SYSTEM PLANNING CORPORATION

OPERATIONAL EFFECTIVENESS OF A MULTIPLE AQUILA CONTROL SYSTEM (MACS)

FINAL REPORT

SPC 929

July 1983

R. W. Brown
J. D. Flynn
M. R. Frey

Prepared for
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

Contract 956503

9950-884

SYSTEM PLANNING CORPORATION
1500 Wilson Boulevard • Arlington, Virginia 22209-2454 • (703) 841-2800

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(NASA-CR-174436) OPERATIONAL EFFECTIVENESS OF A MULTIPLE AQUILA CONTROL SYSTEM (MACS) Final Report (System Planning Corp., Arlington, Va.) 73 p HC A04/MF A01 CSCL 22D

N85-19000

Unclas
G3/14 18695

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This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Contract 956503

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I. EXECUTIVE SUMMARY

A. PURPOSE

System Planning Corporation (SPC) conducted this study to examine the operational effectiveness of a Multiple Aquila Control System (MACS) under a variety of mission configurations. The study was prepared under a contract with the Jet Propulsion Laboratory (JPL), Pasadena, California.

B. BACKGROUND

SPC previously conducted two studies that suggested the use of a centralized launch and recovery concept. The first addressed the control of multiple remotely piloted vehicles (RPVs) using timesharing and other techniques with standard RPV equipment [Ref. 1], and the second analyzed operations of a postulated centralized launch and recovery (CL&R) RPV system [Ref. 2]. Those studies developed a methodology by which the complexity of RPV section operations could be modeled in order to examine the performance achieved using alternative RPV employment concepts. Though coarse, the model proved useful in recommending major operational enhancements to the original RPV concept with independent forward sections. The RPV program has since adopted the CL&R mode of operations in its operational concept.

The configuration of the MACS tactical unit is similar to that of the RPV CL&R concept in that the launch and recovery elements are separate from the forward ground control stations (FGCSs). At the centralized facility in the rear division area, the pieces of equipment that distinguish MACS from the current RPV CL&R concept are the centralized ground control station (CGCS) and its associated central ground data terminal. The MACS CGCS is required to control multiple airborne RPVs simultaneously, allowing the system to be augmented with a variety of additional mission payloads.

SPC was tasked to investigate the operational concept of the postulated MACS unit and project its performance in coordinating RPV activities under an increasing workload with additional missions. Five tasks were developed as a part of this study:

- Analyze the operational effectiveness of MACS for specified mission sets

- Propose changes to equipment or procedures that might enhance MACS effectiveness and reanalyze with changes incorporated
- Determine system sensitivities to range from the MACS complex to the FLOT
- Estimate personnel and equipment requirements for specified mission sets
- Estimate data rates required for ground coordination between MACS units for mission sets.

C. SCOPE

At the time the above tasks were written, the RPV CL&R concept included four forward sections. It is now expected that there will be three forward sections. All analyses in this study reflect the original guidance.

The analyses of MACS operations are structured to examine missions whose required on-station coverage is continuous, compared to the original RPV concept of three 3-hour target acquisition, designation, and aerial reconnaissance (TADAR) missions per day. Comparisons between the results of these analyses and previous program documentation are applicable only where this consideration has been incorporated.

The scenario chosen for this work prescribes an operations concept that, for the purpose of writing a definitive computer simulation, allocates priorities to the types of mission conducted and prevents operations for some types of payloads at the FGCS or CGCS. For example, this study assumes TADAR missions always have top priority and are never controlled by the CGCS, and operations for alternate payloads are never conducted at the FGCS. The RPV platoon is a division asset whose allocation and specific functions will be as directed by the division commander and, therefore, not necessarily according to the assumptions described herein. The postulated MACS operational concept has been coordinated with various RPV program participants but is not to be construed as official or approved doctrine nor as prescribing fixed procedures that deprive the commander of his prerogatives.

D. APPROACH

The unique characteristics of MACS, namely multiple airborne RPVs with various different missions, provided the impetus to develop a computer simulation to address the first three tasks mentioned above. The methodology used in previous SPC studies consisted of manually stepping through the various time-ordered events during a typical RPV mission, using decision theory to assign probabilities of occurrence for each event, generating computer-assisted subroutines where necessary, thereby arriving at average time on station and turnaround time for each mission. No more than two RPVs were airborne at the same time: one each under the control of the FGCS and CGCS.

In moving to a MACS system that can control up to eight air vehicles (AVs) at a time, it was felt that essentially the same operational methodology could be used to examine system performance, but a computer would be more efficient at keeping track of eight RPV missions plus those of the four FGCSs. Some operational procedures that were necessarily simplified for the manual model have been more accurately integrated into the simulation with their effects contributing to the results.

The first step in structuring the simulation is to specify the characteristics that will govern MACS operations. They include the battlefield environment that generates the requests for RPV missions, operating timelines of the RPV-peculiar equipment, maintenance requirements, vulnerability to enemy fire, etc. The set of assumptions and inputs used to form the rules under which this simulation is run are discussed in Chapter II.

With these rules fixed, the model can generate a mission event profile, or a sequence of events during the course of a mission, that might occur under the specified circumstances. A large number of stochastically dissimilar mission profiles are generated under the same set of fixed rules. If enough profiles are generated, all the possible combinations of events that could occur during the course of a mission will be represented and in the proper proportion relative to all other events. This effect is created in the model by simulating MACS operations over a long period of time until enough missions have been generated to consider probabilistic effects negligible. A discussion of how many missions or how many days of operations are necessary appears in Chapter III.

The results of all missions are analyzed and reduced to several key measures of effectiveness, including AV losses, mission coverages, and queueing delays in key operational procedures. Then, the rules (inputs or assumptions) are changed and the sequence above repeated. Results of the second computer run, representing an equally large number of mission profiles created under the new set of fixed rules for that run, are then compared to those of the first. Differences between the results of the two runs are assumed to have been caused by the differences between the fixed inputs or assumptions for each. Such an assumption is valid when probabilistic effects of individual rare events are not significant enough to influence the overall results. Results of baseline computer runs and excursions with proposed system enhancements appear in Chapter III.

Separate analyses were conducted for the last two tasks. Personnel and equipment requirements are estimated based on current allocations and changes that would be expected for equipping a MACS as new missions are added. Command, control, and communications (C^3) data rates are estimated by determining how many messages are passed and what information is necessary in them to support ground coordination between MACS sections. These analyses are discussed in Chapter IV.

The results of this study are most useful in determining trends between different mission configurations rather than as absolute measurements of performance. This is primarily influenced by the specification for continuous operations, which is the most stringent operational condition and may be unlikely for extended periods of time on the battlefield. However, during surge situations, continuous coverage by any or all of the missions included in the study may be required for short periods. Consequently, the simulation is structured to portray MACS at peak demand levels.

E. FINDINGS

1. Baseline Simulation Runs

Overall mission performances degrade gradually as mission types are added to the basic TADAR mission until the fourth alternate, the addition of which causes mission coverages to decline and system delays to increase sharply. Simultaneous control of eight RPVs by MACS is sufficient to handle the basic TADAR mission plus three additional missions. Beyond that point, launcher delays also dominate due to the number of total missions being processed.

The additional number of missions generated by the use of a TADAR hot spare continually on station strains system operations such that all mission coverages are reduced. A revised hot spare concept could increase coverages by as much as 5 percent but would not alleviate existing ground system delays. The suggested concept would call for using the hot spare to replace not only unexpected losses in mission coverage (such as from AV kill, AV failure, or payload malfunction), but also to service certain expected coverage gaps. In particular, when a freshly emplaced forward ground control station (FGCS) calls for a new TADAR mission, a hot spare could service the request rather than wait for an AV from the CL&R facility to arrive at the mission area.

Assuming a 0.95 probability of survival and equipment reliabilities stated in design specifications, 20 days of continuous operations for one MACS platoon using only the TADAR mission will deplete that platoon's wartime allocation of RPVs if the current production plans are maintained. If the MACS concept with multiple mission types is adopted, more air vehicles will be required to support a war effort. The 20-day surge operation scenario was chosen to provide sufficient statistical smoothing to the output data and does not necessarily represent an operational requirement.

2. Simulation Excursions

A base load of 13 TADAR AVs and 3 each of other payload types is sufficient to sustain continuous FGCS operations at a high level of effectiveness. A base load of 10 TADAR AVs provides comparable mission coverage and may be adequate if delays are acceptable.

The addition of a third launcher would decrease launcher delays enough to allow a fourth alternate mission to be flown by MACS. The third recovery system and CGCS do not significantly benefit system operations. The latter point reflects the observations that recovery operations are not a bottleneck in the system, and the third CGCS and MACS antenna do not increase the allowable number of RPVs controlled by the central facility.

Even with a reduced survivability of 0.75, when the MACS facility is already heavily loaded with RPV missions, the benefits of the hot spare are outweighed by delays caused because of the number of extra missions it generates. However, when system operations are not otherwise tasked by additional RPV mission types, the hot spare provides equal or better TADAR coverage (in a low-survivability environment) than in runs when it is not used. Also, when the kill rate is high, a fast resupply time (3 hours) in combination with the hot spare option alleviates most hot-spare-related burdens.

Payload interchange times appear to cause unacceptable delays for that procedure to be included in launch preparations for continuous-coverage missions. Interchanges are assumed to take an average of about 1 hour apiece to perform. It can be a valuable procedure if planned and performed in advance for singular or noncontinuous missions. However, continuous missions achieve more time on station when mission requests are serviced with the next available intact AV-and-payload rather than initiating payload interchange procedures when the required intact AV-and-payload is not immediately available.

Halving the total time the CL&R facility spends in displacement increases mission coverages significantly. The computer simulation assumed CL&Rs would displace twice per day, according to inputs postulated by the RPV TRADOC systems manager (TSM). Moving only once per day, or once every other day if doctrine allows, is preferable.

If a 5-hour planned flight endurance were achievable for TADAR-equipped RPVs (including the hot spare), it would produce a significantly higher percentage of continuous coverage than missions with a 3-hour TADAR endurance. The current RPV air vehicle is designed and configured to achieve a 3-hour flight endurance with either a television or forward-looking infrared (FLIR) package.

3. MACS-to-FLOT Range

A 35-kilometer MACS-to-FLOT range appears to be a good compromise between factors that argue for both a shorter and a longer distance. The computer simulation showed RPV mission performance to be relatively insensitive to variations in range from the CL&R to the FLOT. The best location for the MACS central facility will likely be determined by factors not modeled in this simulation, such as the MACS command and control structure, methods of communication between forward and rear MACS units, the range of the modular integrated control and navigation system (MICNS) data line, and ground system vulnerability. As the former points are being resolved by the RPV community, the latter factor argues for a MACS location outside the range of enemy proliferation artillery, but otherwise as close to the forward area as possible to lessen technical C^3 challenges.

4. Personnel and Equipment Requirements

An additional 18 personnel, eight 5-ton trucks with associated RPV equipment, and 12 AVs are estimated to be required for the fully loaded mission set with four alternate missions as compared to the basic TADAR-only mission in the MACS concept with two CL&Rs.

5. Ground Coordination

It is estimated that the total number of messages passed between MACS units for coordination of standard continuous operations will be less than 400 per day on the average. Each message should average less than 10 items of information, including standard headers.

F. RECOMMENDATIONS

The hot spare should be used on an as-needed basis in brigade-sized areas where continuous coverage is essential for indefinite periods of time. Since it is unlikely that continuous TADAR coverage will be required across the division front for extended periods, the hot spare concept is best suited to smaller areas of responsibility where high AV kill rates are expected and the hot spare mission can be assigned a high priority at the CL&R section. If division-wide hot spare operations are desired, it should be used both for expected and unexpected replacements of lost mission coverage.

A base load of 10 TADAR RPVs at the CL&R facility combined with a resupply concept where RPVs are replaced more often (instead of waiting for a carrier truck to be free of its three AVs) should be investigated as a potential method of reducing costs over the currently planned base load of 16 RPVs in the all-TADAR CL&R concept.

The feasibility of the MICNS data link controlling more than eight RPVs at a time using "park-and-fly" schemes should be investigated. This study assumed each RPV under MACS control required full-time use of one of the eight available control slots. For missions that require only station keeping with infrequent updates, existing dead-reckoning and link-acquisition features of the MICNS can be implemented to provide other missions greater access to the available eight slots.

Efforts to provide the maximum endurance for RPV missions should be continued in view of the enhanced coverages achieved by such missions in the simulation.

Enhanced mission performance achieved with the introduction of improved reliability and maintenance figures indicates that tradeoffs should be investigated vis-a-vis continued efforts to increase equipment reliability as an alternative to pursuing other system enhancements postulated in this study.

II. STRUCTURING THE COMPUTER SIMULATION

A. BACKGROUND

The configuration of the MACS tactical unit is similar to that of the current RPV CL&R concept in that the launch and recovery elements are separate from the forward control sections. The four forward sections[1] in an RPV or MACS platoon have relatively low equipment and manpower requirements to conduct that mission. They are attached one each to one of a variety of possible division elements, as directed by the division commander, including direct support (DS) and general support (GS) artillery battalions, division tactical headquarters, aviation battalion, and military intelligence battalion, among others.

At the centralized facility in the rear division area, the most significant functionally different pieces of equipment that distinguish MACS from the current RPV CL&R concept are the centralized ground data terminal (CGDT) and centralized ground control station (CGCS), hereafter collectively and loosely referred to by the latter term only. The MACS CGCS is required to control up to eight airborne RPVs simultaneously, allowing the system to be augmented with a variety of additional mission payloads. Launch and recovery equipment, air vehicle handlers, maintenance shelters, and cargo vehicles remain essentially the same as in the current CL&R concept (see Chapter IV for a discussion of personnel and equipment requirements of the MACS).

The initial studies by SPC concerning control of multiple RPVs using timesharing and other techniques with standard RPV equipment [Ref. 1] and operations of a postulated CL&R RPV system [Ref. 2] lay the groundwork for this study and the computer simulation employed. Those studies developed a methodology by which the complexity of RPV section operations could be modeled in order to examine the performance achieved using alternative RPV employment concepts. Though coarse, the model proved useful in recommending major operational enhancements to the original RPV concept with independent forward sections.

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[1] At the time the computer simulation was written, the RPV CL&R concept included four forward sections. Doctrine subsequently changed so that it is now expected that there will be three forward sections. All analyses in this study reflect the original guidance.

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The requirements of the MACS effort provided the impetus to develop an all-computer simulation. The original methodology consisted of manually stepping through the various time-ordered events during a typical RPV mission, using decision theory to assign probabilities of occurrence for each event, generating computer-assisted subroutines where necessary (e.g., calculating, through queueing theory, the expected delays at the launcher, recovery subsystem, etc., during stress situations), thereby arriving at average time on station and turnaround time for each mission. No more than two RPVs were airborne at the same time: one each under the control of the forward GCS and the central GCS.

In moving to a MACS system that can control up to eight AVs at a time, it was felt that essentially the same operational methodology could be used to examine system performance, but a computer would be more efficient at keeping track of those eight RPV missions plus those of the four forward ground stations. Also, the computer simulation uses a Monte Carlo approach, in which continuous MACS operations are run over a sufficient period of time, and results from many missions over that time are summed and averaged to arrive at performance data, including variability, for a particular type of mission set. In this way, some operational procedures that were necessarily simplified for the manual model have been more accurately integrated into the simulation with their effects contributing to the results.

B. METHODOLOGY OF MACS COMPUTER SIMULATION

The first step in structuring the simulation is to specify the characteristics that will govern MACS operations. They include the battlefield environment that generates the requests for RPV missions, operating timelines of the RPV-peculiar equipment, maintenance requirements, vulnerability to enemy fire, etc. The set of assumptions and inputs used to form the rules under which this simulation is run are discussed later in the chapter.

With these rules fixed, the model can generate a mission event profile, or a sequence of events during the course of a mission, that might occur under the specified circumstances. Each time a mission event profile is generated, it can be different from any other because of the probabilities associated with the occurrence of events. These probabilities will dictate the eventual outcome of missions according to the rules that represent or simulate actual MACS operations.

A large number of stochastically dissimilar mission profiles are generated under the same set of fixed rules. If enough profiles are generated, all the possible combinations of events that could occur during the course of a mission will be represented and in the proper proportion relative to all other events. This effect is created in the model by simulating MACS operations over a long period of time until enough missions fulfilling combat requirements have been generated to consider probabilistic effects negligible. One computer run generates those missions. A discussion of how many missions or how many days of operations are necessary appears in Chapter III.

The results of all missions are analyzed and reduced to several key measures of effectiveness, which are discussed later in this chapter. Then, the rules (inputs or assumptions) are changed and the sequence above repeated. Results of the second computer run, representing an equally large number of mission profiles created under the new set of fixed rules for that run, are then compared to those of the first. Differences between the results of the two runs are assumed to have been caused by the differences between the fixed inputs or assumptions for each. Such an assumption is valid when probabilistic effects of individual rare events are not significant enough to influence the overall results.

C. TYPICAL TADAR MISSION

Within the computer, files are created that represent the status of pieces of equipment in the MACS platoon and the status of actions or events that affect the equipment. Files are maintained on each CGCS, FGCS, launcher subsystem, recovery subsystem, air vehicle, and mission payload. Those pieces of information on equipment status are coordinated through master files, called mission request files (MRFs), which are chronological records of RPV missions from the generation of a mission request through mission termination. During each cycle of the main program, the simulation moves into successive time increments (usually 1-minute increments) and updates each file.

Equipment files are checked for possible failure during the current increment (based on reliability inputs), are maintained in present status if no changes occurred, or are updated to reflect a new status (e.g., when repair is complete to a failed item, it moves into an "operational" status).

As an example, mission states that an MRF might pass through during a typical successful TADAR mission are shown in Figure 1. The MRF is created by a request for a new mission, perhaps generated because a replacement will be required soon for a TADAR AV nearing the end of its current mission. The simulation is designed to receive an input specifying how long before the end of an ongoing mission a new mission request should be generated to ensure no gaps in mission coverage, given normal operating conditions.

The first state into which the new MRF is placed is AWAITING AV, in which it asks for an AV to be assigned to that mission request. Generally, that happens immediately but will be delayed if the base load of AVs is depleted. In that case, the MRF will not move to a new state until the resupply truck arrives with a new load of AVs, or an AV returning from a mission is recovered and made available for this new mission.

Since the simulation considers that modular RPV payloads can be interchanged among AVs, an AV whose payload has been removed due to a previous failure may become available before one that has the appropriate payload. The MRF would move to EMPTY AV AVAILABLE and ask for a payload to be installed, which takes time. Another state (not shown) could be AV AVAILABLE, WRONG PAYLOAD, in which case payload removal and installation are required with additional delays.

