFETY                       0  1  N    0700-0900  000 000  000                U S
```

```
Menu Item: MX/GB as of 91-10-17 at 08:46. Scheduling date: MON 911021  Page    2
                                                  As of: 17-OCT-1991 at 08:45
 MISSION  REQUEST:  6648                (LNCH HOT ADF-2        )     SCHEDULED
--------------------------------------------------------------------------------
TONE RECORDER                 0  1  N    0700-0900  000 000  000               U S
TYNTELEM                      0  1  N    0700-0900  240 045  015                 S

   CCP                        GP CH DEL  START-STOP PRE POST TURN SU         A C S
--------------------------------------------------------------------------------
AC/CNTR                       0  1  N    0700-0900  000 000  030  A              S
       ACVECT       (020)    SDDS        (033)   VAX        (010)
AMTM                          0  1  N    0700-0900  030 0J0  030  A              S
       STRIP        (100)    TECONCOPY (020)   TECONSOLE (020)   TM        (100)
       VAX          (020)
COMM                          0  1  N    0700-0900  045 000  000  A              S
       COMM         (050)
CSP                           0  1  N    0700-0900  030 000  030  C              S
       AUXP         (100)    FRW2        (100)   PRECAL     (000)   TECONCOPY (033)
       TECONSOLE (025)       VAX         (020)
CSP         #2                0  1  N    0700-0900  030 000  030  A              S
       AUXP         (000)    FRW2        (000)   PRECAL     (000)   TECONCOPY (033)
       TECONSOLE (025)       VAX         (020)
THREC                         0  1  N    0700-0900  030 000  030  C              S
       THREC        (100)

   FREQUENCY                  GP CH DEL  START-STOP PRE POST TURN            A C S
--------------------------------------------------------------------------------
OTH  394.800 MHZ              0  1  N    0700-0900  000 000                      S
OTH  425.000 MHZ              0  1  N    0700-0900  000 000                      S
OTH 5665.000 MHZ              0  1  N    0700-0900  000 000                      S
OTH/5800.000 MHZ              0  1  N    0700-0900  000 000                      S
TM  1493.5    MHZ             0  1  N    0700-0900  000 000                      S
TM  2249.5    MHZ             0  1  N    0700-0900  000 000                      S
UHF 359.2     MHZ             0  1  N    0700-0900  030 000  015                 S

   FCA CODES                  GP CH DEL  START-STOP PRE POST MPRE            A C S
--------------------------------------------------------------------------------
HR                            0  1  N    0700-0900  090 000  000                 S

-PHOTO LAB
--------------------------------------------------------------------------------
   COLOR        - 16MM-MOVIE                      RUSH-IMMEDIATE CONFIDENTIAL
   COLOR        - 35MM-STILL                      RUSH-24 HOURS  UNCLASSIFIED

-GENERAL REMARKS
--------------------------------------------------------------------------------
  1. THIS MISSION IS A SINGLE LAUNCH IN THE F16 ADF SEPARATIONS
     PROGRAM, LAUNCH PROFILE ADF-2 WITHOUT A TARGET.
  2. THE MISSILE IS A LIVE AIM-120 WITH AN OPERATIONAL SEEKER. AN INSTRU-
     MENTATION SECTION WILL REPLACE THE WARHEAD AND PROVIDE TM, BEACON, AND FTS
  3. DIVISION COORDINATION:  MR. STRICKLAND, 2-4873.
             VITRO REVIEW:  MR MCBRIDE, 2-4994.
  4. FOR SC:
     - REQUEST A DECRYPTED MISSION TAPE BE MADE DURING THE MISSION.
     - REQUEST REAL-TIME DIGITIZING OF MISSION TAPES.
     - CCP CONFIGURATION: 761_5.6 FOR TAPE 3 REV 22 AAVI
     - REQUEST TAPE PLAYBACK XT CCP AT MISSION START TIME MINUS ONE HOUR.
       USE SOURCE TAPE 3A REV 22 GTV, 9 MAY 91 FOR MISSILE PLAYBACK
     - THERE IS NO ECM OR TARGET ON THIS MISSION PROFILE.
  5. TANKER INFO: MAX OFFLOAD:   35,000 LBS
                  NUMBER OF RECEIVERS:   AS REQ'
                  ARCT: AS REQ'D THROUGHTOUT RANGE TIME
                  TANKER ALTITUDE:  20,000 FT MSL
                  TANKER PROFILE:  MODIFIED DESTIN ALPHA
                  RECEIVERS:  2 X F16
     NOTE:  TANKER TO CONTACT PROJECT PRIOR TO MSN TIME ON FREQ
            359.2.  TAKEOFF FOR TANKER TO BE COORDINATED WITH PROJECT.
  6. FOR PHOTO LAB:  35 MM STILL PHOTOS REQUIRED PRE AND POST MISSION OF THE
     AIRCRAFT CONFIGURATION.  SAME DAY SPLICE OF ONBOARD CAMERAS IS REQUIRED
     TO FACILITATE SHIPMENT TO CONTRACTOR TO EXPEDITE TEST CONDUCT.  16 MM
     FILM MAY BE UNCLASSIFIED, DEPENDING ON COVERAGE PHOTOG WAS ABLE TO GET.
  7. AIRCRAFT ASSIGNMENTS:
     --> F16A/761 (SHOOTER)
     --> TWO SEAT F16 = PHOTO CHASE AND RANGE SWEEP, NEEDS TO BE 61 OR 62 FUEL
  8. FOR DOU:  REQUEST PHOTOG FOR HOT MISSION; PHOTOG TO USE 16 MM
               MOVIE CAMERA (COLOR); PHOTOG DEDICATED FROM DRESS MISSION.
  9. FOR SAFETY:
      REQUEST NOTAM BE ISSUED IF FTS HAS EXPIRED SAF.  SAME PROCEDURES AS USED
      IN THE PAST FOR NOTAM ISSUE BY JAX CENTER ON USE OF EWTA TO BE EMPLOYED.

-M A     REMARKS
--------------------------------------------------------------------------------
  1. MISSILE TO BE DELIVERED TO AIRCRAFT 3.5 HOURS PRIOR AND WILL BE LOADED
     3 HOURS PRIOR TO TAKEOFF.  AFDTC LOAD CREW WILL CONFIGURE, LOAD, INSTALL
```

MISSION REQUEST: 6648 (LNCH NOT ADF-2) SCHEDULED

BUFFER CONNECTOR, AND DECONFIGURE AIRCRAFT POST MISSION.
2. ALL MISSION AIRCRAFT TO BE CONFIGURED IAW APPLICABLE PART B.
3. AGE REQUIRED: C-10, POWER CART, 3 HEADSETS, "Y" CHORD ADAPTER, F-16 AIR CONDITIONING ADAPTER.
4. REQUIRE CREW CHIEF FOR PRE FLIGHT.
5. REQUEST F16/761 BE LOCATED IN MIDDLE OF HOT GUN LINE. DO NOT PUT IN SPOT #1.
6. F16 SOFTWARE: F07B (ADF)

-O & M REMARKS

---

1. MAXIMUM CLASSIFICATION FOR DATA ON THIS MISSION WILL BE CONFIDENTIAL.
2. REQUEST ALL SITES MAKE DECRYPTED MISSION TAPES. EXPEDITE DELIVERY OF ALL TM AND RADAR TAPES TO EGLIN AFB.
3. CAMERA SHOP: GADS DATA WILL BE REQUIRED, GADS PREFLIGHT OF CAMERAS REQUIRED
4. FREQS:
   394.8 TANKER OPS
   425.0 MISSILE DESTRUCT
   5665.0 MISSILE X-PONDER DOWNLINK
   5800.0 MISSILE X-PONDER UPLINK
   TONES 1,2,4 AND CODE SPACING 11
   1493.5 A/C FDAS TM
   2249.5 MISSILE TM
   359.2 MISSION OPS

-T P REMARKS

---

1. ALL DATA TAPES FROM THIS MISSION WILL BE CONFIDENTIAL.
2. PREFLIGHT F-16A/761 IAW PART B. PREFLIGHT MUST BE COMPLETED IAW NORMAL 3246 TW MISSION TIMELINES.
3. ENCRYPTION KEYING SUPPORT FOR THE MISSILE AND LAUNCH AIRCRAFT IS REQUIRED.
4. ALL AIRCRAFT MUST HAVE A BEACON INSTALLED AND PREFLIGHTED.
5. BOTH AIRCRAFT AND MISSILE WILL HAVE TO BE KEYED WITH THE AMRAAM KEY OF THE DAY. TPE CALL CONTRACTOR PERSONNEL TO COORDINATE MISSILE KEYING. MISSILE KEYING WILL TAKE PLACE ON THE F16 AIRCRAFT 2.5 HOURS PRIOR TO TAKEOFF.
6. MISSILE TM AND BEACON CHECKS TO BE COMPLETED 2.5 HOURS PRIOR TO TAKEOFF
7. USE SCREEN ROOM TO VERIFY AIRCRAFT AND MISSILE KEY.

MISSION REQUEST PART B - 6648-A (LNCH HOT ADF-2 A)

-GENERAL INFORMATION

```
AIRCRAFT: --------------------- F16
TAIL NO.: --------------------- 761
TYPE MISSION: ----------------- FLY/DROP
REQUESTED DELIVERY DATE: ------ 911021
DELIVERY LOCATION: ------------ HOT GUN LINE
DELIVERY TIME: ----------------
LOAD CHECKLIST #: ------------- ADF 16S1500 LAUNCHER/AMRAAM ON 16S1500
```

-MUNITIONS REQUESTED

```
1410-L10-7289-2823, AMRAAM AAVI, S/N CA-50053 (KD-07)
        CLASS: CLASS      TYPE: 1.3      ISSUE: EACH          QUANITY:     1
AIM-9, ANY, INERT PREFERRED
        CLASS: UNCLASS    TYPE: INERT    ISSUE: EA            QUANITY:     3
```

-SPECIAL INSTRUCTIONS

1. AGE REQ'D: POWER, AIR, Y-CORD ADAPTOR WITH THREE HEADSETS.
2. F16 SOFTWARE: ADF (FCC: P07B)
3. OPERABLE RADAR REQUIRED.
4. LOAD 16S1500 PYLON ON STA 3, C/N C0103, INSTRUMENTED PYLON. THE PYLON LOADED ON STATION 7 IS THE ONLY OTHER 16S1500 ON BASE AND IS UNINSTRUMENTED AND HAS NO SERIAL NUMBER ON IT.
5. MISSILE TO BE PICKED UP 3.5 PRIOR FOR UPLOAD 3 PRIOR.

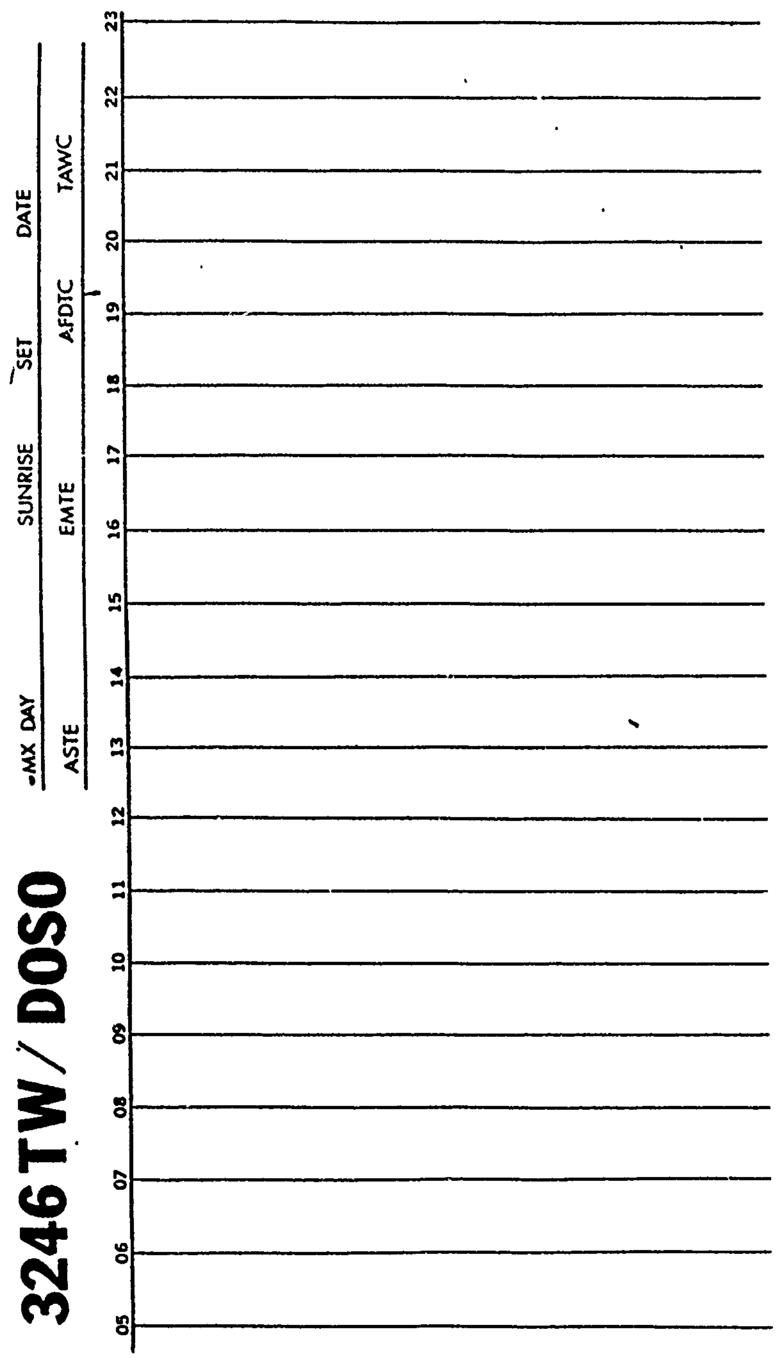
-STATIONS LOADED ON AIRCRAFT
STATION/STORE SPECIAL LOADING INSTRUCTIONS

