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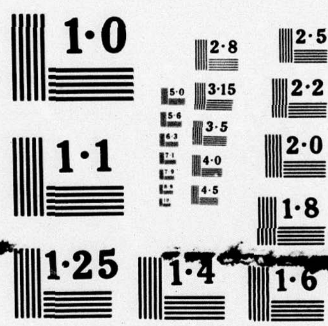

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SUMMARY REPORT OF AMRL REMOTELY PILOTED VEHICLE (RPV) SYSTEM SIMULATION STUDY V RESULTS

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Aerospace Medical Research Laboratory

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The AMRL RPV System Simulation and Research Program was initiated in response to requirements for support of the design of the man-machine/environment interface of AF RPV systems. The major objectives of this program are as follows: (1) Perform RPV system design evaluation studies; (2) Assess RPV system effectiveness, i.e. evaluate the expected effectiveness of a given system configuration such as its overall probability of achieving a target, etc.; (3) Provide man-machine/environment interface engineering data; and

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(4) Test bed new technology. The results of the fifth simulation study are reported herein. This study included automatic RPV heading correction and position reporting smoothing functions. The study employed scenarios requiring that support RPVs, via reprogramming, provide coverage for a set of strike RPVs. The RPV system was assumed to operate in an environment where a radio frequency has to be shared by multiple users, so that a time slot becomes available for RPV use only on a periodic basis. Accordingly, RPV system performance was evaluated under the simultaneous effects of Telemetry Transmission Time, Command Transmission Time, Call Delay for CRT Displays, CRT Update Delay Time, and the Number of RPVs in the System.

PREFACE

Dr. Mills was responsible for the overall management of the AMRL RPV Program. Mr. Aume was responsible for the technical operation of the program and for writing the report. Mr. Gillio was responsible for data collection, handling and analyzing. Mr. Sebasky and Mr. Wartluft were responsible for the development, updating, etc. of the computer software needed to execute the simulation.

The authors acknowledge the assistance of the following individuals: Sgt Jon Van Donkelaar, AMRL; Mr. Jeff Baughman, Miss Suzanne Gross, Mr. Mike Berger, and Miss Deborah Ambrose, University of Dayton. Each of these individuals has contributed substantially to the success of the RPV System Simulation program being conducted in this laboratory.

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1.0 INTRODUCTION

1.1.0 The AMRL RPV System Simulation and Research Program was initiated in April 1973 in response to requirements for support of the design of the man-machine/environment interface of AF RPV systems. The major objectives of the AMRL RPV System Simulation and Research program are listed here.

1.1.1 Perform RPV system design evaluation studies, i.e. evaluate alternative design configurations, assumptions, operating procedures, etc.

1.1.2 Assess RPV system effectiveness, i.e. evaluate the expected effectiveness of a given system configuration such as its overall probability of achieving a target, etc.

1.1.3 Provide man-machine/environment interface engineering data, i.e. recommend displays, etc.

1.1.4 Test bed new technology, i.e. evaluate effectiveness of contractor designed consoles, video bandwidth compression techniques, etc.

1.2.0 The major thrust of this program has been to bring the state-of-the-art in system simulation and system research concepts to bear on the problem of RPV system design and development. System simulation and research concepts assert that an RPV system will be comprised of a number of sequenced phases and events that are dynamically interactive when multiple RPVs must be controlled in real-time by multiple operators. If possible then, exploratory development efforts involving these interactive elements should provide much of the required data for system design. Since large-scale, multiple RPV systems in the AF are yet to be developed, the most practical approach to performing RPV systems research and also satisfying the system dynamics problem is via computer simulation of a "postulated" real-world system.

1.3.0 This technical report summarizes the data of the fifth RPV systems simulation study (RPV Study V) employing the AMRL RPV System Simulation Test Bed.

2.0 AMRL RPV SYSTEM SIMULATION TEST BED

2.1.0 RPV Study V employed the AMRL RPV System Simulation Test Bed. The simulation incorporates a large number of the parameters of a postulated real-world RPV system. The simulation employs four En Route/Return Phase operators and one Terminal Phase Pilot operator (henceforth referred to as Pilot). Each En Route/Return operator monitors and operates a computer graphics terminal (IBM 2250) comprised of a graphic display (cathode ray tube, CRT), alphanumeric keyboard, light pen, a programmable function keyboard, and a small panel for hand-over actions. The pilot operates a pilot station comprised of basic flight instruments, a joystick for controlling a camera over a terrain model, and a closed circuit TV monitor. The simulation is executed in real-time and permits simultaneous control over up to 35 simulated RPVs.