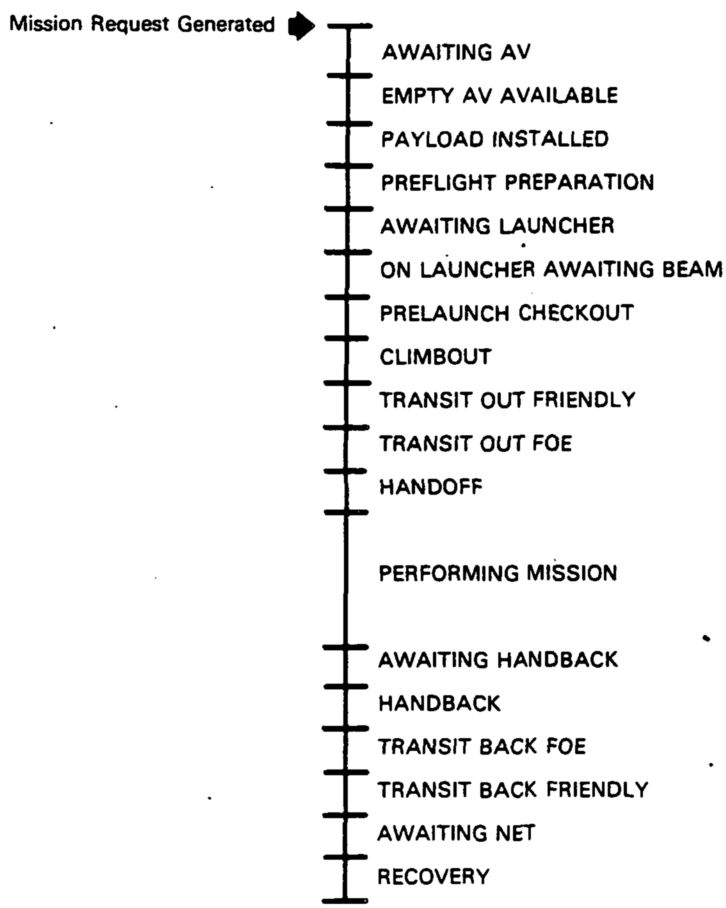

Figure 1. Typical TADAR Mission Profile

When installation or interchange is completed, the MRF moves to PAYLOAD INSTALLED. Under most circumstances, this state is reached with no time delay after the MRF is created because the base load should have enough TADAR AVs to fill the request immediately. PREFLIGHT PREPARATION is next. During this phase, which takes an amount of time as specified in the input parameters, the AV is fueled, checked in the maintenance shelter, and moved to the launch area.

When preparation is completed, the MRF moves to an AWAITING LAUNCHER state. If all launchers are currently unavailable because they are being used, being repaired, or displacing, the MRF waits. When a launcher is available, the AV is loaded and the MRF becomes ON LAUNCHER AWAITING BEAM. The "beam" refers to one of the available control slots in the MACS multiple control antenna, which can direct up to eight AVs at a time. This MRF state is the simulation's way of saying that if the CGCS already has control of eight AVs, another "beam" is not available and the new mission must wait until one becomes available before the AV can be processed and launched. There is also a priority structure in the program so that when a "beam" becomes free, it might be assigned to a higher priority action (e.g., an RPV requiring immediate recovery) before the launch request is filled.

The available beam is assigned to the RPV on the launcher, and PRE-LAUNCH CHECKOUT begins. An input specifies how much time is spent in this activity, after which the AV is launched and the MRF moves into CLIMBOUT.

An equipment failure at any point in the sequence up to AV launch may result in mission delays, but will not cause a catastrophic loss of an AV. As an example of the effects equipment failures can have on the progress of a mission request up to this point, consider the PRELAUNCH CHECKOUT phase. If the launcher fails during this procedure, the MRF is terminated and another is created starting at AWAITING AV. The failed launcher enters a repair phase, the AV is unloaded and returned to the base load, one beam is freed up for assignment to another MRF, and the just-terminated MRF is processed by an analysis routine for compilation of its vital statistics. Meanwhile, the newly created MRF will most likely be assigned the same AV that just came off the failed launcher, unless a higher priority mission requires that AV. Since the AV has the proper payload and has already been through preflight preparation,[2] the new MRF will move directly to AWAITING LAUNCHER with no time passed since the failure. If another launcher is available, the mission continues. The only delays from the progress of the original MRF are the sunk time spent in PRELAUNCH CHECKOUT before launcher failure, the unload time, and reload time. If no other launchers are available, the AV waits and delays increase.

Equipment failures once the AV is airborne may result in delays or loss of an AV. For instance, if the mission payload fails during CLIMBOUT, the AV will be immediately returned and another mission request generated, resulting in a gap in coverage. On the other hand, if the AV fails during CLIMBOUT, it is considered lost.

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[2]The equipment file for that particular AV records its status at every instant independent of the MRF, which records the status of the mission. Since the AV has already been fueled, etc., it is returned to the base load in the "prepared" status.

The remainder of states in Figure 1 through which the MRF would pass in this example are similar to those used from previously mentioned studies but with several refinements. CLIMBOUT occurs at a specified vertical rate until the AV reaches an altitude at which it begins to move towards the FLOT while continuing to climb. The transition point (dictated by AV altitude) from CLIMBOUT to TRANSIT OUT FRIENDLY is calculated based on an input specifying AV altitude when crossing the FLOT (or the on-station altitude if the mission is not over enemy territory). Another input to the program governs how far the AV moves during each time increment while in transit.

The MRF state becomes TRANSIT OUT FOE when the AV crosses the FLOT, beyond which it is vulnerable to enemy fire. Probability of survival is calculated during each time increment beyond the FLOT, whether on station or in transit. If the RPV is killed, a new MRF is immediately generated to replace it.

HANDOFF is assumed to take place at a specified distance beyond the FLOT (see paragraph G.12 in this chapter), where the TADAR mission is assumed to start. The MACS CGCS relinquishes control of the AV, taking some time and with a specified probability of success, while the FGCS assumes control. Normally, this procedure will occur simultaneously with a handback of the returning AV having just completed its time on station.

After HANDOFF, the MRF goes to PERFORMING MISSION. Whether an AV performs its mission at a relatively stationary point or over a wide area at varying altitudes is irrelevant to the simulation, since time of coverage provided is the critical parameter sought.

PERFORMING MISSION time is finished when the AV has enough fuel to make it back to the CL&R section without using any reserve fuel, assuming no unexpected situations arise on the way back. Before HANDBACK to the MACS CGCS can commence, the MRF may spend some time in AWAITING HANDBACK as it waits for a beam to become available. Since a returning TADAR RPV has the highest priority, it should receive the first beam that becomes available under any circumstance. Normally, it simply uses the beam made available by the outbound replacement AV.

Once HANDBACK is complete, the MRF moves through TRANSIT BACK states of FOE and FRIENDLY, shedding the likelihood of being killed as it crosses back over the FLOT towards the recovery area. TRANSIT BACK occurs at a slower velocity than TRANSIT OUT because the RPV is descending at virtually idle engine speed after crossing the FLOT.

When the AV reaches the recovery area, the MRF is put in AWAITING NET to check for the availability of a recovery subsystem. If more than one AV requires recovery, the one with the least fuel remaining gets priority.

D. DESCRIPTION OF MISSION SETS

The baseline mission sets to be examined with the computer simulation are designed with three primary purposes:

- To measure the sensitivity of MACS operational effectiveness to the number of simultaneous missions it is required to sustain
- To determine the overload point, at which there is a sharp decline in system effectiveness due to workload
- To provide a data base from which to postulate and compare methods of enhancing operational effectiveness of a MACS.

The mission sets are summarized schematically in Figure 2 and described as follows. Each mission number in the figure comprises one computer run with hundreds of missions flown over a period of days.

	MISSION NUMBER													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TADAR	●	●	●	●	●	●	●	●	●	●	●	●	●	●
HS		●		●		●		●		●		●		●
ALTERNATE 1 (RR)			●	●	●	●	●	●	●	●	●	●	●	●
ALTERNATE 2 (MTI)					●	●	●	●	●	●	●	●	●	●
ALTERNATE 3A							●	●						
3B									●	●	●	●	●	●
ALTERNATE 4A											●	●		
4B													●	●
MISSIONS PER DAY														
WITHOUT HS	48		53		61		66		69		75		81	
WITH HS		64		69		77		82		85		91		97

Figure 2. Baseline Mission Sets

First, the TADAR RPV mission is examined by itself. It includes handover of AVs from the CL&R facility to four forward GCSs while the AV is over the target area. Continuous mission coverage is desired in each of the four target areas for a division. AVs with the TADAR mission payload have enough fuel for a 3-hour flight plus a 15-minute reserve. Alternate payloads discussed below have differing weights, causing mission endurances to vary due to more or less fuel available on board. Endurances used in the model as stated in the following paragraphs are representative of how the associated payloads would affect mission times but are not necessarily accurate at this time. As payload development programs mature, more accurate estimates of endurance will become available.

That basic mission is also examined in run number 2 with the addition of an orbiting hot spare (HS) continuously on station 10 kilometers on the friendly side of the FLOT until called to replace an RPV lost due to enemy action or other causes. Based on SPC's previous analyses, the hot spare can be expected to greatly reduce the replacement time for lost AVs, thereby increasing the fraction of mission coverage, but at an expense of more complex central facility operations, increased maintenance requirements, and possibly more AVs in the base load.

Subsequent baseline mission sets involve the cumulative addition of RPVs with alternate mission payloads to the basic TADAR mission set (with and without a hot spare) described above. The alternate mission payloads represent a generic set of potential RPV missions characterized by continuous operations. They are distinguished from one another for the purposes of the simulation primarily by their mission altitude, penetration or non-penetration of the FLOT, and mission endurance. For the purposes of this study, all alternate missions are assumed to be controlled from the MACS CGCS. In practice, the FGCS may conduct a variety of these missions in addition to the TADAR mission, at the direction of the division commander.

The first alternate to be added is a radio relay (RR) mission (runs 3 and 4). The requirement is for continuous on-station coverage for radio relay RPVs orbiting 10 kilometers on the friendly side of the FLOT at an altitude of 10,000 feet. Each AV has enough fuel for 5 hours on station plus travel to and from the orbit point and reserves.

The third pair of runs adds a moving target indicator (MTI) radar mission as a second alternate to the RR and TADAR sets. The MACS CGCS will guide the MTI RPVs to a mission altitude of 10,000 feet and up to 30 kilometers beyond the FLOT, receiving MTI video data through the MICNS data link from each on-station RPV. Fuel is provided for a 3-hour on-station time plus travel and reserves. Continuous mission coverage is desired.

The final baseline mission set (runs 7 through 14) involves two alternate RPV missions that are added to the above mission set at four different request rates. The mission payloads for these alternates are unspecified, but their mission profiles are the same as either the RR or MTI profiles described previously. The configurations to be examined are as follows (all include with and without TADAR hot spare):

Runs 7, 8 — Add to the TADAR, RR, and MTI missions a third alternate (called 3A) that, like the RR, orbits at an altitude of 10,000 feet, 10 kilometers on the friendly side of the FLOT. Its on-station time is 5 hours and continuous coverage is specified. This mission adds about five extra launches and recoveries per day to system operations in runs 6 and 7.

Runs 9, 10 — Instead of the above, add alternate 3B, whose mission payload and station orbit point are the same as for alternate 3A, but whose on-station time is 3 hours. This adds eight extra missions per day to runs 6 and 7.

Runs 11, 12 — To alternate 3B, add a fourth alternate (4A), which, like the MTI, penetrates to 30 kilometers beyond the FLOT at a mission altitude of 10,000 feet. Its on-station time is 4 hours for an additional load of six missions per day more than runs 9 and 10.

Runs 13, 14 — Instead of using 4A, add an alternate 4B with the same mission profile as 4A but with an on-station time of 2 hours. This adds 12 missions per day to runs 9 and 10.

The effects of these four mission mixes are first, to gradually increase the number of RPVs that the launch and recovery equipment must handle each day, and second, to add two extra missions that the MACS CGCS has to control with its total of eight beams. Figure 2 shows the total number of missions flown per day in each scenario under ideal conditions (no failures or AV kills). Run 14 has double the number of missions as the first run. The object is to determine the point at which system performance begins to degrade due to excessive workload.

In addition to the 14 baseline mission configurations described, a number of excursion runs will be performed to examine the sensitivities of MACS operational effectiveness criteria for various input parameters. For example, there are excursions that examine the effects of adding a third L&R set and a third CGCS to the MACS complex. The purpose is to investigate methods of enhancing system performance. Therefore, the excursion runs are based on outputs from the baseline runs. The excursions and their results are discussed in detail in Chapter III, after baseline results are evaluated.

E. EFFECTIVENESS CRITERIA

System effectiveness is evaluated in four categories. Three of these--mission coverage, queueing delays, and RPV losses--are computer simulation outputs; the fourth--relative operational and organizational (O&O) cost--is a separate analysis and is discussed in Chapter IV.

Mission Coverage: For TADAR missions, mission coverage is the percentage of time spent over the target area defined in the inputs. Two quantities are calculated in the simulation. The first, called absolute mission coverage, is the total time achieved over the target area by all TADAR RPV missions, normalized to a single mission (divide by 4) and taken as a percentage of the total clock time. The second is relative mission coverage, which is the same time-over-target value but taken as a percentage of the net time that forward GCSs are emplaced and operational.

For other mission types, absolute coverage is calculated using time-on-mission or time-on-station data, whichever is applicable. Relative coverage is not calculated for missions controlled by the MACS, since at least one CGCS is expected to be emplaced and operational at all times.

Queueing Delays: When the workload is temporarily greater than a piece of equipment can efficiently handle, queues develop that cause time delays in delivering RPVs to their intended destination. These delays are manifested as gaps in mission coverage. The program calculates the following six queueing delays for insight into the source of degraded coverage values for a particular mission configuration.

- RPV assignment: the time from generation of a mission request to assignment of an AV to the MRF (time spent in AWAITING AV). If this delay is long, the available base load is probably too small.
- Launcher assignment: the time from completion of preflight preparation to assignment of a launcher to the MRF (time spent in AWAITING LAUNCHER). If long, the available launchers cannot efficiently handle the launch load.
- Launch beam: the time an AV spends in the state ON LAUNCHER AWAITING BEAM. A long delay here indicates the CGCS needs more than eight beams to effectively control RPV operations.
- Handback beam: the time spent in AWAITING HANDBACK. If long, the inference is the same as above but probably more severe, since a returning RPV has highest priority.
- Net assignment: the time spent in AWAITING NET. If long enough to approach the 15-minute reserve fuel limit, the potential for losing RPVs increases.
- Overall launch delay: the total time from mission request to the launch of an AV. This does not include expected time spent in preflight preparation and prelaunch checkout. Whereas the previous five delays flag specific areas of concern, this overall quantity can indicate in general if low mission coverage is related more to operations at the MACS facility or equipment reliability and enemy action.

RPV Losses: The third category of mission effectiveness criteria is the total number of AVs lost for all reasons, which include enemy action, running out of fuel, and a critical equipment or procedural failure while the AV is in flight. The former would apply only to missions that penetrate the FLOT, i.e., TADAR, MTI, and Alternates 4A and 4B.

Relative O&O Cost: The discussion of this category (Chapter IV) weighs mission performance benefits gained with certain mission configurations against the relative cost of personnel and equipment required for each.

F. ASSUMPTIONS

The computer simulation is built around a number of assumptions that describe how a MACS would operate in the field. Operational procedures and equipment data that are currently available from the RPV program are incorporated. Since the MACS concept is still being developed, however, a portion of this information is the result of engineering judgment on the part of the RPV PM, RPV TSM, CACDA, JPL, CSTAL, and SPC.

This section contains a discussion of the assumptions used. They are included if deemed significant to the logic of the simulation, i.e., peculiar to MACs; a change from the current concept, though not necessarily peculiar to MACS; or necessary for emphasis or clarification. Where appropriate, the discussion includes a justification or rationale behind the assumption and how it is expected to affect the simulation. Whereas this section is dedicated to procedures and operational logic, the next section covers the actual input values used in computer runs.

1. Continuous Operations

The statement of work for this study calls for continuous mission coverage as the desired mode for standard MACS operations, which includes all TADAR, HS, RR, MTI, and alternate missions. This is the most stringent operational condition and is unlikely for extended periods of time on the battlefield. However, during surge situations, continuous coverage by any or all of the missions above may be required for short periods. Consequently, the simulation is structured to portray MACS at peak demand levels.

Since the RPV system was designed to operate three 3-hour missions in a 12-hour day (television package), simulating continuous mission coverage for a 24-hour day will cause many more equipment failures and lost AVs than originally intended. The results section has a more specific discussion on this topic.

2. RPV Priorities

When more than one RPV requires service at the same time, priorities establish the order in which they are serviced. For the purposes of this simulation, the system is assumed to be one in which TADAR missions are the first priority activity. On the battlefield, such priorities are at the discretion of the division commander and may be changed periodically to suit specific objectives. The following list of RPV operational conditions requiring service starts with the highest priority.

- RPV with lowest fuel requiring recovery net
- TADAR RPV with critical fuel level requiring handback beam
- TADAR RPV from displacing FGCS requiring handback beam

- TADAR RPV requiring launcher
- Alternate RPV with continuous coverage specified requiring launcher
- Hot spare requiring launcher
- Alternate RPV with noncontinuous coverage requiring launcher.

As an example, if an MTI RPV (i.e., continuous alternate) is in AWAITING LAUNCHER and a TADAR RPV destined to replace another near the end of its mission time enters the AWAITING LAUNCHER state also, the first available launcher will go to the TADAR AV. However, if the TADAR AV is to replace a hot spare nearing the end of its on-station time, the MTI AV would get the launcher. Once on the launcher, an RPV will not be unloaded for one with a higher priority.

3. MACS Control of Eight AVs

The MICNS data link is postulated to provide discrete addresses and a time-division multiple-access (TDMA) structure for control of up to eight AVs simultaneously. The simulation treats the MACS central facility as having this capability as a maximum regardless of the number of CGCSs at that facility. In theory, each CGCS would be able to control eight AVs by itself. When two CGCSs are colocated and operational, their combined capabilities presumably would represent control of up to 16 AVs at a time. It is beyond the scope of this study to address the technical feasibility of that condition (e.g., frequency allocation for 16 discrete addresses from the same facility); however, the operational considerations should still constrain the number of AVs to eight.

First, the tactical commander would limit the total number of AVs in the air under MACS control to the maximum that one CGCS could handle in the event the other CGCS failed. The operational ground station could then regain control of all AVs without exceeding its own capacity. If only one CGCS remained in operation and more than eight AVs were allowed in the air at a time, the amount over eight would be lost.