```
-STATION ID: C12    STORE: 3701   DESC: CAMERA  CARRIER                        C
 CARRIER NAME:  LEFT STRAKE CAMERA
 POWER SOURCE:  AIRCRAFT
 9 MM LENS, GADS PREFLIGHTED, 200 FPS

-STATION ID: C13    STORE: 3701   DESC: CAMERA  CARRIER                        C
 CARRIER NAME:  COCKPIT CAMERA
 POWER SOURCE:  AIRCRAFT
 9 MM LENS, LEFT SIDE BORESIGHT TO STA 3, 200 FPS, GADS PREFLIGHT

-STATION ID: W1     STORE: 3701   DESC: CAMERA  CARRIER                        C
 CARRIER NAME:  AIM-9 CAMERA PODS
 POWER SOURCE:  AIRCRAFT
 LOAD FRONT AND CENTER CAMERAS, 10 MM LENS, 17.5 DEG AND 25 DEG DEPRESSION
   RESPECTIVELY, GADS PREFLIGHT

-STATION ID: W10    STORE: 3701   DESC: CAMERA  CARRIER                        C
 CARRIER NAME:  LEFT CHAFF CAMERA
 POWER SOURCE:  AIRCRAFT
 9 MM LENS, GADS PREFLIGHT, 200 FPS
 NOTE** IF OTHER CAMERAS SHOW UP ON THIS STATION PLEASE IGNORE.  THERE ARE NO
 ENGINE BAY CAMERAS NEEDED.  THE ONLY CAMERAS NEEDED ON THIS JET ARE LEFT CHAFF
 STRAKE, COCKPIT, WINGTIP*****************************************************

-STATION ID: W2     STORE:  901   DESC: MISSILE                                M
 1.  CONFIG WITH STANDARD STUB PYLON AND WEAPONS WING TIP LAUNCHER.
 2.  LOAD AIM-9

-STATION ID: W3     STORE:  901   DESC: MISSILE                                M
 1.  LOAD WITH INSTRUMENTED 16S1500 S/N C0103
 2.  LOAD AAVI THIS STATION

-STATION ID: W4     STORE:  101   DESC: FUEL TANK                              O

-STATION ID: W6     STORE:  101   DESC: FUEL TANK                              O

-STATION ID: W7     STORE: 1901   DESC: EMPTY PYLON OR EMPTY RAIL              O
 STORENAME:  EMPTY PYLON OR EMPTY RAIL
 1.  LOAD OTHER 16S1500, NO S/N THIS STATION.
 2.  DO NOT LOAD ANY MISSILE

-STATION ID: W8     STORE:  901   DESC: MISSILE                                M
 1.  CONFIG WITH STANDARD STUB PYLON AND WEAPONS WING TIP LAUNCHER.
 2.  LOAD AIM-9

-STATION ID: W9     STORE:  901   DESC: MISSILE                                M
```

```
Menu Item: MX/GB as of 91-10-17 at 08:46. Scheduling date: MON 911021  Page    6
                                                  As of: 17-OCT-1991 at 08:45
 MISSION REQUEST PART B -    6648-B  (ADF-3 HOT LAUNCH    B)
-------------------------------------------------------------------------------

-GENERAL  INFORMATION

 AIRCRAFT: --------------------- F16
 TAIL NO.: --------------------- ANY
 TYPE MISSION: ----------------- FLY/DROP
 REQUESTED DELIVERY DATE: ------ 911021
 DELIVERY LOCATION: ------------ RAMP
 DELIVERY TIME: ----------------
 LOAD CHECKLIST #: ------------- NOT REQUIRED

-MUNITIONS REQUESTED
-------------------------------------------------------------------------------
NO MUNITIONS REQUESTED
        CLASS: UNCLASS   TYPE: INERT   ISSUE:             QUANITY:

-SPECIAL  INSTRUCTIONS
-------------------------------------------------------------------------------
 1. FOR THIS TEST POINT, ANY F16B AIRCRAFT CAN BE USED AS CHASE.  NO - REPEAT -
    NO EXTERNAL STORES OTHER THAN THE CENTERLINE FUEL TANK SHOULD BE LOADED.
    FLIGHT EXPERIENCE HAS SHOWN THAT F-16B MODEL AIRCRAFT CANNOT PERFORM SAFETY
    CHASE FUNCTION (I.E. KEEP UP WITH THE TEST AIRCRAFT) WHEN DIRTIED UP WITH
    EXTERNAL STORES.
 2. PLEASE CALL RESPONSIBLE TEs, CAPTS HUBER OR BROLLEY AT 2-4873, SHOULD
    THERE BE ANY ISSUES REGARDING THIS LOADING REQUEST.

-STATIONS  LOADED  ON  AIRCRAFT
STATION/STORE SPECIAL LOADING INSTRUCTIONS
-------------------------------------------------------------------------------

-STATION ID: W1     STORE: 1901   DESC: EMPTY PYLON OR EMPTY RAIL              0

-STATION ID: W5     STORE:  101   DESC: FUEL TANK                              0

-STATION ID: W9     STORE: 1901   DESC: EMPTY PYLON OR EMPTY RAIL              0

--  END OF REPORT  -------------  367 LINES  ---------------  END OF REPORT  --
```

```
Menu Item: MX/GB as of 91-10-17 at 08:46. Scheduling date: MON 911021  Page    5
                                                  As of: 17-OCT-1991 at 08:45
 MISSION REQUEST PART B -    6648-A  (LNCH HOT ADF-2      A)
-------------------------------------------------------------------------------
 1.  CONFIG WITH WEAPONS WING TIP LAUNCHER.
 2.  LOAD AIM-9

-INTERNAL INSTRUMENTATION
-------------------------------------------------------------------------------
#1 AVTR NAC
 1.  TF PREFLIGHT AND LOAD WITH TAPES.
MARS 1414 LT-3D
 1.  TAPES WILL BE CONFIDENTIAL; TF PREFLIGHT AND LOAD TAPES.
 2.  TAPES TO BE DOWNLOADED IMMEDIATELY POST MISSION AND GIVEN TO PILOT
PDAS
 1.  TF OPS CHECK AND LOAD REQUIRED PROGRAM
 2.  TF TO DELIVER TAPES IMMEDIATLEY POST MISSION TO BLDG 422 (CLIMATIC
 HANGAR SIDE), AIR-TO-AIR MISSILE TEST DIVISON.
TCG
 1.  TF TO PREFLIGHT
TM SECURE
 1.  REQUIRE SECURE AIRCRAFT TM
 2.  TF TO ASSIST IN PREFLIGHT AND AIRCRAFT AND MISSILE KEYING 2.5
 HOURS PRIOR WITH CONTRACTOR.
VID CAM HUD
 1.  TF PREFLIGHT AND LOAD TAPES
```

Appendix B. *Plot Timeline Used During Manual Scheduling*



Appendix C. *Algorithm*

This appendix includes a description and pseudo-code for the new interactive algorithm in greater detail than was included in Chapter 3.

Block A The algorithm selects the highest priority mission requiring tanker, CCF, and FCA resources waiting to be scheduled. Only missions with a mission status of *SCHEDULING* will be considered. If an alternate mission is selected, the algorithm checks the mission status of the primary mission. If the primary mission has a mission status of *SCHEDULING*, the algorithm will reverse the priority rank and consider the primary mission first.

Block B The mission start time is 0700 if possible, otherwise 1300.

Block C The RESOMS scheduler attempts to schedule the mission. If this is possible the mission status changes to *SCHEDULED* and the algorithm continues in **Block F**.

Block D If a resource conflict could not be resolved by RESOMS, the user is prompted to determine if any alternate or deletable resources exist that were not shown on the mission request. If changes can be made, the mission returns to scheduling (**Block C**) after resource adjustments are complete. If changes are not possible for the active mission, the user determines if resource adjustments can be made for the conflicting mission. If changes can be made, the user unschedules the conflicting mission, makes the resource change, and tries to reschedule the conflicting mission. If no conflict exists the mission status is returned to *SCHEDULED* and the algorithm tries to schedule the active mission. If no conflict exists with the active mission, the mission status changes to *SCHEDULED* and the process continues in **Block F**, otherwise the active mission continues in **Block E**. If a conflict is encountered when rescheduling the conflicting mission, resources are reset to previous settings and the active mission continues in **Block E.**

<u>Block E</u> If the conflict cannot be resolved for a mission start time of 0700, the scheduling process begins again with a start time of 1300 in **Block B.** If the conflict cannot be resolved for a mission start time of 1300, the mission status changes to *NONSCHEDULED.*

<u>Block F</u> If more missions require the same resources within the search limit, the cycle restarts at **Block A**, otherwise the algorithm proceeds with Part 2.

<u>Block G</u> The same logic as **Block A** except missions requiring CCF and FCA resources are selected.

<u>Block H</u> The mission start time is 0700 if possible, otherwise 1000.

<u>Block I</u> The same logic as **Block C** except the algorithm continues in **Block M.**

<u>Block J</u> If CCF and/or FCA conflicts are pseudo-conflicts, override the conflict and return to **Block I.** The same logic as **Block D** is also applied except the algorithm returns to **Block I** for scheduling when conflicts are resolved. When a mission status changes to *SCHEDULED* the algorithm continues in **Block M**