Second, when the CGCSs must displace, there is virtually no effect on system operations, since the displacing ground station can hand control of its AVs to the one remaining at the site. When the first CGCS is in place and operational at the new location, it coordinates with the CGCS at the old site to regain control of all current airborne RPVs before it displaces. If control of more than eight AVs were allowed between two CGCSs when they were colocated, special procedures would need to be implemented to recover the excess AVs when one displaces.

If a third CGCS is added to the MACS facility, one could argue that the tactical commander would now allow 16 airborne AVs, since failure or displacement of one ground station would still leave two others to handle all the AVs. However, again putting aside the technical questions, this study assumes that the purpose behind including a third CGCS is to avoid the catastrophic occurrence of one CGCS failing while the other is displacing. Therefore, control of eight AVs is still the maximum allowed with three CGCSs per facility.

The simulation does not consider the possibility that more than eight AVs could be airborne under MACS responsibility if some were in a dead-reckoning or "park and fly" mode, where direct control of those AVs does not exist for a period of time. Periodic status updates would have to be sent back to the CGCS in order to maintain a fix on the current AV position. That would require an AV identification address for the GDT to communicate with the AV, just as with the other AVs under continuous control. This is beyond the current capabilities of the MICNS data link, which allows for eight discrete addresses.

4. CGCS Operations

Colocated CGCSs act as a single entity, exchanging data concerning each other's activities and the status of all controlled AVs. The failure or displacement of one results in immediate acquisition of its AVs by the remaining operational stations. The probability of success for this type of acquisition is assumed to be unity.

For the purposes of the simulation, CGCSs operating at separate locations but part of the same MACS platoon act as a single entity also. Therefore, after one CGCS becomes newly emplaced and the second station is in the process of displacing, it is assumed that the third still at the old site can communicate with the first as if they were colocated. Clearly, this is an idealized situation, since data communications between remote ground stations would likely be less effective than communications via cables between two that are colocated. However, data commonality between a CGCS and a sister station at a distant location will be necessary if continuous operations are to be achieved, even with two CGCSs.

If only one CGCS is operational and it fails, all airborne AVs under its control are lost. With continuous operations, this type of catastrophic failure will be unavoidable with only two ground stations per MACS complex. A more complete discussion of this event and of the effect of the third CGCS is contained in the results.

Within the MACS central facility, CGCSs are assumed to act relatively independently of one another with respect to their associated launch and recovery equipment. Therefore, if a CGCS fails, the L&R systems attached to it become unavailable for use.

5. Displacement

The number of displacements per day for both the FGCSs and CGCSs are specified in the input parameters. The simulation, however, handles this activity differently for the two kinds of ground stations. FGCS movements are modeled stochastically, so that a particular FGCS could displace at any time of day but would average the input number of moves per day over a long period of time. The probability of a move in any time period is modeled as a geometric distribution with a specified mean time between moves. An FGCS could potentially begin displacing within minutes after it completed a previous emplacement and then wait several days before moving again. Those types of short and long time increments would be low probability events if the mean time between displacements were, for example, 12 hours. The stochastic model is more representative of a fluid battle situation, in which regular moves for units close to the FLOT are more the exception than the rule.

On the other hand, CGCS displacements are modeled deterministically, with a fixed time increment between moves. This represents a more stable condition for units far from the FLOT, whose movements are primarily designed to stay one step ahead of the enemy's intelligence on current locations.

In both of the above cases, the simulation considers no warning of an impending move prior to march orders being issued. The effect on the model is that ground stations cannot schedule operations based on knowledge of an upcoming move, though some advance notice may be available in a real situation. Operations are abruptly curtailed and redirected when a displacement order is received so that teardown can commence as soon as is practical. Teardown times used in the inputs, however, do reflect that forewarning will be available to the sections to some degree.

TADAR AVs that are on station when an FGCS must displace are immediately put into a state awaiting a MACS beam for handback so the FGCS can be free to commence teardown. This happens regardless of the time that AV has already spent on station.[3] AVs under MACS control when a CGCS is told to move are immediately transferred to another CGCS's control if one is available. Otherwise, a CGCS cannot displace until another station becomes available (i.e., repairs are complete).

6. Utilization of MACS Beams

Aside from the items discussed under assumption paragraph 3, there are several other guidelines for the use of the eight available beams per MACS complex. The first time an MRF requires a beam is when prelaunch checkout begins. The beam is then assigned to that mission throughout prelaunch, launch, climbout, etc., until the AV is handed off to an FGCS, recovered, or lost due to failure or enemy action. In actual RPV operations, the RGT

[3]See Assumptions paragraph 10 for fate of AVs that still have plenty of fuel remaining when their associated FGCS aborts mission due to displacement.

beam is not required for the duration of prelaunch, but the MACS simulation assumes that beams are not switched from mission to mission, even during prelaunch. A TADAR mission being handed back from an FGCS is assigned a beam for the remainder of its flight and recovery sequence.

Handovers of AVs are modeled differently depending on whether a one-way or two-way handover is being attempted. A one-way handoff or handback (only one AV is involved) requires coordination between the CGCS and FGCS throughout the procedure until the receiving party confirms positive control of its newly acquired RPV. One MACS beam is required for the duration of the procedure. In a two-way handover, where the FGCS and CGCS are exchanging depleted and replacement TADAR mission AVs, the FGCS places its AV in a dead-reckoning[4] mode at the handover point, relinquishing control. The FGCS then coordinates with the CGCS to assume positive control of the replacement AV. When the CGCS has completed transfer of AV control to the FGCS, it then acquires the dead-reckoning AV to bring it back to recovery. Again, only one MACS beam is required for the procedure. The coordination between MACS and the FGCS is assumed to be sufficiently accurate and timely that the CGCS's acquisition of the dead-reckoning AV has the same probability of success as a positive control one-way handover. No time delays for data link reacquisition are included.

If the replacement AV is late in arriving, such that the mission AV is too low on fuel to remain on station any longer, the FGCS will begin AV transit under its control back toward the recovery area. If the replacement AV reaches the mission area before the returning AV reaches the recovery area, handoff and handback will commence at those separate points as described above. The CGCS acquires the returning AV en route, wherever it happens to be.

If the replacement AV is very late in arriving (due to excessive delays in launching), such that the returning AV reaches the recovery area under FGCS control, the latter AV is placed in orbit at the recovery site, awaiting a MACS beam for recovery. Meanwhile, the FGCS acquires the outbound AV en route to the mission area. Other instances where the FGCS will acquire an outbound AV before it reaches the standard handoff area are after the FGCS is freshly emplaced or after it has lost an AV; in other words, when the FGCS has no AV to exchange. This procedure frees up a MACS beam several minutes earlier than normal, allowing it to be used elsewhere.

Replacement of AVs that are always under CGCS control does not involve handover. Therefore, two MACS beams are required during the replacement procedure--one to control the on-station AV at all times, and the other to direct the transit of the replacement AV to and from the station point.

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[4]Note how this use of dead reckoning differs from that prohibited by the discussion in Assumption paragraph 3.

7. Mission Payloads

For the purposes of the simulation, all TADAR mission payloads are assumed to be of the same kind, which implies FLIR packages, since day and night operations are conducted. In practice, RPV platoons will likely use a mix of FLIR and television (TV) payloads to perform TADAR missions. This study does not address how such a mix would affect AV base load quantities or TADAR mission performance.

Payloads are interchangeable; that is, a TADAR, MTI, RR, or any alternate payload can be installed in the standard Aquila airframe and exchanged with any other payload as needed. As advanced payloads are developed for the RPV system, design efforts focus on modular payloads so that the number of total AVs in the CL&R section base load can be minimized. Currently, the interchange times are long enough (see inputs) that such a reduction in base load may not yet be realized, because frequent payload interchange could cause unacceptable delays in filling mission requests. The simulation is structured to accept an interchange action, but only as a last resort.

8. Base Load

In view of the preceding discussion, the base load for the MACS CL&R section is designed so that interchanging payloads in AVs will rarely be required. One of the primary assumptions in determining base load size was that enough of each type of RPV must be on hand to supply the section when it is depleted because of AV loss and is expecting resupply and when one CGCS must displace, taking half the available base load with it. Since the simultaneous occurrence of those circumstances is relatively uncommon, they define a base load size that should be adequate except under very infrequent conditions (e.g., failure of the only operating CGCS with a resultant loss of up to eight AVs).

The size of the base load is also determined by the method in which AVs are transported by the CL&R section. In the current RPV O&O concept [Ref. 3], three AVs are carried on each air vehicle cargo truck and two AVs on each AV handler. Those quantities are constrained by the size of RPV shipping crates, whose dimensions are in turn dictated by handling and packaging specifications. It is not expected that the crates will be made smaller to accommodate more AVs per truck. Therefore, the total number of AVs carried per MACS complex must fit the equation 2H + 3C, where H is the number of air vehicle handlers and C is the number of air vehicle cargo trucks. For a MACS with two L&R units (two AV handlers), the possible base load sizes are 4 + 3C, or 4, 7, 10, 13, 16, 19, etc. With three L&R units, the allowed number of AVs is 6 + 3C, or 6, 9, 12, 15, 18, 21, etc. The number of each type of RPV (TADAR, MTI, etc.) must in turn satisfy the individual requirements of the different missions. See Chapter III for numbers of RPVs by type for each mission set run in the simulation. The inputs section also has an example calculation of base load for a specific mission mix.

When CGCSs displace, the rule determining how the base load is split between them is that the number of AVs of each type that is available (i.e., not assigned to an MRF) in the base load at the time of displacement is divided by the number of CGCSs; if the dividend is a whole number, the departing CGCS takes that quantity; if a fraction, it takes the next higher whole number of RPVs. For example, from a total base load of 16 TADAR AVs, 5 of which may be airborne or otherwise assigned to an active MRF, and 2 of which may have been lost to enemy action, a total of 9 AVs is available in the base load when one of the two CGCSs must displace. It takes five AVs with it. As another example, suppose the total base load and current assignments for a MACS with three CGCSs is broken out as follows:

AV Type	Total in Base Load	Number Currently Assigned	Number Lost Until Next Resupply	Number Available on Ground
TADAR	14	6	1	7
MTI	4	1	0	3
RR	3	2	0	1
Alternate #3	3	1	0	2
	24			

The displacing CGCS would take one-third of the available number, or three TADAR AVs, one MTI, one RR, and one Alternate 3.

9. Resupply

Neither the criteria for initiating air vehicle resupply nor the process for accomplishing it have yet been determined for the current RPV CL&R concept. An earlier SPC report [Ref. 2] postulated the mechanisms and timelines involved. Though not approved, the SPC timelines have been recommended by the RPV TSM as acceptable speculations at this time.

Briefly summarizing the referenced report, resupply will be accomplished in the following manner: when three AVs have been lost due to equipment failure, enemy action, or running out of fuel, one AV truck is free of cargo. The empty truck is dispatched, with a driver and assistant, to the AV supply point to exchange the three empty AV containers for full ones. The supply point has not been determined, but is assumed at DISCOM. After getting his load of AVs, the driver will make his way back towards the CL&R section. Since the section will almost certainly have moved since his departure hours ago, the driver must find the new location. The whole process is likely to take several hours because of slow travel times on wartime roads. The aspects of this procedure that are pertinent in the simulation are that resupply is triggered by the loss of three AVs of any type, takes a fixed amount of time dictated by distance to the supply point (see inputs), and is always delivered to the most recently emplaced CGCS in the same proportions as were lost. For example, if two TADAR AVs are lost to enemy fire and one MTI AV crashes when it fails in flight, the same combination of payloads in AVs will be delivered upon resupply.

The resupply mechanism for payload packages independent of air vehicles is not considered in the simulation. Payloads are supplied in air vehicles on a one-for-one basis to those lost, and if spares or parts are needed for any reason, there is extra room in the AV cargo truck to bring back those items from DISCOM after its three new AV crates have been loaded.

Finally, the simmlation considers the supply of AVs and payloads at the supply point to be unlimited. Clearly, the number of AVs and payloads planned in the total RPV procurement will dictate how many each supply depot can store (or conversely, the expected rate of wartime AV losses will be a factor in calculating procurement quantities), but delays in resupply due to shortages at the supply point are not modeled here.

10. Hot Spares

Hot spares are intended to replace TADAR missions that are aborted due to AV failure, payload failure, or AV kill. Their purpose is to reduce the replacement time to minutes rather than the hour or so it takes to generate a new mission request, prepare the AV, launch and transit it to the mission area. It is assumed that hot spares are not for replacing TADAR missions that are nearing time to return for recovery, nor for filling new mission requests generated by a freshly emplaced FGCS. Other mechanisms are designed for those purposes.

For mission sets that specify use of the HS, the simulation assumes one HS to be continuously on station. There are instances where more than one HS may be on station at the same time. That happens when an FGCS is given notice to displace and its mission AV has been on station only a short time. The AV is sent to the HS orbit point instead of being sent back for recovery. If it is not used before its fuel gets to a predetermined level, the AV returns to the CL&R site. In this way, the aborted mission AVs can potentially be used more efficiently.

Chances are the type of HS described above will rarely be used when the probability of TADAR AV survival is high and an HS is continuously on station anyway. TADAR mission AVs will be killed relatively infrequently; when one is, there should nearly always be a standard HS on station to replace it. However, if the survival probability were low, this "abort" HS procedure will alleviate the load on the standard HSs.

11. Initialization

At the beginning of each computer run, operations are set in motion through a series of actions that loosely emulate how a MACS platoon might begin operations from scratch. During the first time increment, one CGCS and one FGCS are considered newly emplaced. The CGCS has its attached L&R equipment and is ready for operations with the entire specified base load of AVs. The FGCS requests its first mission, and the CGCS complies. Each half-hour thereafter, the other FGCSs emplace one by one and request their first mission until all four FGCSs are operating.

Meanwhile, the second CGCS emplaces some time after the first, equal to the time one CGCS would take to tear down, move, and become operational (see inputs). The third CGCS will emplace the same amount of time after the second.

When other missions besides TADAR are included in the run, they are also launched during the first 2 hours as the TADAR missions are being serviced. Figure 3 shows when the GCS emplacements, requests, and launches occur for the first of each mission type in a fully loaded scenario (i.e., all payloads being played). Mission requests are scheduled 15 minutes apart to allow ample time for one launcher to handle AV loading, prelaunch checkout, and launch without incurring delays over many successive launches (unless the equipment fails).

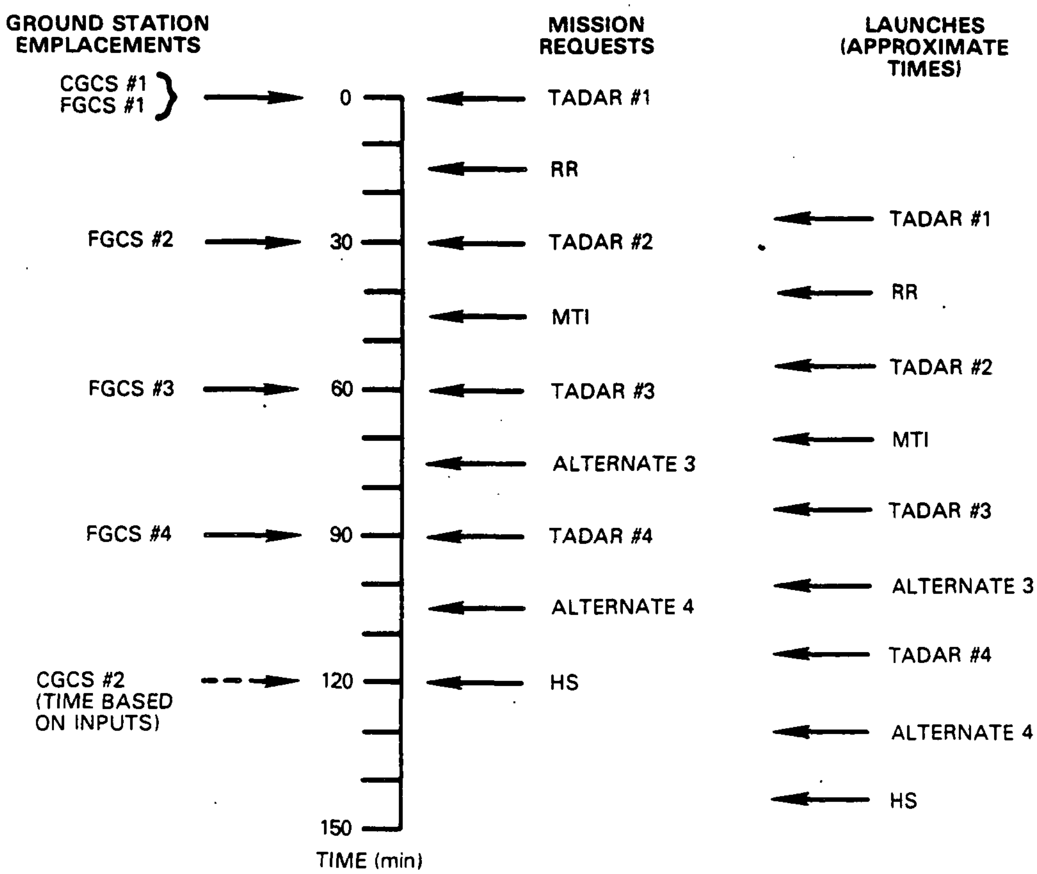

Figure 3. Initialization of MACS Operations

After about 2-1/2 hours, all CGCSs and FGCSs are emplaced (if two CGCSs are played) and all possible missions are airborne. Normal continuous operations are in effect, with missions regenerating themselves. Transient effects resulting from this initialization period should be negligible if the simulation is run long enough.

12. Mission Planning

It is assumed that all activities concerning mission planning at both the broad level (e.g., what type of mission is required, where is coverage needed most) and the detailed level (e.g., flight profile parameters and waypoints) can be performed concurrently with other activities in preparation for a mission. Therefore, mission planning timelines do not impact mission performances achieved in the simulation, except for the first mission after FGCS or CGCS emplacement, as discussed in paragraph G.4.

G. INPUTS

This section lists and discusses the specific input parameters and their values for the baseline runs. There are two types of inputs: those that remain constant for all baseline runs and those that change and form the distinguishing features of the baseline outputs. The values associated with the latter type are given on a case-by-case basis in Chapter III, where inputs for excursion runs are also discussed.

1. Equipment Reliability

The RPV Required Operational Capability (ROC) [Ref. 4] and Prime Item Development Specification (PIDS) [Ref. 5] list reliability minimum acceptable values (MAVs) for each major subsystem of the original RPV system. These numbers are used for all MACS baseline runs. Excursion runs will examine the effects of using a set of updated reliability numbers expected by the contractor to more accurately represent system performance (see Chapter III).