<u>Block K</u> If the conflict cannot be resolved, the conflict is noted, and the mission start time is slipped to the next available time based on turn time. As long as the stop time is within the acceptable time block, the algorithm attempts to schedule the mission using **Block I.**

<u>Block L</u> If the mission cannot be scheduled in the acceptable time block, the algorithm attempts to schedule the mission by bumping the lower priority missions. The bumping process is accomplished by unscheduling one mission at a time until the active mission is scheduled, or no lower priority missions remain. If scheduling the active mission is not possible, the mission status changes to *NONSCHEDULED.* An attempt is made to reschedule bumped missions, high-

est priority first. Rescheduling missions in this order guards against a lower priority mission using resources needed by the higher priority mission. During rescheduling, the user is prompted to resolve conflicts if possible.

Block M If more missions require the same resources within the search limit, the cycle restarts at **Block G**, otherwise the algorithm continues with Part 3.

Block N The same logic as **Block A** except missions requiring tanker resources are selected.

Block O The same logic as **Block B**.

Block P The same logic as **Block C** except the algorithm continues in **Block S**.

Block Q The same logic as **Block D** except the algorithm returns to **Block P** for scheduling when conflicts are resolved. When a mission status changes to *SCHEDULED* the algorithm continues in **Block S**.

Block R If the conflict cannot be resolved for a mission start time of 0700, the scheduling process begins again with a start time of 1300 in **Block O**. If the conflict cannot be resolved for a mission start time of 1300, the algorithm attempts to schedule the mission by bumping lower priority missions. If this is not possible, the mission status changes to *NONSCHEDULED*. An attempt is made to reschedule bumped missions.

Block S If more missions require the same resource within the search limit, the cycle restarts at **Block N**, otherwise the algorithm continues with Part 4.

Block T The same logic as **Block A** except resource requirements are not considered, therefore allowing any remaining mission to enter the scheduling algorithm.

Block U Initial mission start time is 0700.

Block V The same logic as **Block C** except the algorithm continues in **Block Z**.

Block W The same logic as **Block D** except the algorithm returns to **Block V** for scheduling when conflicts are resolved. When a mission status changes to *SCHEDULED* the algorithm continues in **Block Z.**

Block X The same logic as **Block K** except the algorithm returns to **Block V.**

Block Y The same logic as **Block L.**

Block Z If more missions exist within the search limit, the cycle restarts at **Block T,** otherwise add 15 to the search limit and continue the algorithm with **Block A.**

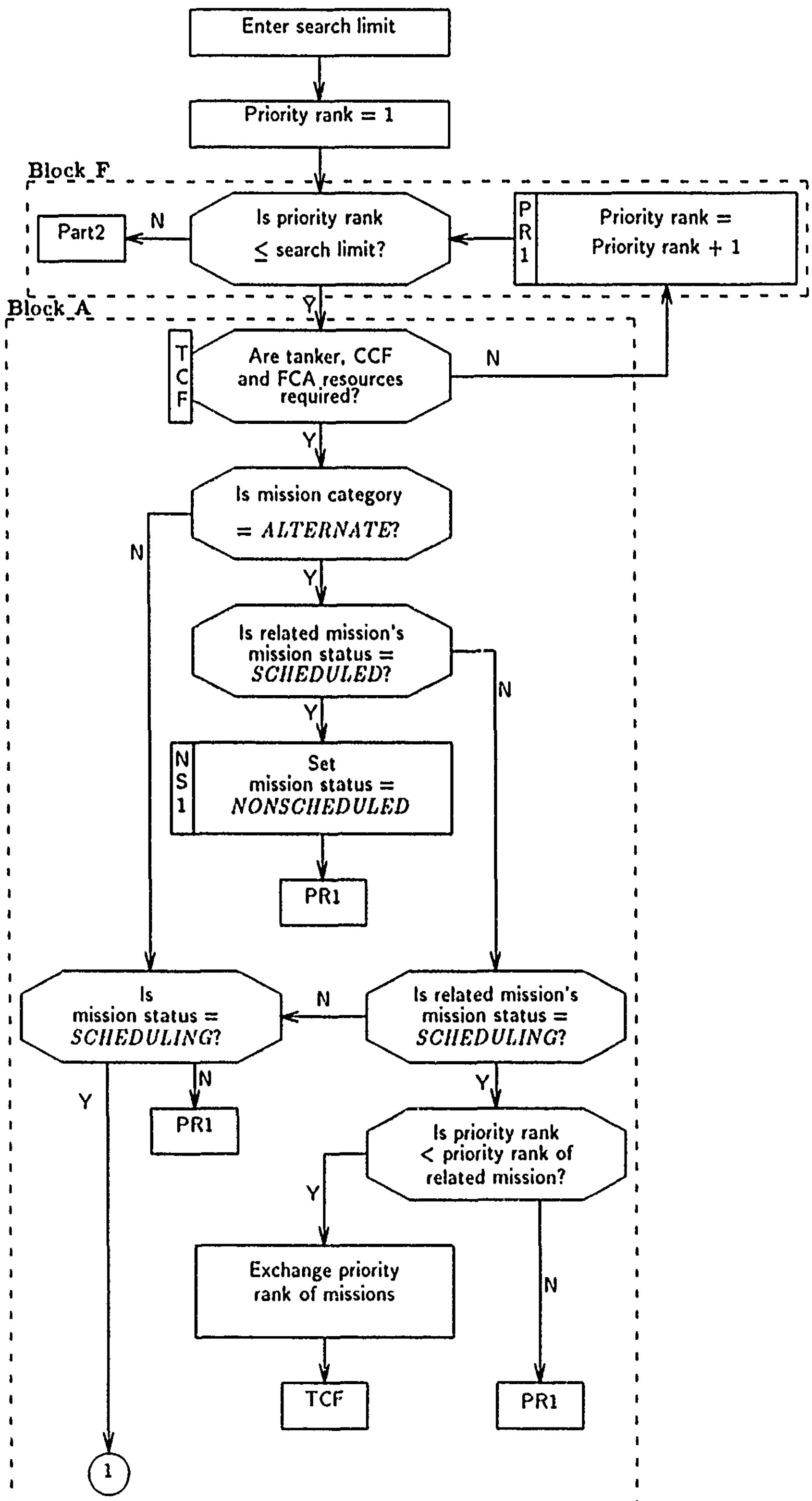


Figure C.1. Algorithm Flow Part 1

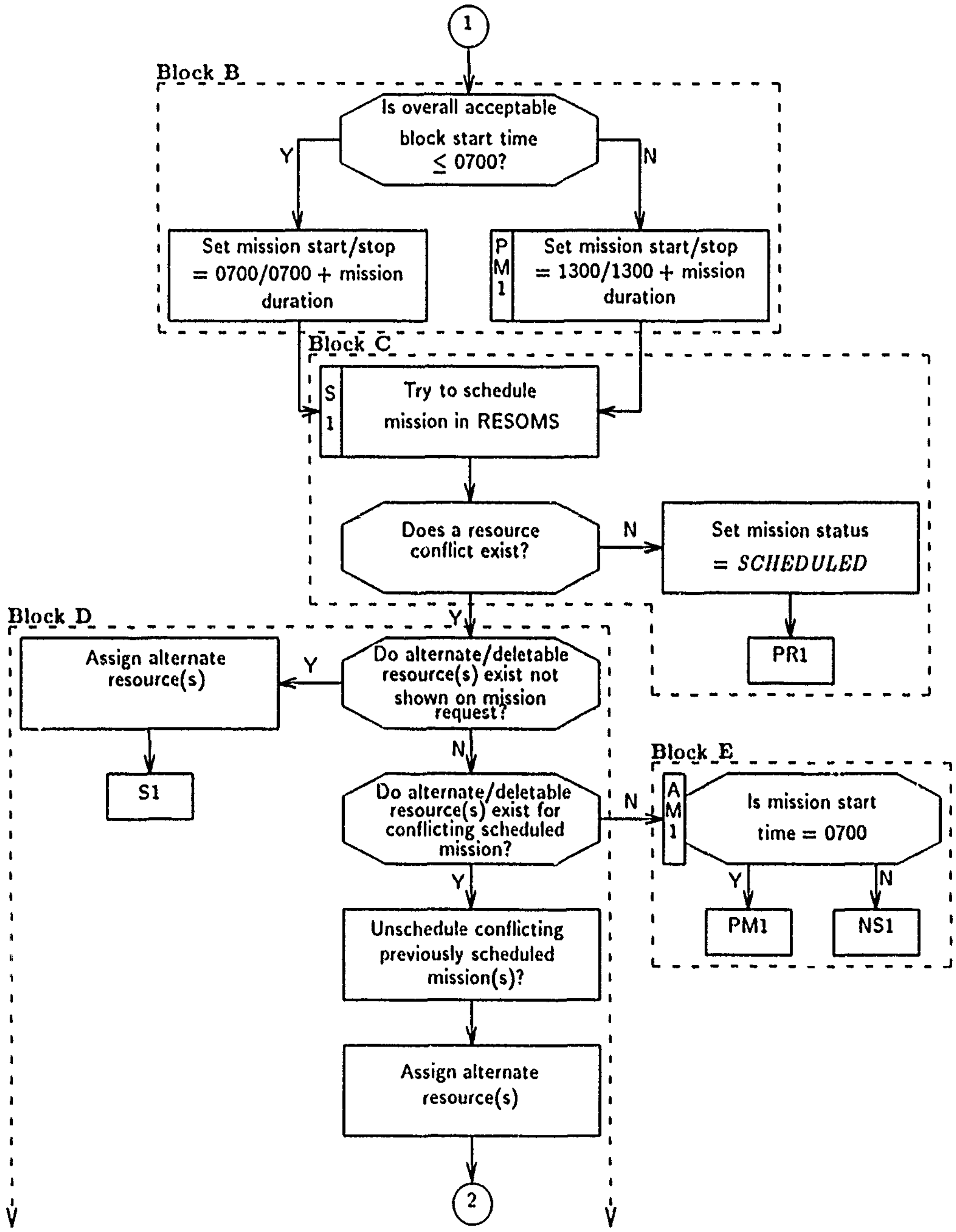


Figure C.2. Algorithm Flow Part 1 (continued)

Block D(cont)

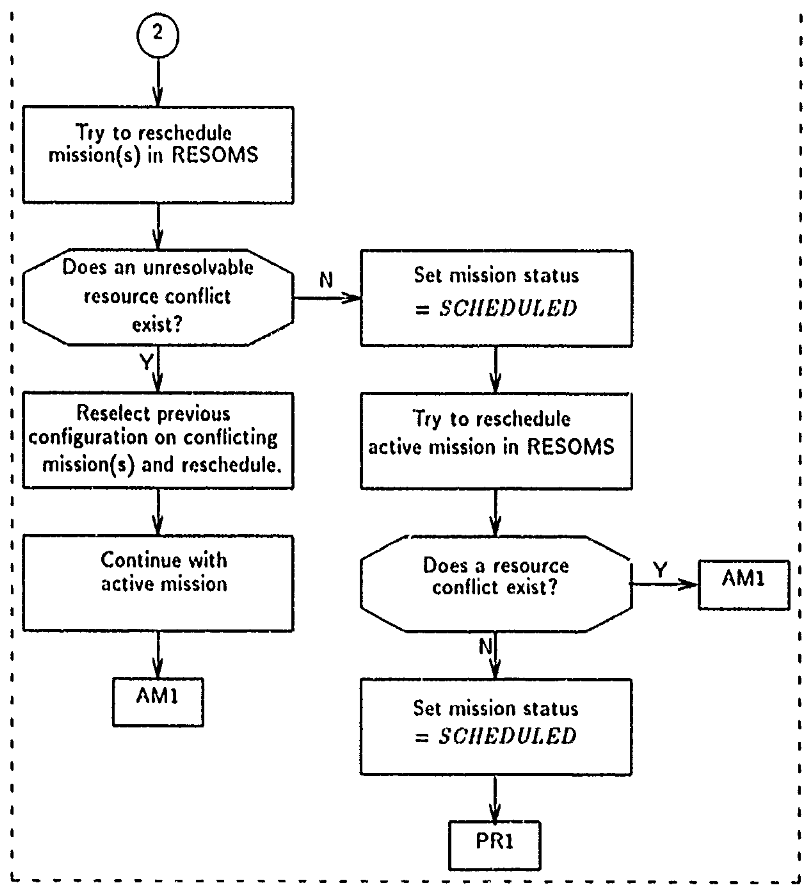


Figure C.3. Algorithm Flow Part 1 (continued)

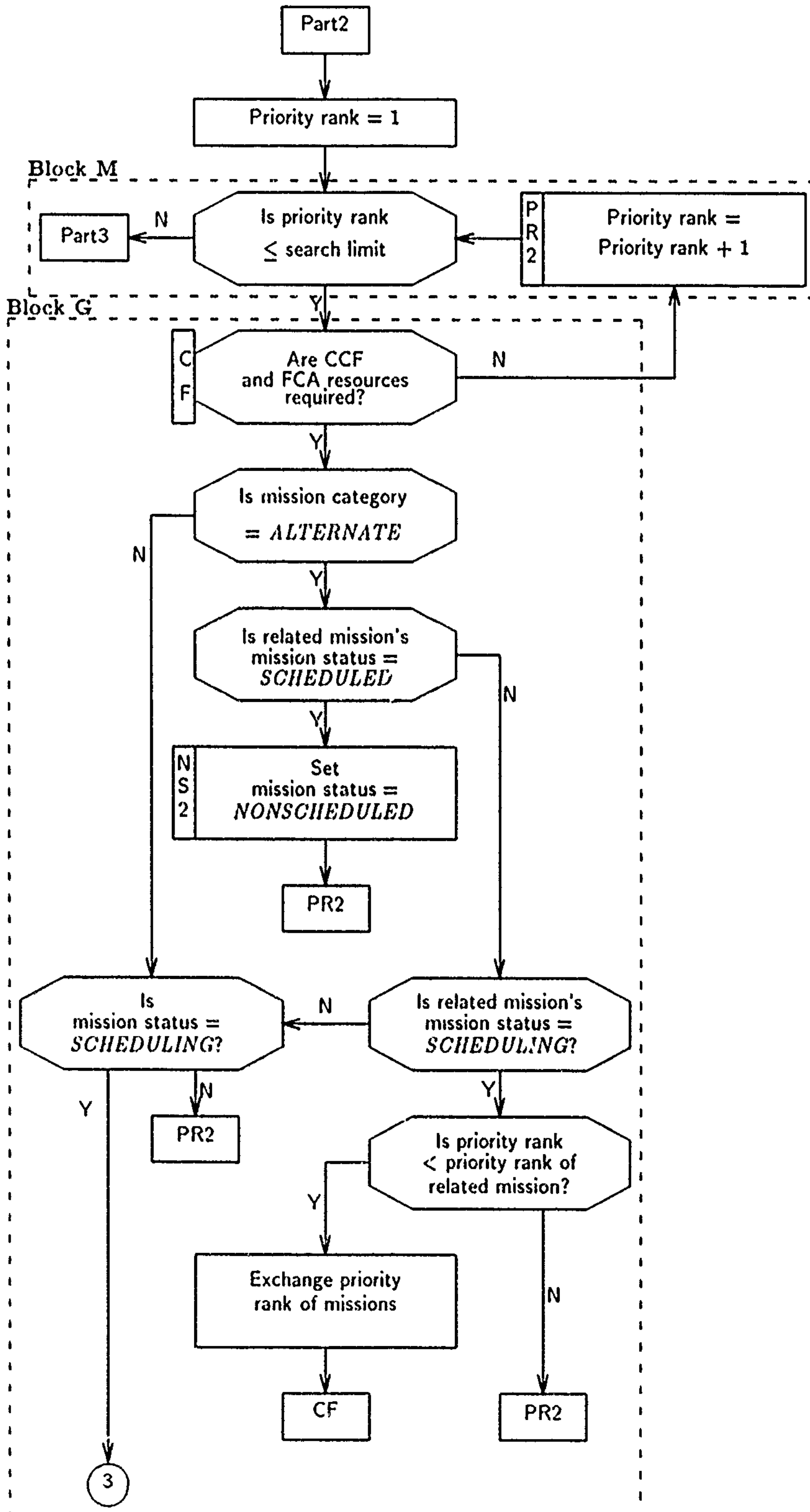


Figure C.4. Algorithm Flow Part 2

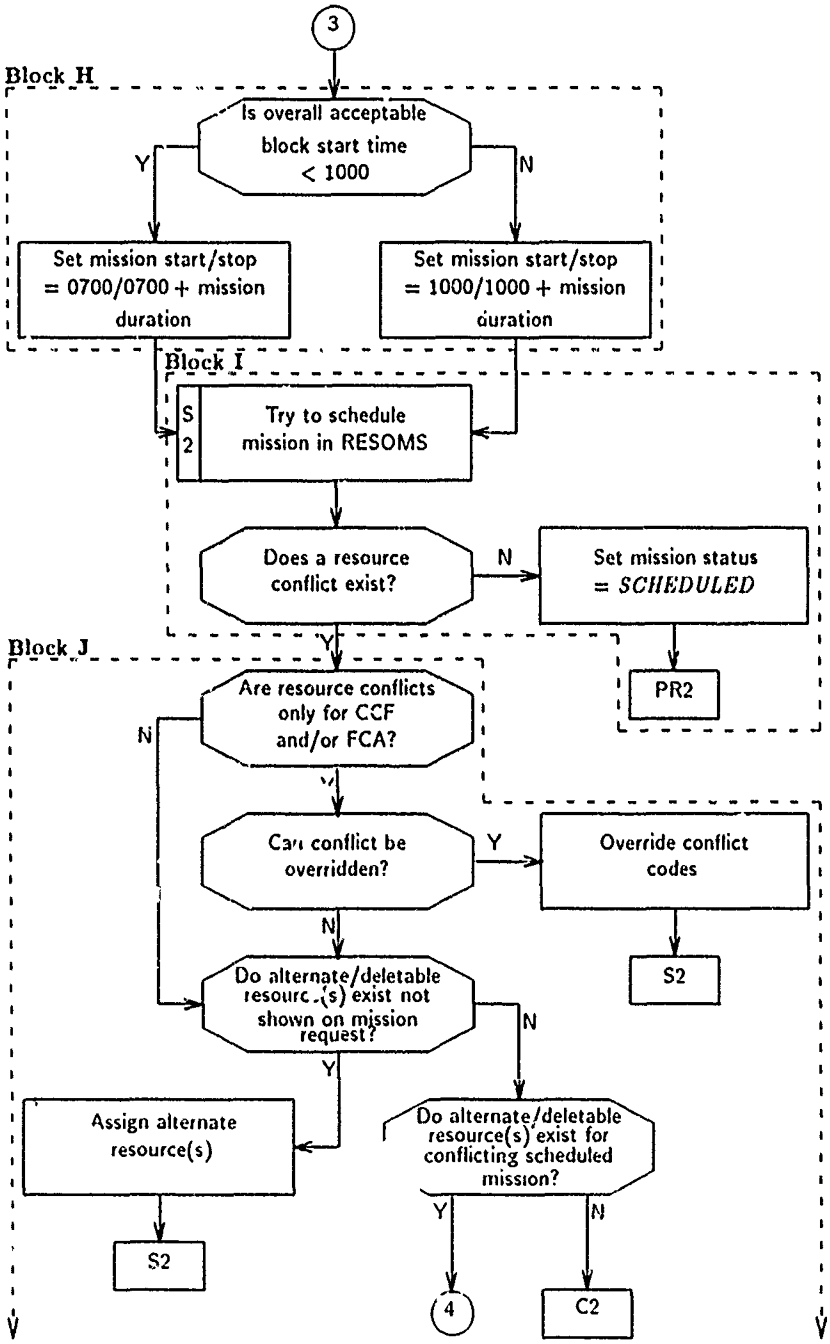


Figure C.5. Algorithm Flow Part 2 (continued)

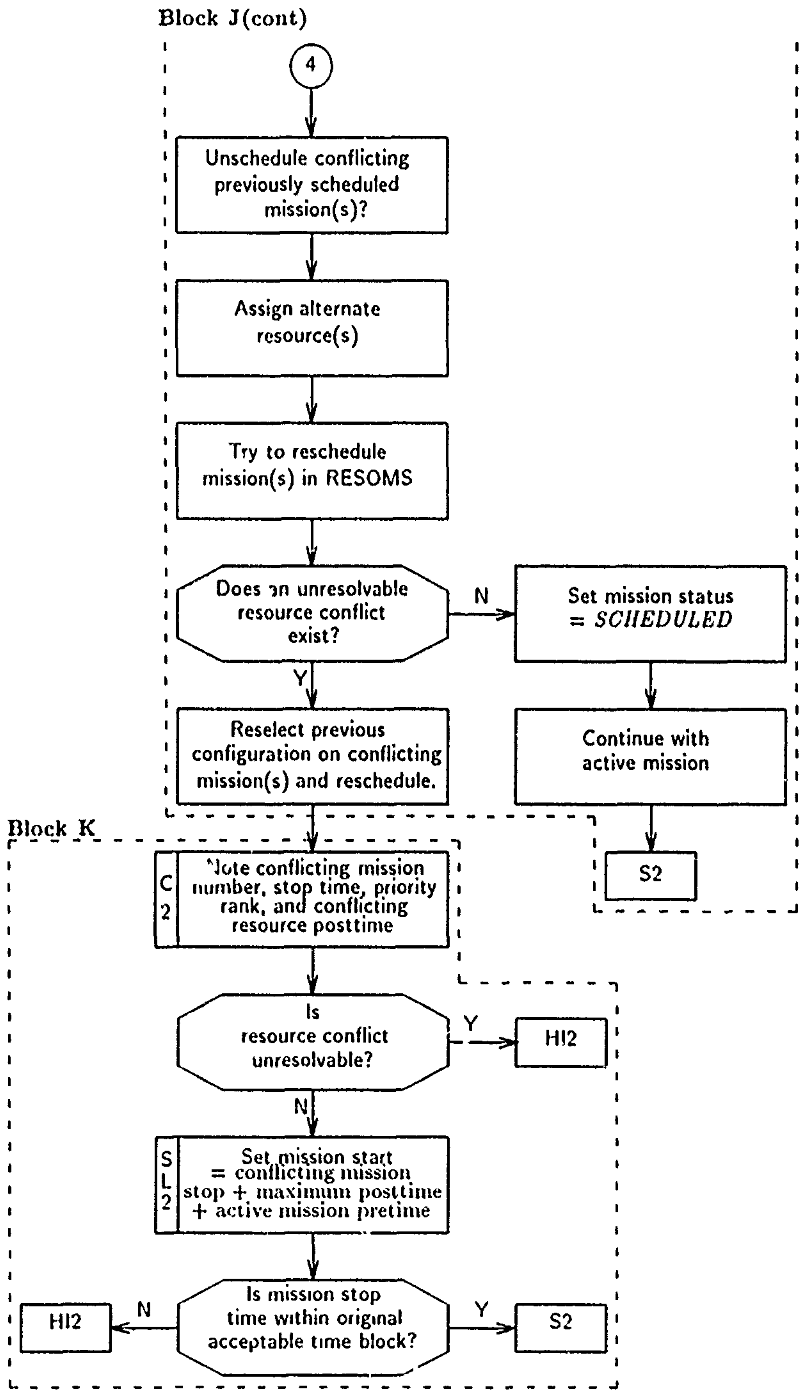


Figure C.6. Algorithm Flow Part 2 (continued)

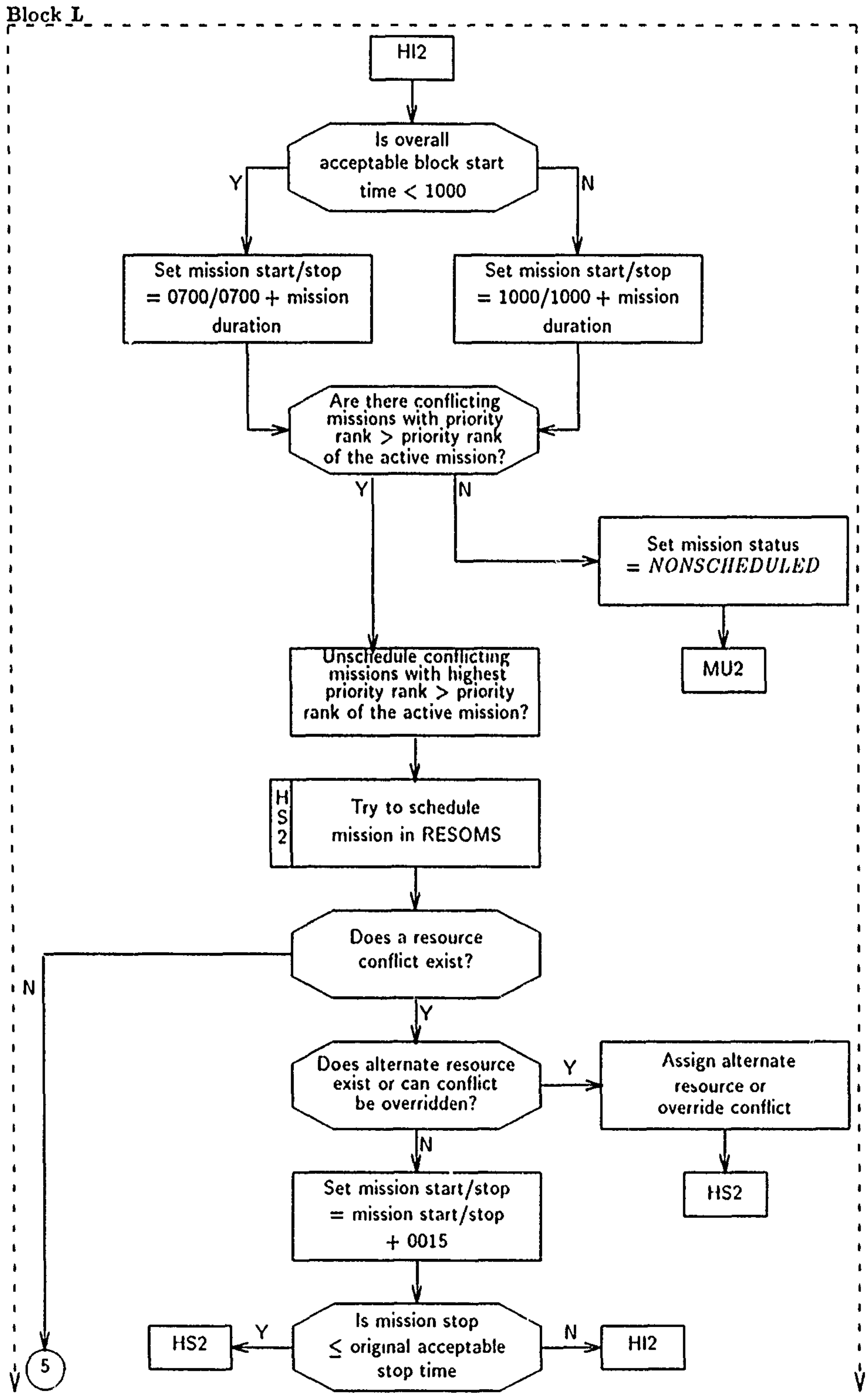


Figure C.7. Algorithm Flow Part 2 (continued)

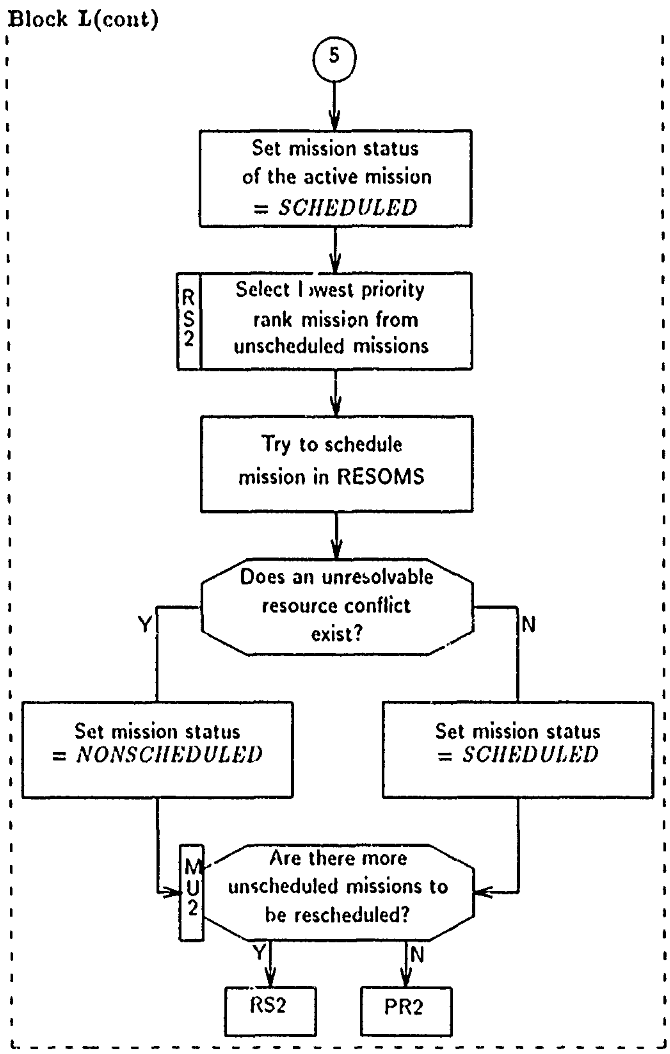


Figure C.8. Algorithm Flow Part 2 (continued)

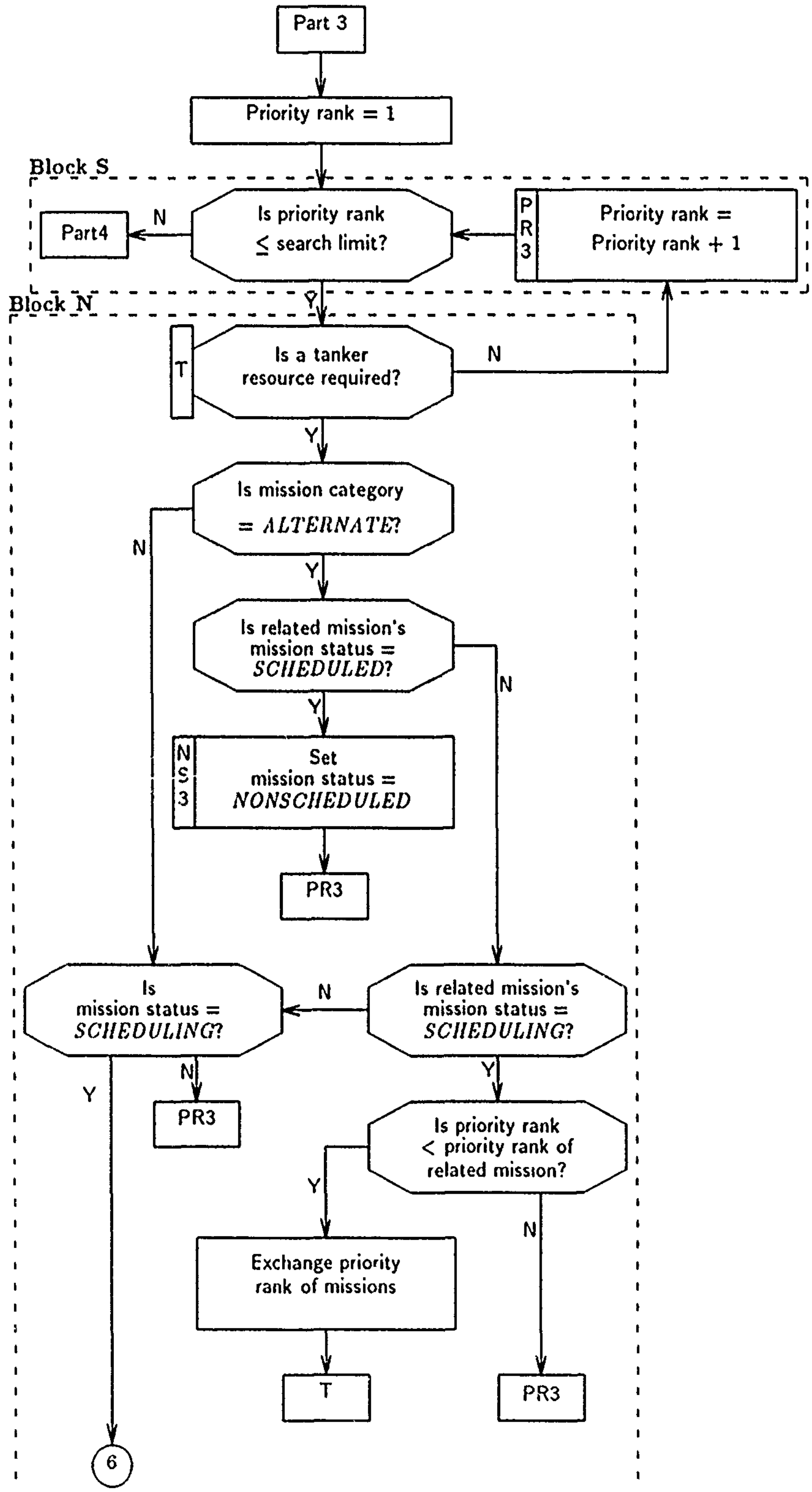


Figure C.9. Algorithm Flow Part 3

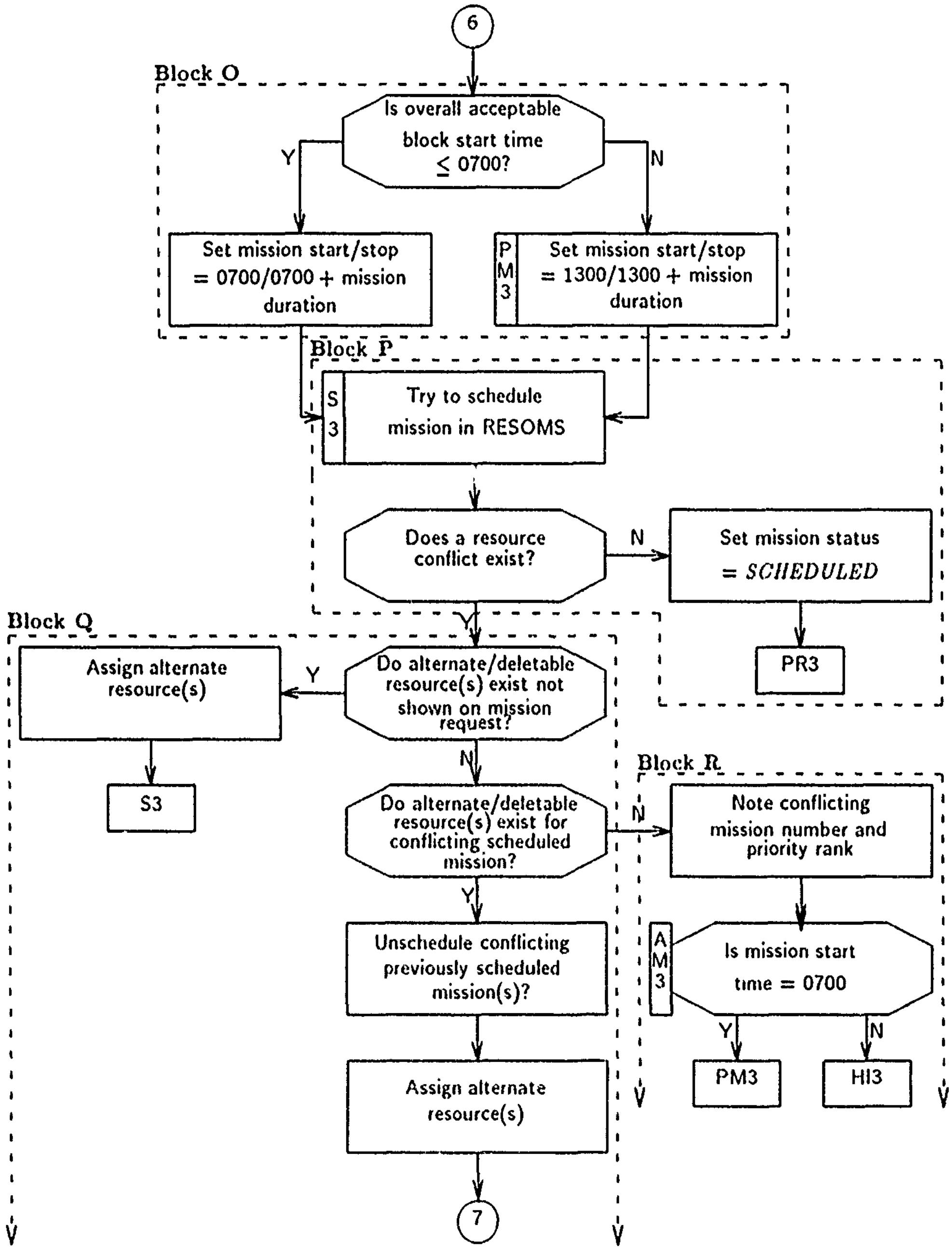


Figure C.10. Algorithm Flow Part 3 (continued)

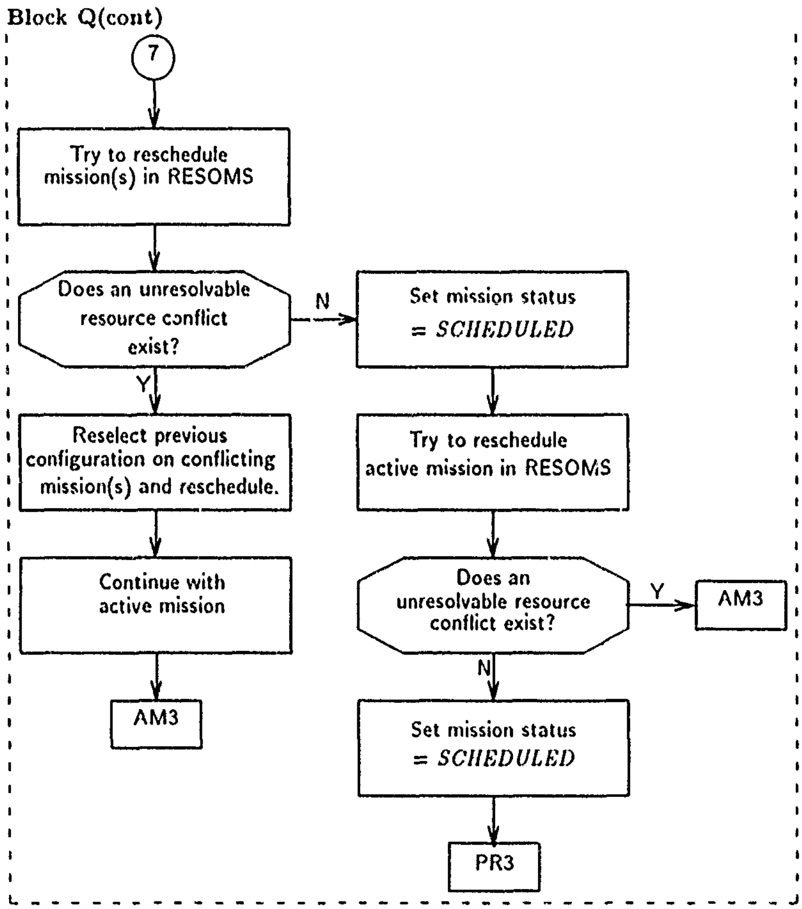


Figure C.11. Algorithm Flow Part 3 (continued)

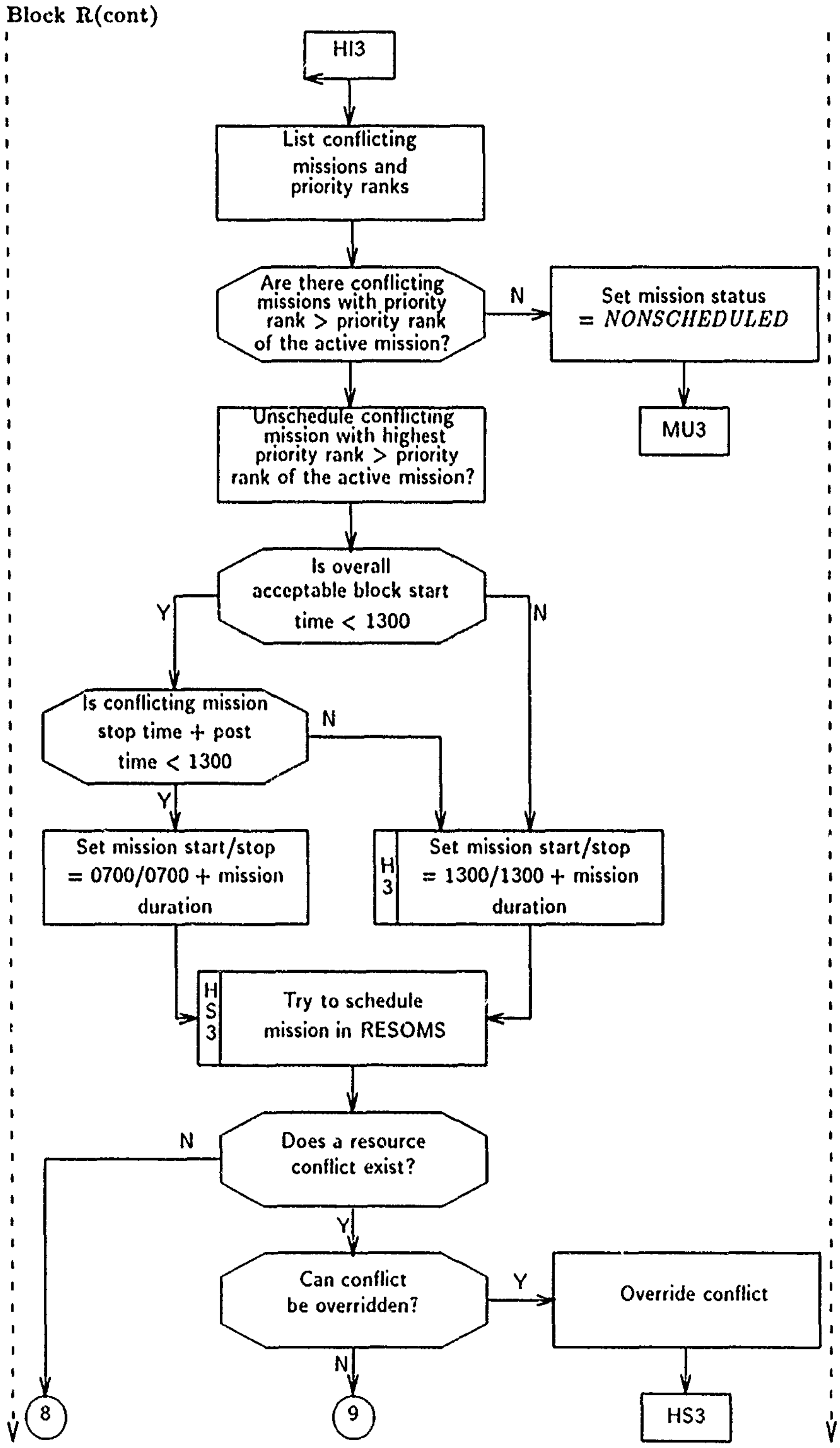


Figure C.12. Algorithm Flow Part 3 (continued)

Block R(cont)

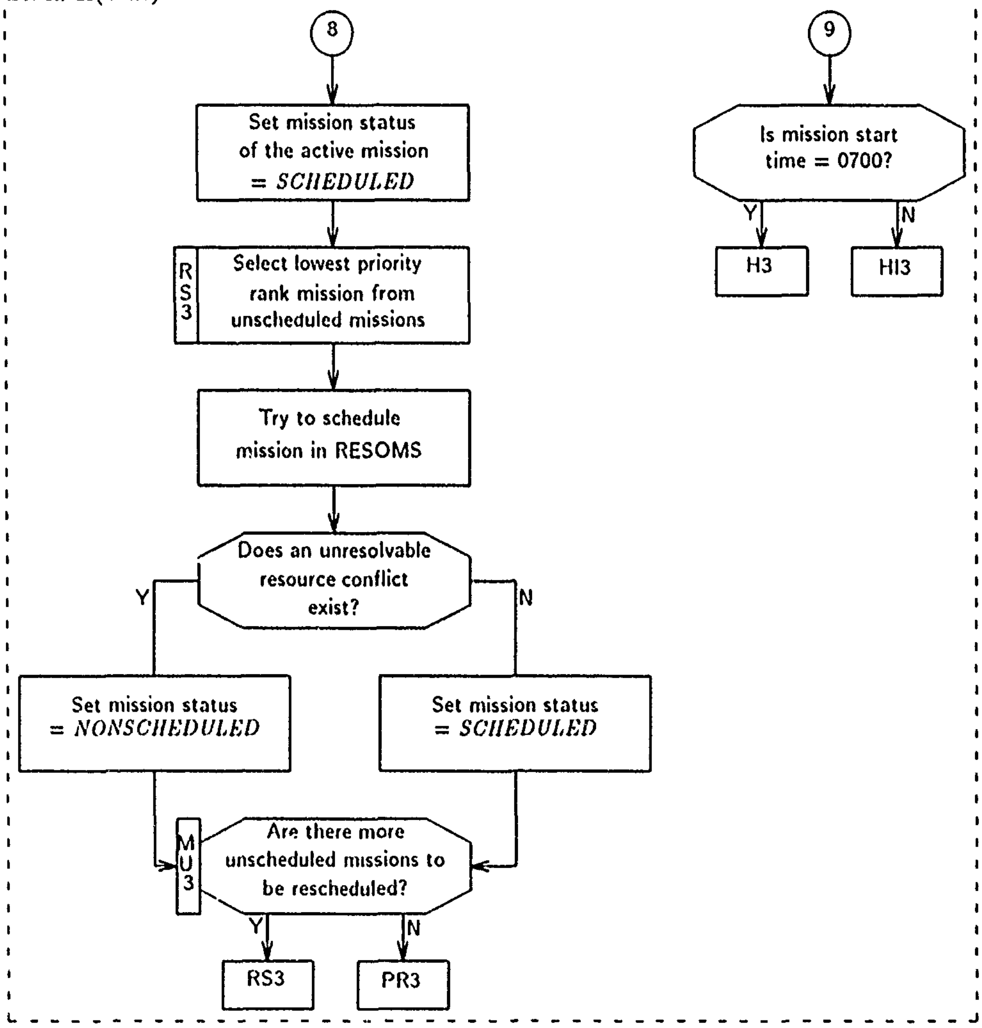


Figure C.13. Algorithm Flow Part 3 (continued)

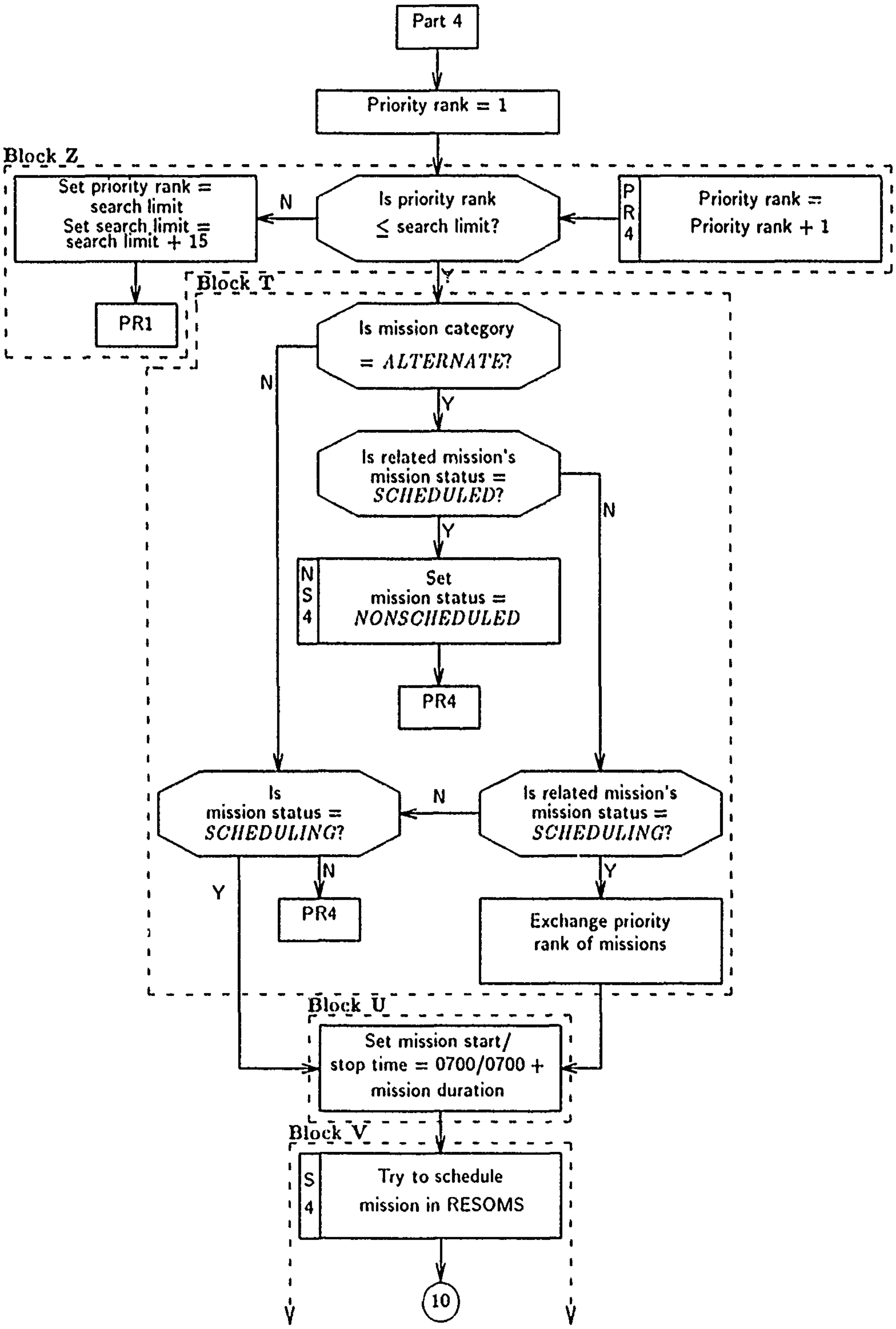


Figure C.14. Algorithm Flow Part 4

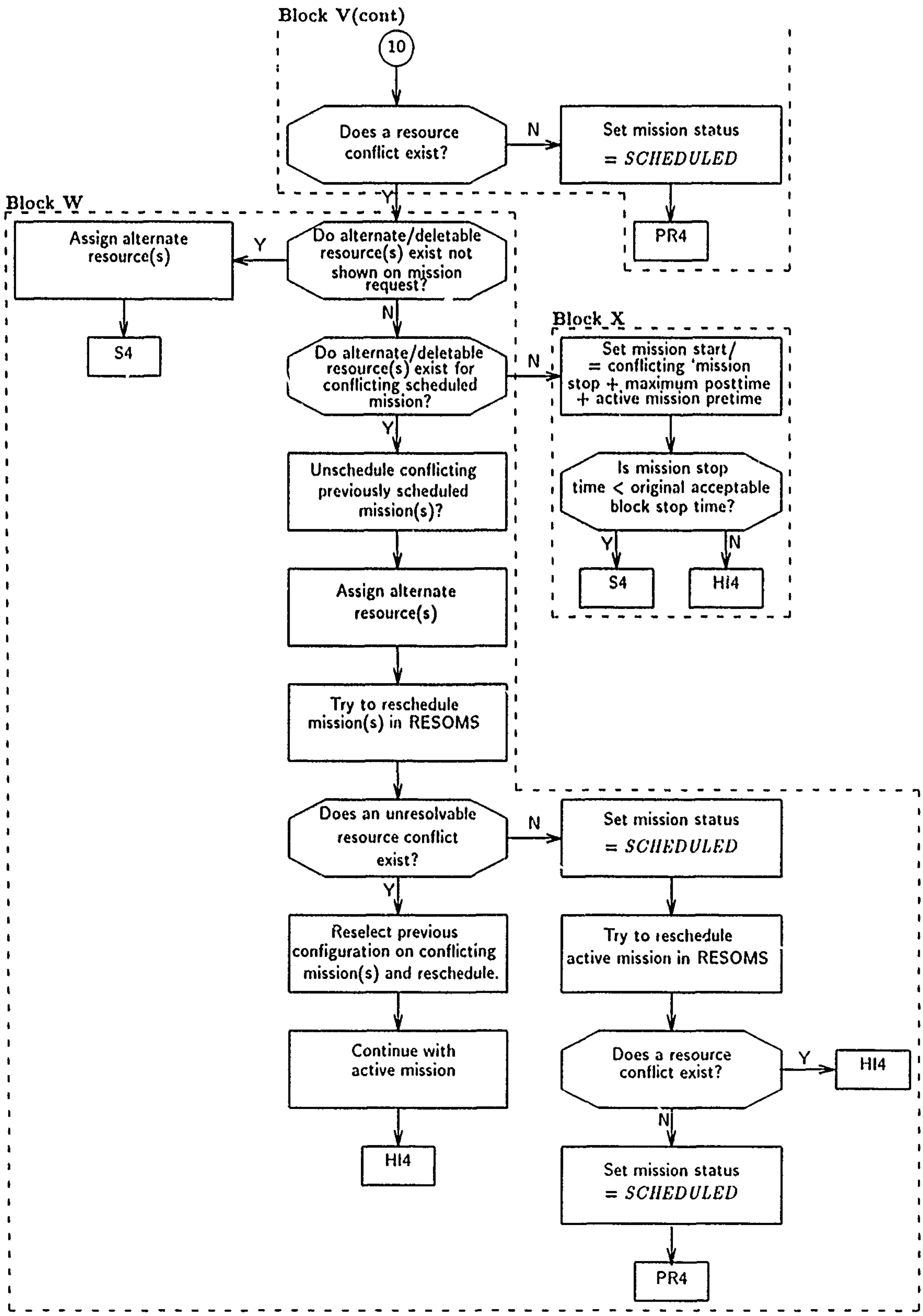


Figure C.15. Algorithm Flow Part 4 (continued)

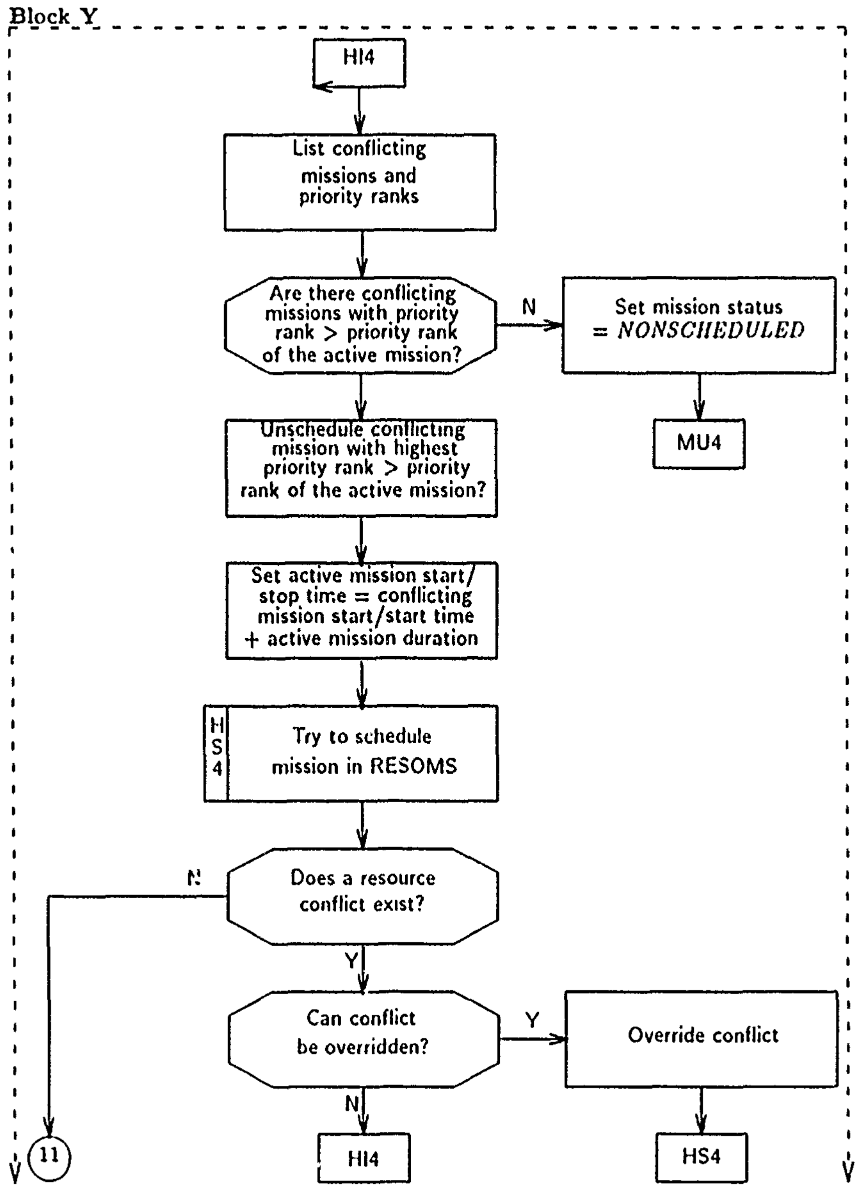


Figure C.16. Algorithm Flow Part 4 (continued)

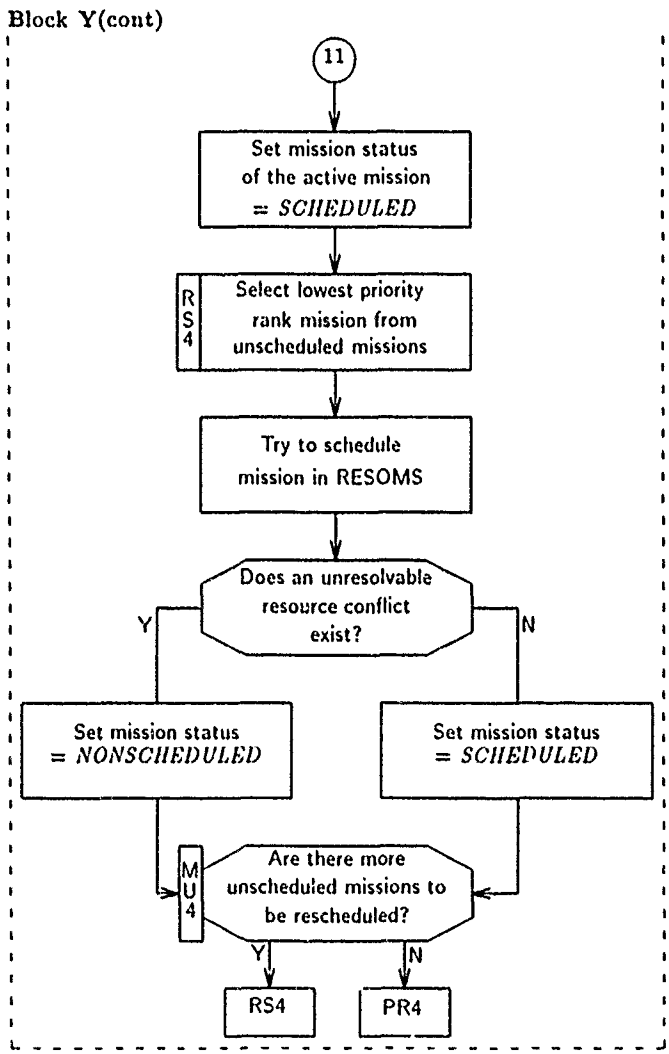


Figure C.17. Algorithm Flow Part 4 (continued)

Appendix D. *Analysis of Nonscheduled Missions*

This appendix contains a more detailed analysis for why nonscheduled missions were scheduled by at least one other scheduling method than is included in Chapter IV. A section is devoted to each scheduling day.

Day 1

The mission number and resource conflicts for missions that were nonscheduled using RESOMS noninteractive mode but were scheduled by at least one of the other methods are indicated in the following list. The list includes an explanation of how missions were scheduled by at least one of the other scheduling methods.

2677 Telemetry (TM) frequency conflict with mission 2756. The manual method and the new algorithm scheduled this mission by scheduling mission 2756 earlier than the requested start time. The earlier start time allowed sufficient time to schedule mission 2677 in the afternoon.

2473 Radar, aircraft, and TM frequency conflict with missions 2478 and 2756. The manual method and the new algorithm scheduled this mission by scheduling mission 2756 earlier than the requested start time. The earlier start time allowed sufficient time to schedule mission 2677 in addition to 2478.

2622 CCF conflict with missions 2756, 2467, and 2468. The conflict was a pseudo-conflict, based on total percentage of CCF resources in use. Schedulers confirm that sufficient CCF resources exist and override the conflict within RFSOMS. This interaction allowed the manual method and the new algorithm to schedule this mission.

2680 B4A TM relay site(B4A) and CCF conflict with mission 2756. The manual method and the new algorithm scheduled this mission by selecting an alternate B4A not listed on the mission request. The CCF was a pseudo-conflict.

2529 Test range conflict with mission 2154. The manual method and the new algorithm scheduled this mission since the conflict results from a safety profile overlapping the requested range. Schedulers schedule both missions by notifying users to coordinate specific activities that present the safety concern.

2403 CCF, TM frequency conflicts. The manual method and the new algorithm scheduled this mission since the CCF pseudo-conflict would have allowed the mission to schedule in the morning, thus avoiding the TM conflict in the afternoon.

2630 Range conflict with mission 2142. The manual method and the new algorithm scheduled this mission. The manual method shortened mission 2142 by 1 hour and scheduled it in the afternoon, while the new algorithm scheduled mission 2142 earlier than RESOMS, allowing time for 2630 to be scheduled later.

2845 B4A and radar conflict. RESOMS picked the alternate mission 2847 to schedule before this primary mission using needed resources. The new algorithm scheduled this mission before the alternate.

2550 Aircraft conflict. The manual method and the new algorithm scheduled this mission. Maintenance assigned needed aircraft to higher-priority missions based on the belief they would be scheduled. The missions were subsequently nonscheduled and the aircraft resource availability was not updated in RESOMS.