The simulation incorporates the reliability figures as a constant probability of failure during each time interval that a particular piece of equipment is in operation. The values are as follows:

- GCS: FGCSs and CGCSs are considered equivalent with respect to reliability. The PIDS states that the GCS and GDT shall have a combined MAV of 0.92 of completing 10 hours of continual operation without a mission-affecting failure. The rate applies here to either type of MACS ground station while it is emplaced and operational. FGCS failure will cause the loss of an AV under its control at the time. CGCS failure will cause transfer of airborne

AVs to an operational CGCS, or loss of all AVs under its control if no operational CGCS is available.

- Mission payload: All RPV payloads for MACS are assumed to have the same reliability. In practice, some will be simpler than others and less likely to break down. Since values do not exist for advanced payloads still in the conceptual phases of design, reliability numbers for the TADAR television payload are used for all mission payload types. The ROC specifies a mean time between failure (MTBF)[5] of 150 hours, which applies to all payload independent failures that would cause a mission abort while the AV is airborne. Therefore, a payload could fail during AV climbout, but it may not become apparent to the GCS operators until the AV is on station and commanded to perform. At that point, it would be sent back and a new MRF generated. Failures while not airborne are not considered.

- AV: The PIDS states that the AV, less mission payload, shall have an MAV of 0.98 of completing 3 hours of continual operation without a mission-affecting failure. This only applies while the AV is airborne, so a failure results in an AV loss.

- Launcher: The PIDS specifies an MAV of 0.99 of completing a launch without a mission-affecting failure. This reliability is assumed to apply over a period of 27 minutes, which is the time provided by Lockheed to complete one full cycle of setup, launch, and teardown. In the simulation, launcher failure is only possible during the prelaunch checkout and awaiting launch beam phases (since "launch" is a zero-time event) and only when the CGCS to which the launcher is attached is emplaced and operating. Launcher failures do not cause AV losses.

- Recovery subsystem: The PIDS specifies an MAV of 0.99 of completing a recovery without a failure that would prevent the subsystem from being recycled for use within 5 minutes (in case of a recovery abort and go-around). This number is taken literally as meaning out of every 100 recovery attempts, the recovery subsystem will fail once. It does not result in an AV loss, however. If the recovery net can be erected, an RPV can be recovered (provided that the GCS or AV does not fail during recovery). A failure in the infrared recovery guidance mechanism on the net will be detected by the AV, and it can go around for a try on the other net. Alternatively, an AV can be guided into the net by the AV operator using its own television mission payload as a viewer. In the simulation, the recovery subsystem can fail any time during the recovery attempt, resulting in a successful recovery and an inoperable net requiring maintenance.

[5]The program converts all reliability numbers into MTBFs.

2. Equipment Maintainability

The ROC specifies that the RPV system be designed so that 90 percent of all failures can be detected and corrected by technicians at the section level with a mean time to repair (MTTR) of 30 minutes. The remaining 10 percent of the failures require repairs by a technician from the general support maintenance unit with an MTTR of 2 hours. These numbers are used in the baseline runs for all MACS equipment repairs. Revised maintainability numbers will be examined in excursion runs.

The details of how general support maintenance will be provided have not yet been decided. One proposal is that contact teams will respond to calls from the RPV sections. In a battle situation, the division general support maintenance could be expected to provide a contact team to the RPV sections supporting the division in a reasonably short period of time. In this study, it is assumed that maintenance teams will respond to the CL&R section in 1 hour. Response by the brigade support teams to the operations sections will also be 1 hour. These travel or response times are added to the repair times for a total MTTR of 3 hours when general support maintenance is involved.

3. Displacement Intervals

FGCSs and CGCSs both are assumed to displace twice per 24-hour period on the average, as recommended for this study by the RPV TSM. FGCS movements are stochastically determined while CGCSs will move every 12 hours, as explained in the assumptions.

4. Displace/Travel/Emplace Timelines

The O&O concept for RPV operations with independent sections (i.e., no CL&R facility) describes timelines for displacement and emplacement activities of the ground complex. Teardown should be achieved in 30 minutes, and emplacement at the new site should be completed in 60 minutes.

In the MACS concept, forward and rear ground stations have different equipment and responsibilities than in tbe original concept, thus timelines are also different. The forward operations sections are far less complex without launch and recovery equipment, an air vehicle handler, and maintenance shelter. Teardown is assumed by the authors to be only 15 minutes. Emplacement is decreased to 45 minutes to reflect less equipment duties but retain the relatively long mission planning responsibilities to prepare for the first mission at the new site. Add to these times half an hour for travel time within the brigade area, for a total of 1-1/2 hours for the forward sections. This does not take into account the displacement timeline of the forward division element being supported by the RPV section, which may dictate RPV movement times more than activities within the section itself.

The CL&R complex has much the same equipment as in the original RPV sections, but is not assumed in this study to have the responsibility to do detailed mission planning upon emplacement. Its mission planning may consist of selecting several way points for climbout and transit routes, which could become somewhat standardized within a division. Teardown is assumed to remain at 30 minutes and emplacement to be decreased to 30 minutes. Add travel time of 1 hour to a new site in the rear division area for a total of 2 hours for CL&R sections. An excursion with longer timelines is described in Chapter III.

5. Probability of Survival

Only AVs that penetrate the FLOT (those on TADAR, MTI, and Alternate 4 missions) are exposed to enemy fire and subject to being killed. In view of the most recent RPV survivability studies (e.g., Ref. 6), the RPV TSM recommended using in the simulation a probability of survival of 0.95 for TADAR missions. Since the other missions mentioned are at a higher altitude, out of range of the most numerous and threatening enemy weapons, a value of 0.97 was recommended for those mission survivability rates.

This will cause a dramatic reduction in the number of AVs lost during continuous operations when compared to the survival probability of 0.75 used in previous RPV studies. Now, 1 in 20 missions will lose an AV to enemy action instead of 1 in 4. Excursion runs will examine the effects of AV survivability and compare with baseline results.

6. AV Transit Speeds

During transit out to the mission area, AVs are assumed to fly 150 kilometers per hour, whether in level flight or climbing while transiting. The return trip to the recovery area is flown at 130 kilometers per hour to account for AV descent at low engine speeds once the FLOT is crossed. Speed while on mission is not a factor, since time on mission is determined by minutes of fuel available.

7. Rate of Climb

AV climb rates provided by the RPV PM office vary according to the environmental conditions and AV weight, which varies among different payload packages and decreases as fuel is expended during a mission. Since climbout usually takes place at the beginning of a mission when the fuel level is high, a "heavy-AV" climbout rate was chosen. The fixed rate used for all AVs in the simulation is 250 feet per minute, which is at the high end of the PM estimate for a heavy AV at an altitude of 4,000 feet on a 95-degree day.

8. MACS-to-FLOT Distance

Baseline runs have the MACS complex located 35 kilometers from the FLOT. The principal effects of this distance on the simulation are reflected in the time for resupply to be accomplished, the time for general support maintenance teams to travel to the section, the number of times the central facility must displace to confuse enemy location techniques, and possibly the amount of time from AV launch to arrival on station. These effects are examined in more detail in excursion runs and are discussed in Chapter III. Ground station vulnerability is also affected by this distance, but is not considered in the simulation.

9. AV Cargo Truck Capacity

The nominal number of AVs that can be carried on a 5-ton cargo truck is three, as discussed previously. This number was made an input to the simulation to allow the flexibility to examine the effect of increasing the load per truck. However, in conversations with the RPV PM office, this possibility was discounted due to handling and shipping constraints that will not allow for any significant reduction in the size of AV shipping crates used now. Furthermore, the increased AV survivability rates recommended for this study probably minimize any anticipated benefits of a larger resupply load, and may in fact show a larger load to be detrimental to mission coverages while waiting for a resupply truck to become empty. Therefore, no excursions concerning this topic are included.

10. Resupply Time

Previous SPC studies have estimated AV resupply to an RPV CL&R section to take 6 to 10 hours using a supply point in the rear division area. Conversations with the RPV TSM indicate this estimate is still supported. In the belief that an optimal procedure will be developed for this critical action, this study uses a fixed resupply time of 6 hours. Excursions will examine the effect of faster and slower times on mission performance.

11. Scheduled Activities

Several stages of a typical RPV mission have fixed timelines within a computer run, each specified by an input.

- Preflight preparation: This includes the time to check out the AV at the maintenance shelter, fuel it, and transport it to the various stations within the ground complex. AVs are assumed removed from their storage containers concurrently with other emplacement activities, and therefore it is not part of the preflight timeline. Preparation will vary with each AV; for example, an AV just recovered may not need to undergo checkout at the maintenance shelter under all circumstances. The simulation assumes that RPVs will be maintained in a "ready" state to some degree, so that when a mission is requested, only 5 additional minutes will be required to prepare the AV before loading on the launcher. For the most part, a longer preparation time would go unnoticed because mission requests would simply be generated earlier to allow for the extra preparation time.

- Load launcher: It is assumed that under normal circumstances when the launcher workload is not heavy, forewarning of the next mission will be available to some degree. This will have the effect of the AV being ready early on the launcher. The simulation treats this as a load time of 0 minutes (or equivalently, a reduced preparation timeline plus 3 minutes to load) under those conditions. When the launcher workload is such that a queue has developed and one AV after another must be launched in succession, a load time of 3 minutes is included after a launch and before the next prelaunch checkout can begin.
- Prelaunch checkout: This is assumed to take 9 minutes, per the RPV PM, once the AV is loaded and engine started. For the simulation, it requires the full-time use of a CGCS beam. Prelaunch checkout concludes with a lauuch, which takes no time.
- Handover: It is expected that since handoffs and handbacks will become routine procedures for the current RPV CL&R concept as well as MACS, each will have a high probability of success (0.995) and take little time to coordinate and accomplish (2 minutes). A two-way handover consists of two 0.995 probability of success events, using a total of 2 minutes. An unsuccessful handover event is assumed to result in a lost AV.
- Recovery: The recovery sequence uses a total of 7 minutes. This is the time the recovery subsystem is dedicated to a single recovery event, including AV approach flight, retrieval from the net, and erection of the net for the next event.
- Payload interchange and installation: The time for these procedures varies with type of payloads involved. For example, current estimates are that removing a television payload and installing a FLIR may take 90 minutes, but removing the TV and installing a simple dispensor payload could only be half that time. The RPV PM office recommended average times of 60 minutes for interchange and 45 minutes for installation of a payload into an empty AV.

12. TADAR Mission Parameters

The following parameters determine the amount of time a TADAR mission AV will spend in the various stages of its mission.

- Mission area begins 10 kilometers beyond the FLOT. For the purposes of the simulation, this is where handovers are assumed to occur and the point at which TADAR AVs are considered performing their mission. The location for handover was chosen to facilitate maximum mission coverages and without regard to survivability. In practice, RPVs are more vulnerable while in a stationary orbit and would probably not be handed off over enemy territory. For the model, the location of handover does not significantly affect the results.

- On-station altitude is 2,000 meters. This is actually the altitude at which the simulation has a TADAR AV crossing the FLOT and transiting to the mission area. Fluctuations in altitude once in the mission area are not pertinent to time on station.
- TADAR fuel capacity is 180 "minutes." Fuel is deducted each time increment as a convenient way to track an AV's time until it must be recovered. Reserves add another 15 minutes of fuel to any stated AV capacity.
- TADAR fuel to return is 30 minutes. When the fuel reaches this level, it signals the simulation to immediately take the AV off station and bring it home. The 30 minutes includes 2 minutes for handback, 21 minutes to fly 45 kilometers to the recovery area at 130 kilometers per hour, and 7 minutes recovery time. Delays in awaiting a handback beam or at the recovery net will cut into the 15 minutes of fuel reserve. A similar value is calculated for each AV mission type.
- TADAR fuel level at which a mission request is generated for a replacement AV is 83 minutes. This includes 5 minutes for preflight preparation of the replacement AV, 3 minutes for launcher loading, 9 minutes prelaunch checkout, 13 minutes in climbout (to 950 meters altitude at 75 meters per minute), 14 minutes in climbout while transiting (at 150 kilometers per hour, climbing to 2,000 meters altitude at the FLOT), 4 minutes in transit to the mission area, and a 5-minute buffer time. If no delays are encountered, the replacement AV will arrive at the handover site 5 minutes before the mission AV reaches its fuel level to return.

13. Hot Spare Mission Parameters

When the HS is played, its required mission is continuous on-station, with the following mission parameters.

- On-station position is 10 kilometers on the friendly side of the FLOT. Therefore, it will take an HS 8 minutes to travel the 20 kilometers to replace a TADAR mission AV.
- On-station altitude is 1,700 meters. This allows the HS to climb to 2,000 meters while transiting the 10 kilometers to the FLOT when called.
- HS fuel capacity is 180 minutes, as with TADAR AVs.

- HS fuel to return is 67 minutes. This is dictated by a 90-minute on-station time, following a 13-minute climbout and 10-minute transit while climbing. Therefore, as a worst case, an HS could have 68 minutes of fuel remaining when called, transit 8 minutes to the TADAR mission area, leaving 60 minutes--30 of which are required to get home.
- HS fuel level to generate a replacement HS is 107 minutes. This includes time for preparation (5), loading launcher (3), pre-launch (9), climbout (13), and transit (10) of the new HS before the old one must return (67).

14. RR and Alternates 3A and 3B Mission Parameters

These missions have the same orbit points, but differ with respect to payload, on-station time, request frequency, and the fuel-level flag to generate the next MRF.

- On-station position is 10 kilometers on the friendly side of the FLOT.
- On-station altitude is 3,048 meters.
- Fuel capacity is dictated by on-station times for the three missions, which are 5 hours for the RR, 5 hours for Alternate 3A, and 3 hours for Alternate 3B. Add times for climbout (31 minutes), transit out while climbing (10), transit back (12), and recovery (7) to arrive at fuel allotted.
- Fuel to return is 19 minutes for all three mission types. It includes transit back and recovery.
- Fuel level to generate next mission is 87 minutes for all three mission types. The breakout is preparation (5), load (3), prelaunch (9), climbout (31), transit out while climbing (10), and a buffer (10) before the AV must return (19).

15. MTI and Alternates 4A and 4B Mission Parameters

These missions also differ with respect to payload, on-station time, request frequency, and the fuel-level flag to generate the next MRF.

- On-station position begins 10 kilometers on the enemy side of the FLOT. Missions may penetrate further, though the simulation does not play that feature.
- On-station altitude is 3,048 meters. However, these AVs are considered to cross the FLOT at 2,748 meters and continue climbing the extra 300 meters to station altitude while over enemy territory.

- Fuel capacity is again driven by on-station times of 3 hours for MTI, 3 hours for Alternate 4A, and 2 hours for Alternate 4B. Add times for climbout (23), transit while climbing (18), transit back (21), and recovery (7) for total fuel capacity.
- Fuel to return is for transit back and recovery, a total of 28 minutes for each of the three missions.
- The appropriate fuel flag for the replacement mission is 96 minutes in each case. The breakout is the same as in paragraph 14, with the extra 9 minutes due to the larger fuel to return value.

16. <u>Base Load Quantities</u>

The quantity of AVs in the base load was estimated for each mission set by considering the number of continuous missions airborne, the average number of AVs at any instant in time that are assigned to an MRF but not actually on mission, the frequency of AV losses, the resupply mechanism, and the effect of a displacing CGCS taking its share of the base load. One example should serve to illustrate the kind of analyses performed for each computer run to arrive at a reasonable base load configuration. In Chapter III, excursions are discussed that test the validity of these manual analyses.

Consider baseline run number 12, which has two each CGCSs, launchers, and recovery nets, and whose missions include TADAR, HS, RR, MTI, and Alternates 3B and 4A. There will be five missions that require TADAR payloads on station at all times: four FGCS mission AVs plus the HS. Also, during about 75 percent of the TADAR and HS on-station hours actually achieved in a continuous coverage mode, two RPVs are airborne or otherwise assigned to each TADAR or HS mission. The second AV is either in transit between the CL&R site and mission area or in some phase of preparation before being launched. This means there will be an average of nine AVs in use at all times to cover the five TADAR-payload missions.

Now consider displacements. When one CGCS moves, it will take half of the available (i.e., not assigned to any MRF) base load. If the TADAR base load were nine, the chances of all nine being already assigned when displacement time comes are something less than 75 percent (by the foregoing arguments). The chances of eight or more being assigned are very high (near certainty) which would leave one unassigned AV. By the rules described earlier, the displacing CGCS would take it, leaving eight in the operating base load of the remaining CGCS. We already know eight is not enough to run five missions continuously without incurring delays.

If the total TADAR base load were 10, and 8 were assigned, the displacing CGCS would take 1 of the 2 available AVs. The remaining AV together with the eight being used would be marginally enough to sustain operations if no equipment failures occur.

This scenario must also be viable when RPVs are lost and resupply is forthcoming. Therefore, when 3 AVs have been killed and the resupply truck is out, 10 total TADAR AVs must still be in the usable base load at the complex. When all is considered then, the minimum AV base load to sustain TADAR operations at four FGCSs under standard conditions appears to be 13.

The base load for the other types of mission AVs can be likewise analyzed to arrive at three RRs (one up, one replacement, and one for displacement contingency), three MTIs, three Alternate 3Bs, and three Alternate 4As as minimums. Adding up all AVs gives 25 as a lower bound. From previous discussions in Assumption paragraph 8, we know the total has to fit 4 + 3C. Thus, 25 AVs is the correct amount in the base load for this run.

III. BASELINE RESULTS AND EXCURSIONS

A. BASELINE RESULTS

This section presents the results of computer runs for the baseline mission sets. Before giving the details of the 14 runs, discussions are appropriate of how many missions are enough to dampen out probabilistic effects and what general trends in the simulation results can be intuitively anticipated.

1. Simulation Covergence

As the model was being developed and as the first runs were being made in the debugging process, criteria were established by the programmers to ensure that enough missions would be generated during each run to minimize probabilistic effects. In particular, events that occur infrequently but with consequences that influence the overall results should be allowed to occur at least once each run for a valid comparison between runs. For example, the failure of a CGCS while all other CGCSs are inoperable (displacing or being repaired) would appear to be of sufficient consequence that it should happen each run in order to have a basis of comparison.[1] In planning, therefore, runs were designed to be long enough to include all such foreseeable events.

The primary criterion established to test convergence was that the mission coverages achieved by the four forward operational sections show no more than a specified percentage spread. The four FGCSs are identical with respect to how they are serviced by the MACS central facility. There are no distinguishing features built into the model that should cause one FGCS to achieve a high coverage while another suffers low coverage. The only cause for differences in FGCS coverages is the stochastic nature of FGCS displacements, equipment failures, repair timelines, and enemy kills of on-station AVs. These effects are minimized by requiring the difference between the highest and lowest FGCS coverages to be less than 5 percent. The stated TADAR coverage achieved for each computer run is the mean of the four individual coverages.