The mission number and resource conflicts for missions that were nonscheduled when plotted manually on a schedule but were scheduled by at least one of the other methods are indicated in the following list. The list includes an explanation of how missions were scheduled by at least one of the other scheduling methods.

2341 ECM/FCA conflict with missions 2473 and 2478. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority mission 2473.

2382 Airspace and radar conflict with mission 2473. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority mission 2473.

2845 B4A and radar conflict. The manual scheduler scheduled the alternate mission 2847 due to an oversight of a deletable resource not indicated on the mission request. The new algorithm scheduled this mission before the alternate.

The mission number and resource conflicts for missions that were nonscheduled using the new scheduling algorithm but were scheduled by at least one of the other methods are indicated in the following list. The list includes an explanation of how missions were scheduled by at least one of the other scheduling methods.

2341 ECM/FCA conflict with missions 2473 and 2478. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority mission 2473.

2382 Airspace and radar conflict with mission 2473. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority mission 2473.

2847 This is an alternate for mission 2845. RESOMS and the manual scheduler both scheduled this mission, but not the primary mission 2845.

Day 2

The mission number and resource conflicts for missions that were nonscheduled using RESOMS noninteractive mode but were scheduled by at least one of the other methods are indicated in the following list. The list includes an explanation of how missions were scheduled by at least one of the other scheduling methods.

3223 Range conflict with mission 3226. The manual method and the new algorithm scheduled this mission as a result of scheduler knowledge that the missions are related. Mission 3223 and mission 3226 are associated with the same test program, so range turn-time activities could be shortened, thus allowing room for the second mission.

3397 CCF conflict with mission 3385. The manual method and the new algorithm scheduled this mission by scheduling mission 3385 earlier in the morning, thus allowing sufficient time to schedule mission 3397 in the afternoon.

3429 and 3428 Aircraft conflict with mission 3385. Mission 3429 and mission 3428 are identical. The manual method and new scheduling algorithm scheduled mission 3429 and mission 3428, respectively, by scheduling mission 3385 earlier in the morning, allowing sufficient time to schedule a mission in the afternoon.

2778 and 3372 CCF conflict with several missions. The missions are similar, except the first mission required more resources than the second. The CCF conflict is a pseudo-conflict allowing the manual method and the new algorithm to schedule one of the missions. Resources are not available for both missions. The manual method scheduled the larger mission (2778) by not using a tanker in the morning and shortening other tanker missions later in the day. The new algorithm scheduled the smaller mission (3372) without affecting other missions.

3750 Airspace, ECM/FCA, radars conflict with missions 3385 and 3748. The new algorithm scheduled this mission by scheduling mission 3385 earlier in the morning, thus allowing sufficient time to schedule mission 3750 in the afternoon. The manual method scheduled mission 3750 instead of a very similar mission (3748).

The mission number and resource conflicts for missions that were nonscheduled when plotted manually on a schedule but were scheduled by at least one of the other methods are indicated in the following list. The list includes an explanation of how missions were scheduled by at least one of the other scheduling methods.

3428 Aircraft conflict with mission 3385 and 3429. The new algorithm scheduled this mission instead of an identical mission (3429).

3372 Aircraft conflict with mission 2778. The new algorithm scheduled this mission without conflicts, instead of mission 2778.

3748 Airspace conflict with missions 3385, 3429, and 3750. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority missions 3429 and 3750. The new algorithm was able to schedule this mission by assigning alternate airspace the manual scheduler overlooked.

3141 Range and B4A conflict with missions 2778 and 3385. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority mission 2778.

The mission number and resource conflicts for missions that were nonscheduled using the new scheduling algorithm but were scheduled by at least one of the other methods are indicated in the following list. The list includes an explanation of how missions were scheduled by at least one of the other scheduling methods.

3429 Aircraft conflict with mission 3385 and 3428. The manual scheduling method scheduled this mission instead of the other identical mission (3428).

2778 Aircraft conflict with mission 3372. The manual scheduling method scheduled mission 3372 by shortening other missions, rather than scheduling a less demanding similar mission.

3141 Range and B4A conflict with missions 3372 and 3385. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority mission 3372.

Day 3

The mission number and resource conflicts for missions that were nonscheduled using RESOMS noninteractive mode but were scheduled by at least one of the other methods are indicated in the following list. The list includes an explanation of how missions were scheduled by at least one of the other scheduling methods.

4271 ECM/FCA conflict with mission 3179. Airspace and CCF conflict with 3868. The manual method and the new algorithm scheduled this mission by scheduling missions 3179 and 3868 at the same time allowing time for mission 4271 to be scheduled later in the day.

4262 ECM/FCA conflict with mission 3179. Airspace and CCF conflict with 3868. The manual method and the new algorithm scheduled this mission by scheduling missions 3179 and 3868 at the same time allowing time for mission 4262 to be scheduled later in the day.

3887 CCF conflict. The conflict was a pseudo-conflict, based on total percentage of CCF resources in use. Schedulers confirm that sufficient CCF resources exist and override the conflict within RESOMS. This interaction allowed the manual method and the new algorithm to schedule this mission.

4303 ECM/FCA conflict with mission 3179. Airspace and CCF conflict with 3868. The new algorithm scheduled this mission by scheduling missions 3179 and 3868 at the same time and leaving little idle time between other missions that required the needed resources.

3718 Range conflict with 3719. This mission was the *related* mission to *alternate* mission 3719. The manual method and the new algorithm scheduled this primary mission first.

4483 B4A conflict with mission 3179. The manual method and the new algorithm scheduled this mission by scheduling missions 3179 and 3868 at the same time allowing time for mission 4483 to be scheduled later in the day.

The mission number and resource conflicts for missions that were nonscheduled when plotted manually on a schedule but were scheduled by at least one of the other methods are indicated in the following list. The list includes an explanation of how missions were scheduled by at least one of the other scheduling methods.

4303 ECM/FCA conflicts with 3179, 4271, and 4262. The new algorithm scheduled this mission by leaving little idle time between other missions. The scheduler overlooked the opportunity to compress missions and schedule mission 4303.