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[1] In fact, the consequences of such a failure are not critical enough to alter the overall conclusions of this study. However, several RPVs, each costing $0.5 million, are lost with each occurrence, so that efforts to avoid failure would be worthwhile.

The 5-percent spread is chosen in view of the very large amount of computer time that would be necessary to reduce the spread to an even smaller value, such as 2 or 1 percent. To achieve the 5-percent goal, each run simulates MACS operations minute by minute over a 20-day period. Almost 30,000 cycles of the main program are processed each run, which generates between 1,000 and 2,000 RPV mission requests, depending on the mission set being analyzed in the run. About 70 to 80 percent of those mission requests result in missions flown. The 20-day runs produce clear trends in the major effectiveness criteria discussed in Chapter II when comparing results of runs with different mission sets. To achieve the smaller coverage spreads mentioned previously would not only require two to three times the computer resources, but would only slightly increase confidence in the validity of the overall conclusions.

2. General Results

Before the computer analyses were completed, a "back-of-the-envelope" analysis was performed to anticipate the kind of outputs that would be generated by the simulation and also to assist in detecting unexpected results during the debugging process that might indicate errors in program logic. Several outcomes of that less rigorous analysis are discussed here to show what can be expected from the simulation.

a. Maximum Expected TADAR Coverage

After an FGCS tears down, moves to a new location, and sets up operations again, it calls for a new mission. Since hot spares are assumed not to be allocated for servicing newly emplaced FGCSs, the mission request is processed at the MACS facility and a new AV arrives on station approximately 45 minutes later. FGCSs displace twice per day on the average, so there are 90 minutes each day when an FGCS is operational but receives no coverage. In addition, handovers take 2 minutes, during which neither AV is performing a mission. One FGCS should conduct about 10 missions in a 21-hour operational day (3 hours are for displacements) with 10 associated handover events for a total of 20 more minutes without coverage. Because of the mechanisms described, 110 minutes in each 20-hour operational day are without coverage at each forward section. Even if no equipment failures occurred, the maximum relative coverage attainable for TADAR missions would therefore be about 91 percent; the corresponding maximum absolute coverage would be about 80 percent.

When expected failures of the AV, mission payload, and FGCS itself are considered, along with expected kills of TADAR mission AVs, additional gaps in mission coverage are caused because of the time to replace failed or lost items. Based on reliability and survivability inputs stated in Chapter II, the additional daily failures and AV kills should reduce TADAR coverages another 3 to 5 percent, bringing maximum relative coverage to between 86 and 88 percent and absolute coverage about 10 percent lower than that.

Actual TADAR coverages from computer outputs will be degraded from the above values in accordance with the input values of two parameters: how many missions of all types must be processed by ground facilities and how many different types of RPV missions must be controlled by the MACS antenna. As the total number of missions increases, launch operations will develop longer servicing queues, resulting in increased delays for a larger percentage of missions, and reducing coverage. Also, as mission types (e.g., HS, RR, MTI) are added to the RPV fleet, the MACS antenna will be using its eight beams almost continuously, resulting in delays in receiving a beam for AVs on the launcher and AVs awaiting handback. Coverage will again decrease. Therefore, assuming the base load of RPVs is sufficient to supply the needs of the section (and we have designed it to be so), TADAR mission coverages less than 86 percent should be accompanied by launcher and beam delays in proportion (though not necessarily linearly) to the amount below the 86 percent mark.

b. MACS Beam Allocation

An estimation can be made of the number of beams required to sustain continuous operations of any particular mission set. As an example, consider the fully loaded set, with HS, RR, MTI, and Alternates 3B and 4B. There are five missions besides the standard TADAR mission that must be continuously supported by MACS. The discussion in Chapter II, section G.16 pointed out that in order to sustain continuous operations of the four FGCSs and the HS, an additional four TADAR AVs will be in use at all times, either in transit, recovery, prelaunch checkout, or preparation. Of those four AVs, three will require full-time use of a MACS beam, on the average. Similarly, additional RPVs are needed to sustain the continuous operations of the other four mission types, namely RR, MTI, and Alternates 3B and 4B. That requires about one-half of an AV per mission, or two more AVs total. Thus the breakout of AVs under MACS control at all times is:

5	mission AVs (HS, RR, MTI, 3B, 4B)
3	TADAR support AVs (including HS)
2	support AVs for other 4 missions
10	total

MACS will need to control 10 AVs at a time to comfortably handle (i.e., without excessive delays) the fully loaded mission scenario.

If only the HS, RR, and MTI missions are flown with the basic TADAR mission, the breakout is:

3	mission AVs
3	TADAR support AVs
1	support AV for other 2 missions
7	total

It appears that eight beams should handle a mission set somewhere between the two examples illustrated.

c. AV Losses

Continuous RPV operation is the single most important element that drives the general results of the computer runs. As an example, the previously studied standard concept for a TADAR RPV section calls for three 3-hour flights per day, which allows for about 6 hours of coverage over the target area in a 24-hour period. Continuous operations require roughly twelve 2-hour periods of coverage back-to-back in 24 hours. On the average, four times as many RPVs are exposed to enemy action in continuous operations compared to the standard concept, so AV kills should be four times as high.

Launch and recovery equipment will be operating four times as often, with proportionate increases in failures. AV failures will cause losses to quadruple in that category as well.

On the other hand, based on guidance from the RPV TSM, this simulation uses a survivability value of 0.95 for a 160-minute TADAR mission compared to 0.75 for the same time period used in previous studies. There will be five times fewer AV kills for an equivalent time over the enemy area.

The above two effects do not cancel each other out entirely. The net effect is that this simulation should show on the order of double the total number of AV losses when compared to a 20-day simulation of the original RPV concept with a survivability of 0.75.

3. Computer Outputs

The results of baseline runs 1 through 14 appear in Tables 1 and 2 and are graphically summarized by category of effectiveness criteria in Figures 4 through 8. Table 1 presents runs made without the TADAR HS option; runs in Table 2 include the HS. Refer to Figure 2 in Chapter II for a breakout of mission types used in each run. Note that in moving from runs 1 and 2 to runs 7 and 8, the RR, MTI, and 3A missions are added to the missions contained in the previous run. In runs 9 and 10, however, 3B is used in place of 3A. Runs 11 and 12 add 4A to 3B, and runs 13 and 14 replace 4A with 4B.

AV losses are shown in the tables according to the cause of the loss, including enemy action, equipment or procedural failures, and the AV running out of fuel. Mission coverages for each of the missions being played are given as percentages. TADAR coverages include both relative and absolute, as defined in Chapter II, Section E.1; other mission coverages are absolute. Five of the six queueing delays are given as a percentage followed by a time in minutes. The percentage is the fraction of missions delayed for the reason indicated; the time is the average delay for those missions that did experience a delay. The overall delay is given in minutes

TABLE 1. RESULTS OF BASELINE RUNS WITHOUT HS

		WITHOUT HS						
		TADAR 1	RR 3	MTI 5	3A 7	3B 9	4A 11	4B 13
AV Losses	Enemy kill	26	34	38	35	36	40	33
	FGCS fail	12	9	10	10	18	10	12
	CGCS fail	3	0	10	0	16	12	19
	Handover fail	8	11	12	12	7	10	7
	AV fail	15	19	25	35	23	32	33
	Fuel gone	0	0	2	5	1	8	3
	Total	64	73	97	97	101	112	107
Mission Coverage (%)	TADAR: rel	84	82	83	82	81	81	78
	: abs	74	72	72	71	70	70	68
	RR	--	96	96	93	94	92	88
	MTI	--	--	96	94	96	92	88
	Alt 3	--	--	--	94	96	92	80
	Alt 4	--	--	--	--	--	90	84
Queueing Delays (%/min)	RPV	1/41	1/28	2/15	1/12	2/24	1/20	2/29
	Launcher	10/16	14/17	16/14	21/19	25/17	31/15	37/20
	Launch Beam	0/0	0/0	0/0	5/12	7/11	25/15	30/15
	Handback Beam	0/0	0/0	0/0	3/9	3/8	12/10	10/10
	Recovery	2/5	4/5	5/4	6/5	7/4	6/4	8/5
	Overall (min)	4	6	6	8	8	13	17

TABLE 2. RESULTS OF BASELINE RUNS WITH HS

		WITH HS						
		TADAR 2	RR 4	MTI 6	3A 8	3B 10	4A 12	4B 14
AV Losses	Enemy kill	28	26	36	37	30	32	43
	FGCS fail	16	17	6	7	15	21	15
	CGCS fail	2	4	4	0	0	8	13
	Handover fail	7	8	10	16	8	10	8
	AV fail	18	22	31	34	34	30	32
	Fuel gone	0	0	2	6	6	8	20
	Total	71	77	89	100	93	109	131
Mission Coverage (%)	TADAR: rel	83	83	81	81	79	76	75
	: abs	72	73	70	71	69	66	65
	RR	-	94	91	91	89	83	86
	MTI	-	-	91	92	90	81	80
	Alt 3	-	-	-	90	91	80	82
	Alt 4	-	-	-	-	-	81	77
Queueing Delays (%/min)	RPV	5/29	4/20	3/22	3/23	2/22	2/18	3/25
	Launcher	17/12	19/15	25/23	30/15	33/13	54/25	57/25
	Launch Beam	0/0	0/0	5/12	17/13	23/14	43/18	46/18
	Handback Beam	0/0	0/0	4/7	5/9	6/9	14/10	17/11
	Recovery	5/4	6/4	8/5	6/5	8/4	7/5	9/5
	Overall (min)	5	7	11	13	14	27	28

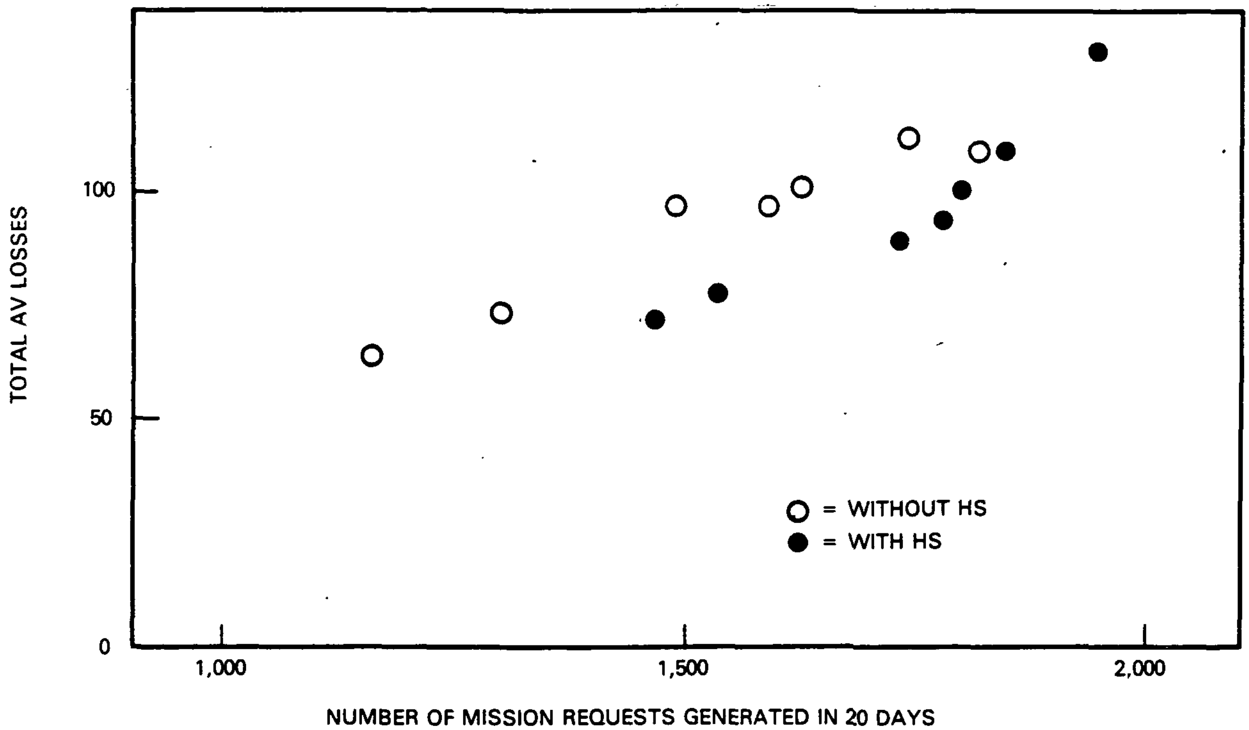

Figure 4. AV Losses for Baseline Runs

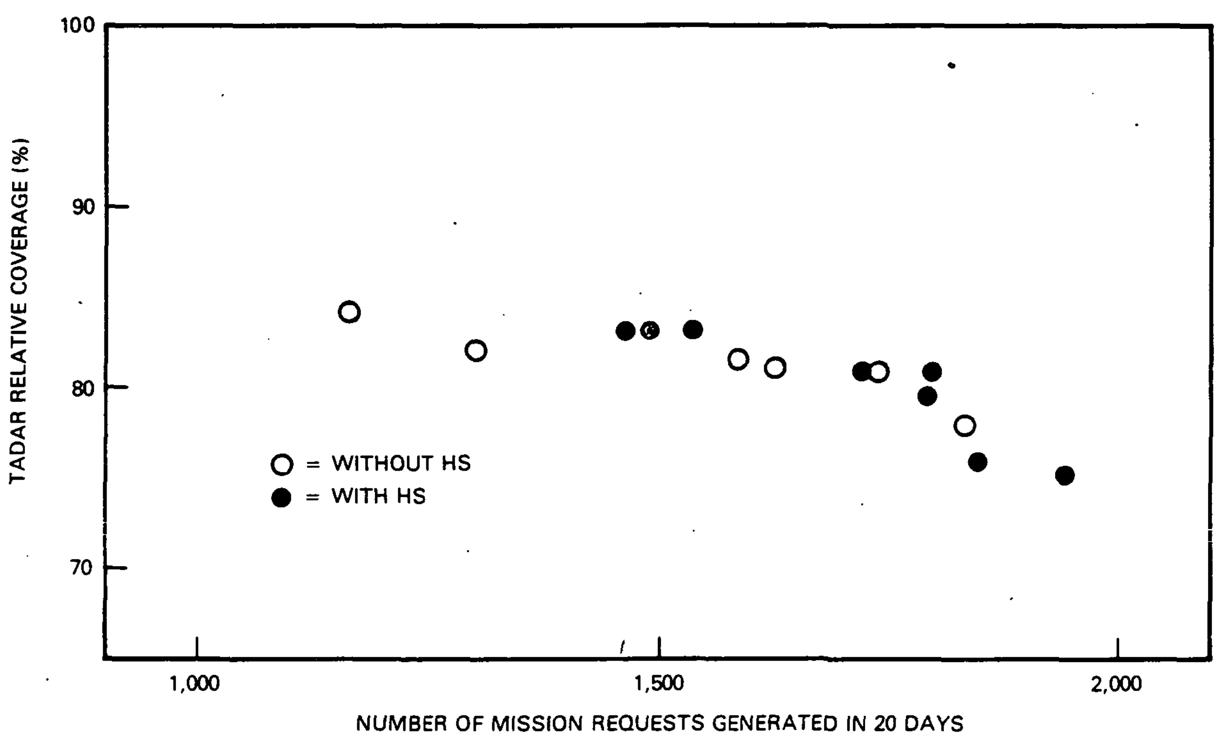

Figure 5. TADAR Mission Coverage for Baseline Runs

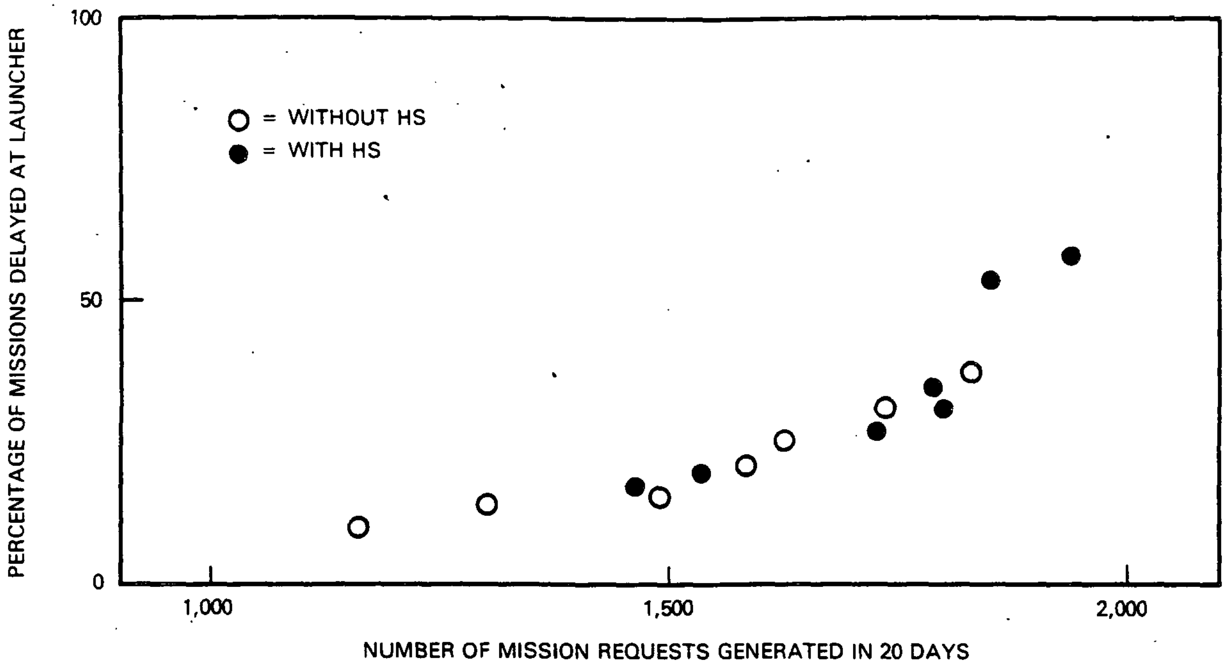

Figure 6. Launcher Queueing Delays for Baseline Runs

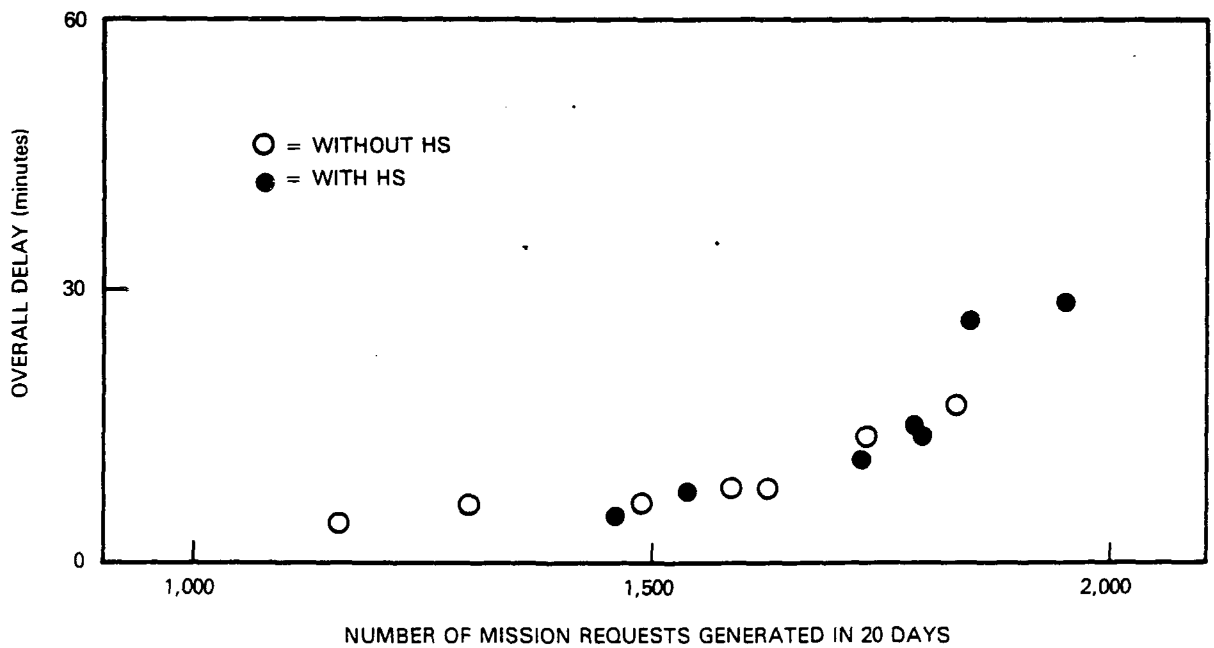

Figure 7. Overall Delays for Baseline Runs

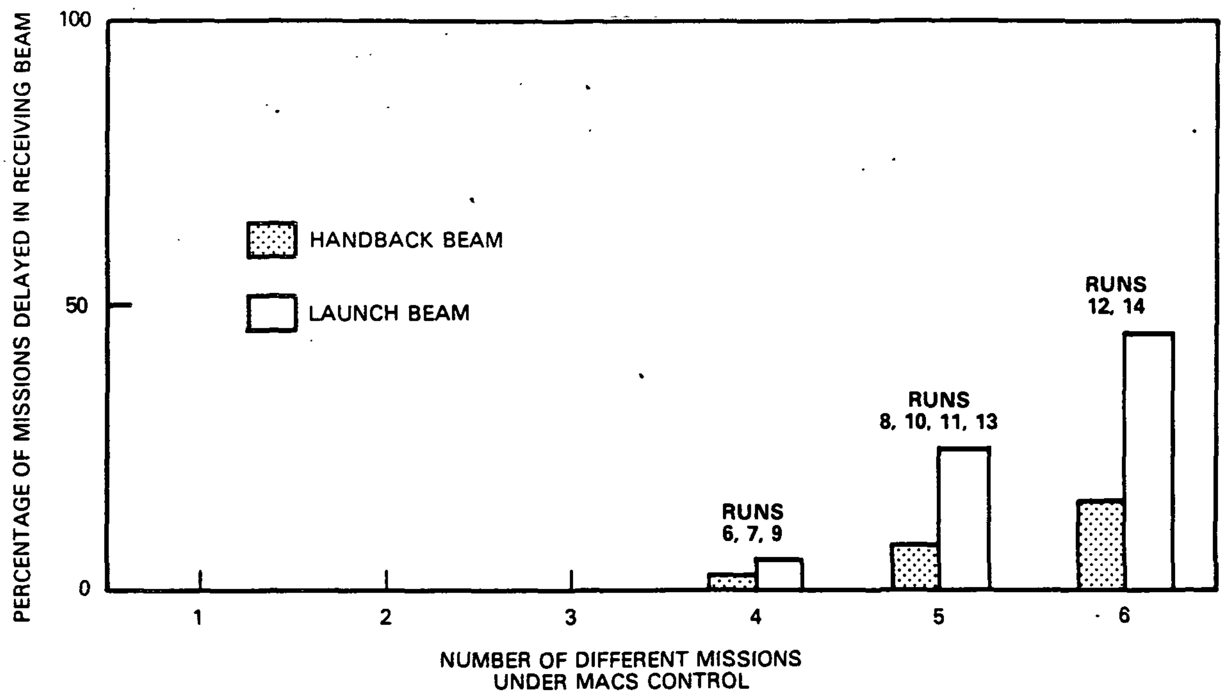

Figure 8. Beam Queueing Delays for Baseline Runs

only, since all missions experience a delay of at least 1 minute due to the 1-minute clock increment used in the simulation. The summary figures are discussed by topic below.

Base load quantities for runs 1 through 14 were chosen in light of the discussion in Chapter II, section G.16. Each run includes 13 TADAR AVs plus 3 more for each additional mission payload type being played. Therefore, runs 1 and 2 have the 13 TADAR AVs only; runs 3 and 4 have 13 TADARs plus 3 RRs; runs 5 and 6 have 13 TADARs, 3 RRs, and 3 MTIs; and so on until the fully loaded set of runs 13 and 14, which have 13 TADARs, 3 RRs, 3 MTIs, 3 Alternate 3Bs, and 3 Alternate 4Bs for a total of 25 AVs in the base load. Excursion runs discussed later in this chapter vary the TADAR base load number, examining the effects of using 10 or 16 TADAR AVs as alternatives to the 13 chosen for all baseline runs.

a. <u>AV Losses</u>

The total number of AV losses for all reasons is plotted in Figure 4 against the number of mission requests generated over the 20-day period of each simulation run. The abscissa scale of "mission requests generated" is chosen for convenience, as it is a direct output from the simulation. Plotting AV losses against number of missions flown (which is proportional to missions requested) is more meaningful than against run number, since it is the total number of missions that drive the mechanisms causing AVs to be lost. Such is also the case for Figures 5 through 7.

Figure 4 shows that total AV losses increase more or less linearly as more missions are requested and flown. Two lines are apparent--one with and one without the HS. Using an HS creates between 100 and 300 extra mission requests with the only additional losses coming as a result of a few more equipment failures, not enemy kills. Therefore, the "with HS" line reflects approximately the same number of total losses (slightly higher on the average) as "without HS," but further along the abscissa.

Referring back to Tables 1 and 2, although total losses increase gradually as missions are added, there is no clear trend within the individual categories of causes for AV loss. These categories are not totally free from probabilistic effects during a 20-day run due to the long time between events, as is evident when comparing losses from CGCS failure across the tables. The probabilities for CGCS failure result in between one and two instances, on the average, that a CGCS will fail when the other CGCS is displacing or in repair itself over the course of 20 days of continuous operations. In runs 3 and 7, it never occurred. In run 5, it occurred three times with three or four AVs lost each instance. In run 13, it also occurred three times, but with six or seven losses each time because more missions are under MACS control in run 13 than in run 5. Individual loss categories may not show consistency in a 20-day period, but probabilistic effects roughly balance out when losses are totaled. Since losses due to enemy action and running out of fuel do not rise significantly from the first runs to the last, the increasing total losses can be attributed primarily to increasing equipment usage and associated increases in equipment failure.

The total loss figures also bear upon the procurement totals for RPVs in the current budget. As of March 1982, plans [Ref. 7] called for production of roughly 1,000 AVs to supply U.S. Army needs among 16 active and 8 reserve and national guard divisions plus training and maintenance float. If the U.S. committed 10 active and 6 reserve Army divisions to a war effort in a European scenario [Ref. 8] 16 divisions would require RPV assets. Liberally assuming 90 percent of the total production number of AVs would be available, committed to the war effort, and distributed equally among 16 divisions, each MACS platoon could draw from its total allocation of about 56 AVs. The lowest number of AVs lost in a 20-day MACS simulation is 64 for the TADAR - only mission without HS.

Conclusions: *AV losses increase nearly linearly with the number of missions requested and flown, primarily due to mounting equipment failures. There is no clear point that distinguishes acceptable from unacceptable losses.*

Assuming a 0.95 probability of survival and equipment reliabilities stated in the ROC, 20 days of continuous operations for one MACS platoon using only the TADAR mission will deplete that platoon's wartime allocation of RPVs if the current production plans are maintained.

b. Mission Coverage

TADAR relative mission coverage is plotted in Figure 5. Based on the discussion of Section A.2 in this chapter, the coverage curve should become asymptotic to a horizontal line at about 86 to 88 percent. The graph shows a gradual decline in TADAR relative coverage as the number of mission requests increase, until about 1,800 mission requests when coverage starts a sharp decline. This is partially due to delays caused by the greater mission workload at the MACS ground facility, but as discussed later, it is also caused by delays incurred when the MACS antenna's eight beams become overburdened. The gradual decline from 83 to 80 percent can be justified if benefits from the additional mission types (RR, MTI, etc.) compensate for the reduced TADAR coverage. However, referring again to the tabulated results, the addition of the fourth alternate mission, particularly in runs 12, 13, and 14, causes a clear degradation in TADAR coverage. Coverages by other mission types also show a sharp drop at the same point, including those of run 11.

Differences in coverage between runs with and without the HS are discussed in Subsection d.

Conclusion: *Mission coverages are relatively insensitive to an increasing MACS workload until the fourth alternate mission is added, at which point all coverages decline sharply.*

c. Queueing Delays

Tables 1 and 2 show delays in six categories; Figures 6, 7, and 8 illustrate four of those categories. The remaining two--RPV delays and recovery net delays--do not become significant factors in the baseline runs. They become useful when excursions are run regarding base load variations and the addition of a third set of launch and recovery equipment.

Figures 6 and 7 plot launcher delays and overall delays, respectively, against number of mission requests. Launcher delays are expressed as the percentage of missions delayed at the launcher, while overall delays are expressed in terms of the total delay time in minutes between generation of a mission request and launch of that mission. Overall delays do not include standard waits, such as times spent in preflight preparation and prelaunch checkout.

Although the units on the ordinate are different for the two delays, the graphs look quite similar, indicating that the percentage of delays incurred at the launcher is a factor driving the overall effectiveness of ground system functions. Launcher delays are roughly asymptotic to the 10-

percent line,[2] rising steadily until the fourth alternate is added with an HS (see tabulated data for runs 12 and 14). The number of delays jumps over 50 percent as the system is heavily taxed. Similarly, overall delays jump to nearly half an hour in those two runs after rising steadily from 4 or 5 minutes in the first runs. The increasing delays do not show linear behavior, but are smooth until Alternate 4 is added.

Clearly, when over half the missions are waiting nearly half an hour for a launcher, the resulting gaps in mission coverage become a significant percentage of the potential coverage time. This is one of two main reasons for the sharp decline in all mission coverages that was discussed in Subsection b.

The other reason can be inferred from the histogram of beam delays in Figure 8. The percentage of missions delayed in receiving a launch or handback beam is plotted against the number of different simultaneous missions MACS must control and support. For example, in run 5, there are three missions to support--TADAR, RR, and MTI. In run 12, there are six--TADAR, HS, RR, MTI, 3B, and 4A. The HS is included here as a separate mission, since MACS must maintain an HS continuously on station and support that mission distinctly separate from its support of the basic TADAR mission.

Runs 1 through 5 show no beam delays of either kind. When the fourth mission is included, which is the MTI if an HS is being used (run 6) or Alternate 3 if no HS is used (runs 7 and 9), launch beam delays occur in about 6 percent of the missions and handback beam delays in about 3 percent--both insignificant numbers. However, when the fifth mission is added in runs 8, 10, 11, and 13, launch beam delays jump to 24 percent and handback beam delays more than double to 8 percent. Further increases to 45 and 16 percent, respectively, accompany the addition of a sixth mission in runs 12 and 14. As anticipated in the discussion of Section A.2.b of this chapter, the addition of those last two missions cause substantial beam delays because the MACS antenna can control no more than 8 AVs at a time and the mission scenario is calling for about 10.

Conclusions: *Launcher delays dominate overall CL&R system delays, rising steadily with the total number of missions flown and increasing sharply when the fourth alternate mission is added.*

Simultaneous control of eight RPVs is sufficient to handle the basic TADAR mission plus three additional missions. The HS counts as one of these missions if it is used.

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[2] This observation is not evident from the graph but from the results of runs made by the programmers during debugging. When the system is running smoothly, about 10 percent of the missions are still delayed (though for shorter periods) because of the mechanics of scheduling and performing launches. See Table 3 for more evidence of this effect.

d. Utility of the HS

When runs without an HS (Table 1) are compared with their sister runs with an HS (Table 2), it is evident that the HS runs show poorer coverage performance on the average. With an HS, all mission coverages are generally lower, ranging from 1 or 2 percent less in the TADAR coverages to as much as 10 percent less in the alternate mission coverages (runs 11 and 12). Although the differences are usually small for the first 10 runs, this result is counterintuitive. The purpose of the HS is to increase coverage.

There are two underlying reasons for the degraded performance with an HS. First, the additional number of missions generated by using the HS cause more and longer delays in waiting for available launchers and beams. This is particularly visible in the later runs when system operations are loaded with extra missions besides the HS. Nevertheless, the percentage of launcher delays is consistently 5 to 9 percent higher with an HS even in the first several less burdened runs. Launch beam delay percentages are from 12 to 18 percent higher with an HS than without when the third and fourth alternates are played in the mission set. These figures are reasonable, since maintaining an HS requires up to 16 extra launches per day in a high-survivability environment,[3] and it takes full-time control of roughly 1-1/2 MACS beams, which adversely affects all missions vying for the available eight beams.

A second significant issue in understanding the HS performance is related to the doctrine that is assumed in this simulation for HS usage. The discussion of Section A.2.a of this chapter pointed out that after each displacement, an FGCS waits approximately 45 minutes for the MACS facility to deliver its next mission AV. It was assumed that the mission commander would desire this first mission after emplacement to be a full-term mission, that is, it would use a fresh RPV with a full fuel load. Therefore, the mission request is processed at the MACS facility rather than provide that FGCS with an HS that might have to return home soon after it reaches the mssion area. In practice, the assumption used in the simulation will probably be the rule rather than the exception, since a gap in coverage on the order of 45 minutes every 12 hours is probably acceptable for most TADAR missions. With proper coordination between the newly emplaced FGCS and the CL&R facility, that 45 minutes might be reduced significantly.

At those times when a 45-minute gap is not acceptable and in the interest of providing maximum continuous coverage, an FGCS could be serviced by the HS (if one is available at that time) and shorten its wait to roughly 8 to 10 minutes. Meanwhile, a new mission could also be processed at the CL&R facility and delivered to the mission area to replace the HS if it was nearing its time to return home when it was called. This procedure

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[3]When AVs are seldom killed by the enemy, the HS mission has less influence on overall system effectiveness because HSs are launched and returned to base more often than they are used for their designated purpose.

should increase TADAR mission coverage, but would not alleviate any existing delays at the CL&R facility.

Conclusion: *The additional number of missions generated by the use of an HS strains system operations such that all mission coverages are reduced. A revised HS concept could increase coverages by as much as 5 percent but would not alleviate existing ground system delays.*

B. EXCURSIONS

This section presents the results of excursion runs that examine the effects of changing selected input parameters on the operational effectiveness of a MACS. With the exception of the set of base load runs, which were performed before the baseline runs, excursions were chosen after analyzing results from the baseline runs, giving consideration to topics currently receiving attention within the RPV community.

1. Base Load Variations

The quantity of TADAR AVs in the base load for runs 1 through 14 was established at 13 according to rationale discussed in Chapter II, Sections F.8 and G.16. To test the adequacy of that quantity, excursions with 10 and 16 TADAR AVs were run for the basic TADAR mission, both with and without the HS option. The results of these four runs are given in Table 3, along with the previously tabulated results of runs with 13 AVs for comparison.

There are no clear conclusions to be drawn from the AV losses. One might observe that losses when using the HS are generally higher, but there are not enough data to be confident that the abnormally high losses in one run are not due to random effects.

TADAR coverages do show a trend. There is no significant difference between coverage achieved with base loads of 13 or 16 AVs. When only 10 AVs are used, however, coverage decreases by about 3 or 4 percent. The reason can be seen in the RPV delays. In three of four runs with 13 or 16 base load, only 1 percent of the mission requests were delayed in being assigned an AV; the fourth run shows only 5 percent delayed. With 10 AVs in the base load, RPV delay fractions increase to 14 percent for the non-HS run and 32 percent for the HS run.

Runs using a base load of 7 TADAR AVs were not performed, in view of the degradation already apparent with 10. Base loads not conforming to the 4 + 3C equation (see Chapter II, Section F.8) are also not considered. The base load of three AVs for each additional payload beyond the basic TADAR mission is deemed necessary and sufficient to sustain normal operations; therefore, no variations on that quantity were exercised.

TABLE 3. TADAR BASE LOAD VARIATIONS

		NUMBER IN BASELOAD					
		WITHOUT HS			WITH HS		
		10	13	16	10	13	16
AV LOSSES	ENEMY KILL	25	26	26	33	28	38
	FGCS FAIL	14	12	10	6	16	19
	CGCS FAIL	7	3	3	1	2	5
	HANDOVER FAIL	12	8	10	2	7	14
	AV FAIL	14	15	12	27	18	17
	FUEL GONE	0	0	7	2	0	3
	TOTAL	72	64	68	71	71	96
MISSION COVERAGE (%)	TADAR: REL	80	84	83	80	83	83
	: ABS	69	74	74	69	72	71
	RR	--	--	--	--	--	--
	MTI	--	--	--	--	--	--
	ALT 3	--	--	--	--	--	--
	ALT 4	--	--	--	--	--	--
QUEUEING DELAYS (%/MIN)	RPV	14/25	1/41	1/36	32/28	5/29	1/30
	LAUNCHER	12/17	10/16	9/14	11/15	17/12	16/15
	LAUNCH BEAM	0/0	0/0	0/0	0/0	0/0	0/0
	HANDBACK BEAM	0/0	0/0	0/0	0/0	0/0	0/0
	RECOVERY	2/5	2/5	2/6	3/4	5/4	5/6
	OVERALL (MIN)	7	4	3	12	5	5

Conclusions: *A base load of 13 TADAR AVs and 3 each of other payload types is sufficient to sustain continuous FGCS operations at a high level of effectiveness.*

A base load of 10 TADAR AVs provides comparable mission coverage and may be adequate if delays are acceptable.