3893 Aircraft conflict with mission 4271. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority mission 4271.

4179 Airspace conflicts. The new algorithm scheduled this mission by leaving little idle time between other missions. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority missions.

4177 Airspace conflicts. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority missions.

4030 Aircraft conflict with mission 4262. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority mission 4262.

3719 B4A conflict with mission 3718. RESOMS scheduled this alternate mission prior to scheduling the primary mission 3718.

The mission number and resource conflicts for missions that were nonscheduled using the new scheduling algorithm but were scheduled by at least one of the other methods are indicated in the following list. The list includes an explanation of how missions were scheduled by at least one of the other scheduling methods.

3893 Aircraft conflict with mission 4271. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority mission 4271.

4177 Airspace conflicts. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority missions.

4030 Aircraft conflict with mission 4262. The resource was available for RESOMS to schedule this mission since it did not schedule the higher-priority mission 4262.

3719 B4A conflict with mission 3718. RESOMS scheduled this alternate mission prior to scheduling the primary mission 3718.

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Vita

Captain Jeffery S. Antes was born on 27 April 1959 in Elmira, New York. He graduated from Elmira Southside High School in 1977 and attended Syracuse University. He received the degree of Bachelor of Science in Industrial Engineering/Operations Research in May 1981. Upon graduation, he received his USAF commission through the AFROTC program. His first assignment was Undergraduate Pilot Training at Reese AFB, Texas in May 1981. Following graduation and KC-135 upgrade training Captain Antes served as a KC-135A pilot and KC-135R aircraft commander at McConnell AFB, Kansas from September 1982 to July 1986. He was reassigned to Griffiss AFB, New York as a KC-135 aircraft commander and Chief of Wing Flying Safety until entering the School of Engineering, Air Force Institute of Technology, in August 1990.

Permanent address: 1004 Pennsylvania Avenue
Elmira, New York 14904

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This research develops an algorithm that integrates into an existing computerized scheduling system to improve the mission scheduling function for Eglin AFB test ranges. The primary objective of this research was to design an improved computerized scheduling aid. The measure of performance for this approach is the number of missions scheduled using this aid as compared to current Eglin capabilities. Constructive heuristics are used in the algorithm to schedule missions according to critical resource groups while ensuring mission priority is not violated.

The success of this new interactive scheduling algorithm is measured against a schedule produced by the current computer system, and against a schedule produced manually. The schedules that were produced using the new algorithm suggest improvement over the current computer system in terms of airborne test, task, and task-oriented training missions. Reimbursable costs were also improved. The new algorithm also produced a schedule comparable to one produced manually, and tends to suggest a small improvement. Improved mission throughput is one of the benefits that can be realized by incorporating the new algorithm as part of the current computer system.

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