2. Three L&Rs and CGCSs

Since the primary delays in the baseline runs were in being assigned a launcher and a beam, the next set of excursions adds first a third L&R set, then a third CGCS to the baseline runs with three and four alternates and an HS, namely runs 8, 10, 12, and 14. The primary purpose of a third L&R set is to investigate whether substantial launcher delays encountered in these runs can be alleviated. The third CGCS is for examining whether perturbations caused when a CGCS fails while the other is unavailable for duty are significant, and if so, whether they can be eliminated. Note that the 3-CGCS runs include the third L&R set. Also, in order to fit the equation 6 + 3C, the TADAR base load in these runs is reduced to 12, while other missions still have 3 AVs each. The results of these eight runs are presented in Table 4 and should be compared to the corresponding runs in Table 2.

TABLE 4. ADDING A THIRD L&R AND CGCS
(compare with runs 8, 10, 12, 14)

		3 L&Rs				3 CGCSs			
		3A 15	3B 16	4A 17	4B 18	3A 19	3B 20	4A 21	4B 22
AV Losses	Enemy kill	39	30	39	49	37	30	42	44
	FGCS fail	22	6	13	13	11	20	18	12
	CGCS fail	14	7	7	13	0	0	0	0
	Handover fail	5	5	4	7	6	6	11	10
	AV fail	32	36	30	24	40	32	40	38
	Fuel gone	4	6	12	21	5	6	16	13
	Total	116	90	105	127	99	94	127	117
Mission Coverage (%)	TADAR: rel	80	83	79	78	80	81	81	77
	: abs	69	72	69	68	70	70	72	67
	RR	93	95	89	90	93	92	91	87
	MTI	94	93	85	85	94	96	87	82
	Alt 3	95	95	88	87	95	96	89	87
	Alt 4	-	-	87	82	-	-	86	81
Queueing Delays (%/min)	RPV	3/16	2/31	2/17	3/23	0/0	1/11	1/15	1/5
	Launcher	15/17	13/12	35/21	35/14	14/15	17/14	34/23	42/22
	Launch Beam	23/17	31/16	54/22	67/24	27/15	28/15	54/21	62/21
	Handback Beam	8/10	8/10	16/9	17/9	8/10	9/9	15/10	18/10
	Recovery	2/6	2/6	1/6	3/4	1/3	1/4	0/0	1/4
	Overall (min)	11	10	23	24	9	11	23	26

There is no clear trend in AV losses with the addition of a third L&R set. One would expect that AV losses are not directly affected by launch and recovery equipment, but more so by total operational hours of flight-critical items, such as the GCSs (including GDTs) and the AV itself. The third recovery net does not appear to eliminate AVs running out of fuel, indicating that the reason they run out of fuel has more to do with hand-back beam delays that overrun the 15-minute fuel reserve. Also, the third net displaces with one or the other CGCS, meaning two nets are on the move while one operates. Recovery queues naturally still develop during this time.

The only significant change in AV losses when the third CGCS is added is that AVs are no longer lost due to CGCS failure. While this may save up to 19 AVs in some runs (see run 13 in Table 1), the overall losses are not consistently decreased.

Mission coverages of all types are generally enhanced by the addition of the third L&R set, but not significantly increased when the third CGCS is in turn added. The former is due to the diminished delays with the extra launch equipment, but again there is no indication that three CGCSs benefit the overall results. The largest increases in coverage are for the non-TADAR missions when compared with runs 8, 10, 12, and 14. With the third

L&R present, mission coverages for all missions are comparable to those in runs having one fewer alternate mission and only two L&R sets. In other words, the third L&R allows one more alternate mission to be added to the MACS fleet. The fully loaded scenario, however, still suffers a sharp drop in mission coverage (see coverages of alternates in runs 17, 18, 21, and 22 and TADAR coverages in runs 18 and 22).

Queueing delays are clearly influenced in these excursions. RPV delays drop to 1 percent or less when the third CGCS is present. While one CGCS is displacing, two are operating, resulting in two-thirds of the base load being available instead of only half when two CGCSs are used.

The fraction of launcher delays is cut from over 30 percent in runs 8 and 10 to 15 percent or less when the third L&R is added. That is less than in run 2, which had only the basic TADAR mission plus HS. Higher mission coverages reflect the return to "normal" launch operations. Launch delays are also decreased from about 55 percent in runs 12 and 14 to an average of 37 percent in runs 17, 18, 21, and 22. However, that figure is still high enough to cause large overall delays and degraded mission coverages.

Decreased launch delays with the same number of mission requests result in more missions on a launcher asking for a beam. Therefore, the number of launch beam delays increases. The larger number of beam delays is not enough to counterbalance the diminished launch delays in runs 15, 16, 19, and 20, but does so in the runs with four alternates.

An important note here is that it was assumed the third CGCS does not increase the total number of beams that are available to the MACS section, as explained in Chapter II, Section F.3. If this were feasible, the third CGCS could be a great asset to MACS operations. As it is, the third CGCS merely serves as a backup on the infrequent occasions when both of the other CGCSs are unavailable.

Conclusions: *The addition of a third launcher would decrease launcher delays enough to allow another alternate mssion to be flown by MACS.*

The third recovery system and CGCS do not significantly benefit system operations.

3. Reduced Probability of Survival

The enemy's perception of the value of an RPV to U.S. forces has a large influence on his decision to allocate limited assets to pursue and kill the RPV if detected. The 0.95 probability of survival used in the baseline runs for a TADAR mission can be viewed either as an upper bound on the effectiveness of the RPV's survivability design or the result of conditions where the enemy perceives the RPV as of little value to friendly forces, or both. Six excursions were performed postulating that conditions might exist where the RPV's survivability drops to 0.75. This number has been used in earlier program documentation studies already referenced in this report and might be considered a lower bounding case for this study. All penetrating missions are subject to the increased kill rate.

Of the six runs, numbers 23 and 24 are identical to baseline runs 9 and 10, and excursions 25 and 26 are identical to baseline runs 1 and 2 in all respects except for the survivability factor. The other two runs--27 and 28--are identical to 24 except for the resupply times. Table 5 displays the results for all six excursions.

TABLE 5. REDUCED P_s, VARIABLE RESUPPLY TIMES

		Similar to Baseline runs:				Resupply Time	
		9	1	10	2	3 hrs.	12 hrs.
		without HS		with HS		with HS	
		23	25	24	26	27	28
AV Losses	Enemy kill	191	154	184	156	160	168
	FGCS fail	13	11	8	15	13	9
	CGCS fail	4	2	8	6	9	5
	Handover fail	10	6	10	8	10	9
	AV fail	29	19	23	14	30	21
	Fuel gone	1	0	3	3	4	5
	Total	248	192	236	202	226	217
Mission Coverage (%)	TADAR: rel	77	79	74	80	79	70
	: abs	68	67	63	69	69	60
	RR	89	--	86	--	91	81
	MTI	84	--	81	--	86	71
	Alt 3	93	--	86	--	91	76
	Alt 4	--	--	--	--	--	--
Queueing Delays (%/min)	RPV	3/22	5/30	6/23	13/27	2/20	13/31
	Launcher	26/20	9/8	35/18	12/8	34/17	27/27
	Launch Beam	4/9	0/0	13/13	0/0	15/13	10/13
	Handback Beam	2/9	0/0	7/7	0/0	6/9	4/8
	Recovery	6/4	3/4	6/5	3/4	7/4	6/5
	Overall (min)	11	4	16	7	13	24

As expected, AV kills increase by a factor of four to six when comparing excursion and baseline runs. No other AV loss category shows a substantive change. The AV kills cause lower coverages for all missions--a 3- to 5-percent drop in TADARs and nonpenetrating alternates (RR and Alternate 3) and about a 10-percent drop in the penetrating alternate mission (MTI). The only significant changes in delay percentages are that RPV delay fractions increase, expecially in the HS case, and handback beams are more available. The former point reflects an increased strain on the base load because AVs are being lost more frequently while resupply remains constant in runs 23 through 26. Handback beams are not in as much demand because the more RPVs that are killed on mission, the fewer that require a beam to come home.

The significant result from runs 23 and 24 is that the HS still provides less coverage when it is used than when it is not. The reasons for this are subtle and only partly evident from the computer outputs. First, although the HS is being used more often for its designated purpose when the kill rate is high, there are still about 10 percent more TADAR-payload missions generated (and subsequent launches performed) when the HS is used. With MACS operations already under a high workload (as was seen in runs 9 and 10), this 10 percent adds to an already strained system.

Second, AVs are being lost frequently and resupply takes 6 hours once initiated, resulting in a strained base load where an AV is unavailable a higher percentage of the time. This is true with or without the HS, but is more severe when the HS mission contends for the available base load. When no TADAR AVs are available, the simulation attempts to fulfill requests for TADAR AVs by interchanging a spare TADAR payload with an unwanted payload installed in an available RPV. The interchange takes an hour and is performed 41 more times in run 24 (with HS) than in run 23 (without). Coverage gaps accrue.

Third, only about half of the AV kills are replaced by an HS. In the other half, the standard mechanism that generates a follow-on TADAR mission has already been activated before the current mission AV is killed. An HS is not sent when a replacement is already on the way.

For these reasons, the benefits of faster replacement times provided by the HS for killed AVs in the relatively few cases per day in each FGCS mission area are outweighed by delays caused as the HS adds extra missions to an already strained system.

The first evidence that an HS can be beneficial overall is seen in runs 25 and 26. These use only the basic TADAR mission with and without the HS and therefore represent the system with no real strain on it. Coverages are still lower than in runs 1 and 2 because of the lower AV survivability. However, the HS run produces higher coverage than the run without the HS. A 1-percent difference is not enough by itself to draw valid conclusions in this simulation, but the 5-percent decrease from run 1 to 25 compared to only a 3-percent decrease from run 2 to 26 is a bit more material. Even with RPV delays over 10 percent in run 26, coverage is maintained at a high level.

Run 27 is identical to run 24, but the resupply time has been shortened to 3 hours. RPV delays are reduced significantly; therefore, payload interchanges are required less frequently (50 fewer, not shown). Although launch and beam delays do not change, coverages increase by about 5 percent for all missions when compared to run 24. In fact, the combination of an HS with short resupply times produces generally better coverages than without the HS (run 23), where resupply times are not critical, even in a heavily loaded scenario.

On the other hand, if the resupply mechanism is such that times on the order of 12 hours are more valid, run 28 shows coverages will suffer dramatically as RPV delays and payload interchanges increase.

Conclusions: With an RPV survivability of 0.75, AV losses multiply fivefold and all mission coverages decrease 4 to 6 percent.

Even with the higher kill rate, the benefits of the HS are outweighed in a heavily loaded scenario by delays caused because of the number of extra missions the HS generates. However, when system operations are not otherwise tasked by additional RPV mission types, the HS provides equal or better coverage than in runs where it is not used.

A fast resupply time in combination with the HS also alleviates most of the HS-related burdens in a low-survivability continuous coverage environment.

Payload interchange times cause delays that appear unacceptable for that operation to be standard procedure in launch preparations for continuous-coverage missions.

4. Less Frequent CGCS Displacement

Forward ground stations will probably not displace more than twice every day but could be forced by combat conditions to move only once each day. This, however, is not operationally desired, so no excursions are performed that vary FGCS displacement parameters.

On the other hand, two moves per day for the CL&R facility may be excessive, considering its distance from the FLOT and that current RPV sections are experiencing difficulty during tests meeting displacement timelines spelled out in the O&O concept. Run 29 examines effects of the CGCSs and associated equipment displacing once every second day, with a timeline of 4 hours for each full CL&R set to displace, move, and emplace. The option of once every other day was chosen instead of once per day in order to emphasize any effects resulting from the less frequent displacements. Once per day with a 4-hour timeline is probably not much different from twice per day with a 2-hour timeline. Results of run 29 are included in Table 6 and should be compared to baseline run 10.

Less frequent CGCS displacements have a significant effect on all mission coverages, increasing TADAR coverage by 4 percent and alternates coverages by 8 percent. Since CGCSs and launchers spend half as much total time moving, there are two of each of these pieces of equipment available more often. Catastrophic CGCS failures are reduced (there are none in run 29) and launcher delays decrease. Launch beam delay fractions increase because more AVs are on launchers ready to fly, asking for a beam.

Conclusion: *Halving the total time the CL&R facility spends in displacement increases mission coverages significantly--about 4 percent for TADAR and 8 percent for alternate missions.*

TABLE 6. CGCS DISPLACEMENT AND EQUIPMENT RELIABILITY EXCURSIONS

		Fewer Displacements	Higher Reliabilities	
	Similar to Baseline Runs:	10	9	10
		29	30	31
AV Losses	Enemy kill	32	38	38
	FGCS fail	14	10	11
	CGCS fail	0	6	24
	Handover fail	7	10	8
	AV fail	38	11	13
	Fuel gone	5	0	5
	Total	96	75	99
Mission Coverage (%)	TADAR: rel	83	86	83
	: abs	73	76	72
	RR	97	98	94
	MTI	98	99	93
	Alt 3	99	99	94
	Alt 4	--	--	--
Queueing Delays (%/min)	RPV	1/28	1/10	2/11
	Launcher	21/11	18/9	28/13
	Launch Beam	30/15	7/12	27/14
	Handback Beam	9/9	3/7	10/9
	Recovery	4/5	6/4	7/4
	Overall (min)	11	5	11

5. Increased Equipment Reliability

In Sections G.1 and G.2 of Chapter II, assumed reliability and maintenance figures for the RPV equipment were taken directly from the ROC. As the RPV program has matured and performed limited testing, reliability numbers representing expected equipment performance have become available from the contractor. Excursion runs 30 and 31 are identical to baseline runs 9 and 10--having the TADAR, RR, MTI, and 3B missions, with and without the HS--except for the following changes [Ref. 9]:

- Launcher and recovery subsystems are not allowed to fail. The revised reliabilities are high enough that only one or two failures would result in 20 days of continuous operations, introducing probabilistic effects. To avoid that, the ideal case of no failures is assumed.
- All mission payloads are assumed to have an MTBF of 443.4 hours, the currently estimated figure for the TV payload.
- The AV has a reliability of 0.9905 for completing 3 hours of continual operation.

- Forward and central ground station reliabilities do not change. The revised figures are close enough to the ROC values that no impact on system operations would be visible from the simulation.

- Equipment repair times and distributions are as follows (in minutes):

	90%	10%
GCSs	16	121
Launcher	23	118
Recovery Net	17	116

  The longer repair times include 1 hour travel time for general support maintenance teams. Repairs for AVs and payloads are not played in the simulation since AVs are assumed to fail only in flight (and are lost), and failed payloads are assumed to be interchanged with a good payload concurrently with other ground operations.

Results for runs 30 and 31 also appear in Table 6 and are to be compared with baseline runs 9 and 10.

The only meaningful change in the number of AVs lost is in AV failures. The higher AV flight reliability reduces losses by over 50 percent in that category. Other loss categories are unaffected by the enhanced reliability figures used in these runs, particularly since FGCS and CGCS failure rates were not changed. Overall losses should drop by an amount equal to the decrease in AV-failure losses, but the variation in overall losses from run to run is still too high to clearly see that effect. For example, even with the same CGCS reliability numbers, comparable runs 10 and 31 had losses due to CGCS failure of 0 and 24 AVs, respectively. In the latter case, there were four failures of the only available CGCS at those times, with a loss of 5 to 8 AVs each instance. Such an event did not occur (by chance) in run 10.

All mission coverages increase 3 to 5 percent with the enhanced reliabilities and reduced maintenance times. This can primarily be attributed to the absence of launcher failures, which results in a lower percentage of launcher delays with reduced average wait times. Also, the fewer number of AV and payload failures are responsible for reducing the number of unexpected replacements required and the accompanying coverage gaps. Performance with the HS still lags behind that when it is not used.

Conclusion: *Enhanced mission performance achieved with the introduction of improved reliability and maintenance figures indicates that tradeoffs should be investigated vis-a-vis continued efforts to increase equipment reliability as an alternative to pursuing other system enhancements postulated in this study.*

6. MACS-to-FLOT Range

Baseline runs have the MACS complex located 35 kilometers from the FLOT. Excursion runs 32 and 33 examine the effects of using a MACS-to-FLOT distance of 25 and 50 kilometers, respectively.

The principal effects of this range on the simulation are reflected in the time for resupply to be accomplished, the time for general support maintenance teams to travel to the CL&R section, the frequency with which the central facility must displace to confuse enemy location techniques, and the time AVs spend in transit back from the mission area. The latter parameter increases by 11.5 minutes when the AV must fly an additional 25 kilometers to the recovery net.

The time spent in transit out to the mission area is not similarly affected by distance from the FLOT. Since RPVs can climb at the same rate during climbout and transit out to the mission area, the time from launch to arrival on station is determined by the altitude at which the AV must cross the FLOT, not the range to the FLOT. For a traverse-FLOT altitude of 2,000 meters, the foregoing is true out to about 66 kilometers, at which point the AV spends no time in strictly vertical climbout.

The inputs used for the parameters mentioned are as follows:

MACS-FLOT range (km)	25	35	50
Resupply (hr)	8	6	4
GS maintenance MTTR (min)	210	180	150
CL&R displacements/day	2	2	1

Resupply variances result from the time required to drive different distances. Similarly, general support teams are assumed to travel another half-hour longer or shorter from the times used in baseline runs; times shown are total MTTR including travel. From a baseline of two moves per day, sections 25 kilometers from the FLOT are assumed to move as often, but only half as often when at 50 kilometers.

Runs 32 and 33 include the same missions used in baseline run 12. Results of the excursions are given in Table 7, with the 35-kilometer data from run 12 included for comparison.

In moving from the 25-kilometer to 50-kilometer run, total AV losses rise. Upon closer examination, this rise appears to be due to random effects and is not a true trend. For example, enemy kills increase over 60 percent from run 32 to run 33, but RPVs spend the same amount of time over enemy territory in all three runs. Also, AV failures increase by a third moving left to right across the table. This could be justified in part because at the greater range, AVs spend more time in transit and less time on station. Therefore, they must be replaced more frequently, meaning more total AVs are in the air on the average at any instant. This increases total flight hours and thereby chances for failure. But the effect should be smaller than results indicate.

TABLE 7. MACS-TO-FLOT RANGE VARIATIONS

		MACS-TO-FLOT 25 KM	MACS-TO-FLOT 35 KM	MACS-TO-FLOT 50 KM
		32	12	33
AV LOSSES	ENEMY KILL	24	32	39
	FGCS FAIL	12	21	10
	CGCS FAIL	7	8	8
	HANDOVER FAIL	10	10	12
	AV FAIL	28	30	37
	FUEL GONE	10	8	17
	TOTAL	91	109	123
MISSION COVERAGE (%)	TADAR: REL	74	76	75
	: ABS	64	66	65
	RR	86	83	87
	MTI	79	81	86
	ALT 3	80	80	85
	ALT 4	81	81	83
QUEUEING DELAYS (%/MIN)	RPV	2/39	2/18	1/18
	LAUNCHER	55/32	54/25	50/22
	LAUNCH BEAM	32/17	43/18	57/21
	HANDBACK BEAM	15/9	14/10	16/11
	RECOVERY	10/5	7/5	6/5
	OVERALL (MIN)	28	27	26

Of the remaining results, the notable differences between runs are in alternate mission coverages for run 33 and launch beam delays across the board. Alternates' coverages are higher for the 50-kilometer case because CL&Rs displace half as frequently. Launch beam delay fractions nearly double from left to right but are compensated by decreased launcher delay times, resulting in comparable overall delays among the three runs.

TADAR coverages are likewise not significantly different for the three cases. From previous discussions, the performances appear to be influenced more by mission workloads, which are approximately equal here.

Conclusion: *Mission performance under the assumptions specified in this simulation is relatively insensitive to variations in range from the CL&R to the FLOT.*

Other factors not modeled in the simulation will likely determine the best location for the MACS central facility. Such factors could include:

- The command and control structure for the proposed MACS platoon, whose mission responsibilities might extend across several Army disciplines

- Technical characteristics of communications devices to be used between MACS units, especially FGCSs and CGCSs
- Range of the MICNS data link, and the mission profiles of penetrating RPVs it must control
- Vulnerability of the CL&R complex to enemy weapons.

The first three factors are subjects of continuing studies within the RPV community. Ground system vulnerability is a mature area of analysis within the RPV program, with ballistic hardening criteria already established and incorporated into existing hardware.

The effect of MACS-to-FLOT range on ground system vulnerability is related to the capabilities of the enemy's weapons and his willingness to pursue efforts to render the MACS facility inoperable. With respect to the capabilities of enemy ground fire, if the CL&R complex were 25 kilometers from the FLOT, it would be at the edge of the engagement range of known enemy proliferation artillery weapons deployed in the forward area [Ref. 10]. Moving back to 35 kilometers would place MACS beyond the range of those weapons and into a category where if the enemy is determined to destroy the ground systems, there is little difference between 35 and 50 kilometers from the FLOT.

Ranges beyond 35 kilometers appear to provide no substantial benefits, while remaining as close as possible to forward units and RPV target areas would lessen the technical challenges mentioned in the earlier bullets.

7. Increased TADAR Fuel Load

Presently, the RPV is programmed for a 180-minute flight plus 15 minutes of reserve fuel using either the FLIR or TV TADAR payload. Analyses have shown [Ref. 11] that it might be possible to achieve a 5-hour flight endurance if modifications are made to the AV. Although it has not been proven if the 5-hour endurance were possible, excursions 32 and 33 examine the potential effects of such an endurance for TADAR missions. Results appear in Table 8 and can be compared with runs 9 and 10, identical except for the fuel load.

Coverages are among the highest achieved in any run performed under the current study, with 5 to 7 percent better TADAR coverage and up to 8 percent better alternate coverages than in runs 9 and 10. RPV delays are negligible, while launcher and launch beam delays are cut nearly in half.

The 5-hour endurance allows TADAR AVs to be over the mission area twice as long as with a 3-hour endurance. Since TADAR missions are the majority of all missions launched by the CL&R and they are reduced to half the previous number, all delays are minimized. Also, the HS now stays on station 2 hours longer than before, reducing its load on MACS operations to about seven missions per day--not the strain it was before. Therefore, coverage with the HS is equivalent to that without it, even though delays are still higher.

TABLE 8. 5-HOUR FUEL LOAD FOR TADAR RPVs

		NO HS 34	HS 35
AV Losses	Enemy kill	39	31
	FGCS fail	12	11
	CGCS fail	5	5
	Handover fail	2	3
	AV fail	27	38
	Fuel gone	0	3
	Total	85	91
Mission Coverage (%)	TADAR: REL	86	86
	: ABS	75	73
	RR	97	97
	MTI	99	98
	Alt 3	99	98
	Alt 4	--	--
Queueing Delays (%/MIN)	RPV	0/0	1/18
	Launcher	15/12	20/14
	Launch Beam	4/12	12/16
	Handback Beam	3/6	6/11
	Recovery	6/4	6/6
	Overall (min)	5	9

Conclusion: *A postulated 5-hour planned endurance for TADAR-equipped RPVs (including the HS) would produce 5 to 8 percent higher coverages than identical runs with a 3-hour TADAR endurance.*

IV. SUPPORTING O&O ANALYSES

This chapter presents the analyses of personnel and equipment requirements for the MACS and C^3 data rates for ground coordination among MACS units.

A. PERSONNEL AND EQUIPMENT REQUIREMENTS

This analysis is based on the requirements of the current RPV CL&R concept [Ref. 12], which is designed for 24-hour-a-day operations. From that basis, manpower and items of equipment are postulated that might be necessary to support MACS operations as different RPV missions are added. No evaluation is made in this study as to the adequacy of the proposed O&O concept for those current CL&R operations that would also become standard for MACS, considering the similarities between the two systems. Also, the personnel and equipment estimates here are assumed unconstrained by Army-wide manpower and cost considerations. There are several other important assumptions concerning MACS operations that are pertinent to this portion of the study.

First, forward ground stations are assumed to be exactly the same for MACS as in the current CL&R complex. Personnel and equipment, therefore, do not change and are not further considered.

Second, the MACS CGCS is assumed to perform primarily an air traffic control function for multiple airborne RPVs, coordinating launches, recoveries, prelaunch activities, transits, and handovers while also monitoring the status of certain alternate missions while they are on station. It is therefore presumed that interpretation and subsequent dissemination of any video data received through the MICNS downlink (e.g., from MTI RPVs) is not the responsibility of personnel in the CGCS. That duty is assumed delegated to operators in a separate facility, whose relationship to the CGCS will be functionally similar to the relationship between CGCS and TADAR FGCS. The MACS-peculiar ground station, however, need not be geographically separated from the MACS central facility.

Finally, in view of the above, detailed mission planning is assumed to take place at the responsible mission ground control station, not the CGCS. Therefore, TADAR mission profiles are planned at the FGCS once direction is received from the commander of the supported unit, who determines desired areas of TADAR coverage for that mission.

Table 9 presents the estimated personnel and equipment requirements for several key MACS mission configurations along with those of the current RPV CL&R concept. The tabulated data for MACS reflect mission configurations used in computer runs 1, 5, 13, 17; and 21, as discussed in the previous chapters. Run 1 included only the basic TADAR mission; run 5 also included the RR and MTI; run 13 added alternates 3 and 4 to that. Those three mission sets used two L&R systems and two CGCSs at the central facility. Runs 17 and 21 both had three L&Rs, but included two and three CGCSs, respectively. They also had all four alternates, as in run 13. The figures in Table 9 are independent of whether or not the HS is used.

The only personnel changes from the current CL&R concept to the MACS with two L&Rs are in operator/mechanics, AV and mission payload (MP) operators, and operators in separate ground stations peculiar to MACS. An increase in operator/mechanics to eight in the fully loaded scenario (run 13) is projected due to the corresponding increase in the number of MACS-peculiar vans (discussed later) and the complexity of four alternate payloads requiring periodic maintenance.

MP operators, though desired in the current CL&R concept for possible control of a TADAR mission from the CGCS, are not included as part of the MACS requirements, since only air traffic control functions are allowed, as discussed previously. AV operators increase with the number of alternate missions. In the TADAR-only scenario, one operator on duty in each CGCS (and one backup each for the next shift) should be able to handle servicing functions for the four forward ground stations. Each AV operator is assumed to be capable of monitoring the activities of two AVs (i.e., two beams) at a time on the average. There are times he will be fully occupied with one AV in prelaunch and other times he will have only to keep track of two or three AVs on a preprogrammed transit route. In the fully loaded scenario, all eight MACS beams will be used quite often, requiring four AV operators on each shift for a total of eight. If "park and fly" procedures are implemented for missions requiring only infrequent control and status updates, three AV operators per shift would probably be sufficient under noncontinuous operating conditions and in many situations where continuous operations are required for short periods.

Additional personnel are required when missions passing video data are flown. The configuration of run 5 was chosen for inclusion in the table because it uses the MTI RPV. For reasons discussed earlier, this requires a separate facility to conduct such a mission. The details of what that facility will encompass are beyond the scope of this study, but an MTI GCS van (similar to a TADAR FGCS) is assumed colocated with each CGCS for a total of two vans to support continuous MTI operations during CL&R displacement. MTI operators in the van include an AV operator, MP operator, and a mission commander, for a total of six additional personnel in configuration 5. Similarly, run 13 adds two more vans and six more people to support continuous operations of Alternate 4, a penetrating RPV whose mission data must be interpreted and distributed to appropriate users.

TABLE 9. PERSONNEL AND EQUIPMENT REQUIREMENTS AT CL&R COMPLEX

	Current CL&R Concept	MACS Concept				
		2 L&Rs + 2 CGCSs			3 L&Rs +	
					2 CGCSs	3 CGCSs
Comparable Run No.	-	1	5	13	17	21
No. of Alternates	-	0	2	4	4	4
Personnel						
RPV technician	2	2	2	2	2	3
Section chief	2	2	2	2	2	3
Team leader	4	4	4	4	6	6
L&R team chief	2	2	2	2	3	3
Operator/mech.	6	6	6	8	9	9
AV operator	4	4	6	8	8	9
MP operator	4	0	0	0	0	0
Crewmen	12	12	12	12	18	18
Generator mech.	2	2	2	2	2	3
MACS-peculiar	--	0	6	12	12	18
Total	38	34	42	52	62	72
Equipment						
CGCS - 5T	2	2	2	2	2	3
Launcher - 5T	2	2	2	2	3	3
Recovery - 5T	2	2	2	2	3	3
AV handler - 5T	2	2	2	2	3	3
Maint. van - 5T	2	2	2	2	3	3
AV cargo - 5T	4	3	5	7	6	6
Other cargo - 5T	2	2	2	2	2	3
MACS-peculiar - 5T	--	0	2	4	4	6
Total 5T	16	15	19	23	26	30
CGDT	2	2	2	2	2	3
Cargo - 5/4 T	4	4	4	4	5	6
30-kW gen.	4	4	6	8	8	12
AV base load	16	13	19	25	24	24

The configuration of run 17, with three L&Rs, adds a third set of personnel and equipment associated with L&R operations to the basic TADAR configuration. The exception is AV operators, which remain at eight, since that is the maximum number required to monitor eight MACS beams. The configuration of run 21 adds to the above a third set of personnel and equipment associated with mission control. AV operators are increased to nine so that each CGCS has an equal number. The personnel and equipment added due to the MTI and Alternate 4 missions now include three pairs of mission-peculiar GCSs, each van containing three operators.

As the AV base load increases to accommodate more types of RPV missions, the number of AV cargo trucks also increases. Each cargo truck carries three AVs and each AV handler carries two. Generators also increase as additional GCSs are added to the complex. Currently, equipment and air conditioning power requirements draw about 24 kilowatts from the 30 produced by one operating generator. The second generator per GCS is for backup. When two MTI vans are added in configuration 5, only two generators (instead of two per van) are added to the total for the CL&R facility. For each CGCS/MTI van pair, two generators could be operating at a time with the third as backup. In configuration 13, there are a total of eight generators in the CL&R complex to provide power for four MACS-peculiar GCSs, two CGCSs, plus maintenance shelters.

B. C^3 DATA RATES FOR GROUND COORDINATION

Data rates are estimated for message traffic between MACS units, i.e., between CGCSs and FGCSs, that are geographically separated and must use radio or data link communications to pass information. Message traffic between elements of colocated units and either into or out of the MACS platoon is not included in this analysis. Colocated units are assumed to be linked by hardwire or using internal radio nets. Communications with outside units (such as on FGCS receiving mission orders from its supported artillery battalion) are considered independent of MACS operations and are not peculiar to this study.

The assumptions stated at the beginning of section A above, especially concerning the air traffic control function of the CGCS and mission planning responsibility of the FGCS, are pertinent to this analysis as well. The approach is to first determine the types of messages that would pass between MACS units to coordinate activities; next, estimate the frequency of those messages under standard continuous operations; and finally, estimate the amount of information required in each message.

There are basically five types of messages to be passed:

- Mission requests from the FGCSs to the CGCSs
- Notifications from the FGCSs of intended displacement
- Acknowledgements by either party of messages received
- Notification from the CGCS of late arrival of replacement AV due to delays
- Coordination messages during handover procedures.

There are also routine and emergency messages that will occur as a result of operations, but these are not considered in the analysis due to their variability in frequency and content.

Table 10 shows the expected frequency of messages by type between separated elements of the MACS platoon. Mission requests generated by the FGCS are enumerated in five categories. The normal replacement of an ongoing TADAR mission will likely be requested by the FGCS in control of the mission, rather than by some automatic procedure at the CGCS as used for convenience in the computer simulation. Each of the four FGCSs operates approximately 21 hours per day (3 hours for two displacements) with TADAR missions lasting about 2 hours each for a total of 42 nominal replacement requests per day. Not all of these will actually be generated, due to AV kills, etc., while on mission. The figure represents an expected maximum.

TABLE 10. TYPE AND FREQUENCY OF MESSAGES WITHIN MACS PLATOON

	Messages per day (average)
FGCS to CGCS	
Mission requests	
Normal replacement	42
AV killed or lost	2
MPS failed	1
FGCS emplaced	8
FGCS repaired	1
Notifications	
FGCS displacing	8
FGCS failed	1
Acknowledgments	variable
CGCS to FGCS	
Acknowledgments	55
Change orders	variable
Handovers	
CGCS/FGCS	
Two-way (x5)	170
One-way forward (x4)	44
One-way back (x3)	24
CGCS/CGCS (x6)	12
Total	< 400

The remaining numbers of mission requests are based on inputs for equipment reliability and FGCS displacements, as discussed in Chapter II. Notification must also be sent to the CGCS when the FGCS must displace during an ongoing TADAR mission. This message therefore generates a request for handback and return of the AV to the CL&R. FGCS failures are only critical to the CGCS if a replacement AV is outbound, in which case the AV is either rerouted, placed in a waitng orbit, or returned.

The primary reason messages would be sent from the CGCS to the FGCS is in acknowledgment of messages received. The quantity of 55 comes from 54 mission requests plus 1 FGCS failure notification. The eight notifications of FGCS displacement are followed up with handback procedures rather than simply an acknowledgment. The frequency of change orders from the CGCS notifying forward elements of delays in RPV deliveries on station will vary according to the workload, but is not expected to be high in any event since FGCS operators will start sending in requests earlier if delays at the CGCS persist over extended periods of the day.

There are four types of handovers. Those between FGCSs and CGCSs can be two-way (for normal replacements and exchange for AVs with a failed MPS), one-way forward (for other mission requests listed), or one-way back (when the FGCS must hand back a mission AV due to impending displacement). RPVs must also be handed from a CGCS getting ready to displace to its associated CGCS that has just completed emplacement at a new location. These are all one-way handovers.

Two-way FGCS and CGCS handovers are assumed to require a sequence of five messages to accomplish the procedure:

Sender	Message
CGCS	Ready to commence handover
FGCS	Acknowledge
FGCS	Old AV placed in dead-recon orbit
FGCS	Control of replacement AV established
CGCS	Acknowledge

The CGCS must still acquire the dead-reckoning AV but need not send a message confirming it since the FGCS could not help if acquisition were unsuccessful. Eighty percent of the mission requests requiring two-way handover are assumed to eventually result in handover (others are aborted or made one-way because of AV kill, etc.) for a total of 34 events with five messages each.

One-way forward handovers need only four messages--the third in the sequence above is eliminated. One-way back handovers also eliminate the second message in the sequence, since it is the FGCS that generates the "I am displacing" message and waits for the CGCS to acknowledge with "ready to commence handback."

CGCS-to-CGCS handovers require a ready-to-commence message, acknowledgment, followed by pairs of "transferring AV" and "AV acquired" messages for each AV under MACS control at the time. For an average of two airborne TADAR RPVs under MACS control at all times to service only the basic TADAR FGCS missions, that is six messages for the handover sequence. (If eight AVs are under MACS control. as in the fully loaded scenarios described in Chapter II, there could be a string of 18 messages in the sequence.) Two CGCS displacements per day are assumed for the total of 12 messages per day in Table 10.

The total of all messages generated during an average day of standard MACS operations comes to less than 400. Peak hourly loads could double the average rate, but still should not burden data communications expected to be in place by the time MACS is fielded.

The information contained in each message will vary with the message type, but the following list should include all the information necessary to communicate the proposed messages:

Message ID
Time of message
Sender
Location of sender
Destination address
Purpose of message
Status
Type of handover
Time of handover
Coordinates of AV being relinquished
RPV code, frequency, and synchronization
Comments

The purpose could be "requesting replacement RPV," "acknowledging message received," "abort previous message," "control of AV established," etc. Status would then refer to a reason for the message, if applicable. Examples are "AV killed," "MPS failed," "standard replacement," etc. Type of handover is two-way or one-way forward or back. The comments are for any additional information not covered by the standard format. There are approximately 10 items of information that would be passed in the maximum-length message under this format, not including alphanumeric comments.

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ACRONYMS

AV	air vehicle
C^3	command, control, and communications
CACDA	Combined Arms Combat Development Agency
CGCS	centralized ground control station
CGDT	centralized ground data terminal
CL&R	centralized launch and recovery
CSTAL	Combat Surveillance & Target Acquisition Laboratory
DS	direct support
FGCS	forward ground control station
FLOT	forward line of own troops
GCS	ground control station
GS	general support
HS	hot spare
JPL	Jet Propulsion Laboratory
L&R	launch and recovery
MACS	Multiple Aquila Control System
MAV	minimum acceptable value
MICNS	Modular Integrated Communications and Navigation System
MRF	mission request files
MTBF	mean time between failures
MTI	moving target indicator
MTTR	mean time to repair
O&O	organizational & operational
PIDS	prime item development specification
PM	program manager
RGT	remote ground terminal
ROC	required operational capability
RPV	remotely piloted vehicle
RR	radio relay
SPC	System Planning Corporation
TADAR	target acquisition, designation, and aerial reconnaissance
TDMA	time-division multiple access
TSM	TRADOC System Manager
TV	television

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