2.2.0 Figure 1 is a schematic layout of the simulation facility as it is presently configured. Note that there is closed loop manual or automatic control over the camera of the terrain model facility. Figure 2 is a photograph of a team of 5 operators performing a simulated RPV mission in the facility. Figure 3 provides a closer view of one En Route/Return operator's terminal and the Pilot's station with video from the terrain model.

2.3.0 The AMRL RPV system simulation can be briefly characterized in terms of the major submodels that are dynamically interfaced in the simulation. These submodels are listed below.

2.3.1 Simulated RPV heading, altitude, and velocity flight parameters with automatic or manual, digital update capability while in the automatic flight mode or manual, continuous update capability while in the continuous control flight mode (Terminal Phase).

2.3.2 Three data links (Command, Position Reporting, and Video) for each simulated RPV and with interference parameters.

2.3.3 Simulated RPV fuel load and rate of usage as a function of velocity and altitude.

2.3.4 Simulated RPV attrition probability parameters based on altitude and on the extent of (lateral) cross track deviation from the programmed flight plan.

2.3.5 Simulated RPV subsystem reliability operating in real "operational" time in conjunction with a simulated RPV inventory.

2.3.6 Simulated RPV navigation system parameters (RPV Study V employed parameters for Inertial, Doppler, and Basic Dead Reckoning systems).

2.4.0 Specific displays and controls available in the simulation, and operating procedures are described in "Remotely Piloted Vehicle (RPV) Simulation Program Instruction Manual." This manual is intended for operator instruction and generally interested persons. It is being continually expanded and updated, and therefore is in draft form. A copy can be obtained from AMRL/HEB, Wright-Patterson AFB, Ohio 45433.

2.5.0 En Route/Return operators are provided with displays (updated in real-time) showing, for each RPV; a flight plan, a track signature and vector displayed according to reported position, expected times of arrivals (ETAs) to waypoints, status of Command data link, command and actual velocity, command and actual altitude, fuel remaining, lateral distance of the RPV from flight plan, various alarm conditions, etc. The CRT display in Figure 3 shows four flight plans, a listing of RPV tail numbers and associated information down the right side of the display, a status information block in the lower left corner, and two other message blocks in the lower center and the lower right areas. Operators also have the capability to window (zoom) around an RPV at two display scaling levels. Each operator can make use of all control devices (i.e. light pen, alphanumeric keyboard, programmable function keyboard, and the hand-over switch panel).

3.0 <u>RPV STUDY V MISSION SCENARIO PARAMETERS</u>

3.1.0 RPV Study II (Mills et al., 1975a) employed a "generalized" mission scenario, intended to establish base-line data, and represented a cross-section of specific scenarios in that it contained system task elements considered to be present in most real-world RPV missions. RPV Study III (Mills et al., 1975c) employed a slightly more specialized mission scenario assuming that a limited set of support RPVs (Electronic Warfare and Low Altitude Reconnaissance) is available for coverage of a set of strike RPVs or manned aircraft. RPV Study IV (Aume et al., 1976) continued to use this type of mission scenario. RPV Study V used equal numbers of Strike, Electronic Warfare, and Low Reconnaissance RPVs, and required that the maximum number of Electronic Warfare RPVs be used to provide coverage to Strike RPVs.

3.2.0 Most of the major parameters of the RPV mission scenario for RPV Study V are the same as for RPV Study IV. All are listed below. It is indicated where parameters differ from those of the RPV Study IV scenario.

3.2.1 RPV launch and recovery phases are assumed to occur "outside" the simulation.

3.2.2 Each RPV has an independent preprogrammed flight plan that is assumed to be stored in the Drone Control Facility and RPV computers.

3.2.3 Each flight plan is assumed to be optimal with respect to terrain and defenses. Thus, the Mission Planning subsystem is also assumed to be outside the simulation.

3.2.4 Each RPV is designated one of three mission types; Strike (Weapons delivery), EW (Electronic Warfare), and Low Recce (Low Altitude Reconnaissance).

3.2.5 A round trip of approximately 300 NM per RPV is simulated, with the center of the target area located 150 NM from the launch insertion and recovery coordinates. Strike and Low Recce RPVs held quite closely to their path lengths. EW RPVs, due to repeated passes over targets, traveled considerably farther than the preprogrammed path length.

3.2.6 Each RPV has an initial command velocity of 350 knots and a command altitude of 200 feet. Velocity is dynamically variable between 300 and 400 knots at the operator's discretion.

3.2.7 In the RPV Study V scenario RPVs are launched according to type. The group of EW RPVs are launched first on 15 second intervals. These are followed by the Low Recce, also on 15 second intervals. The Strike group is launched last on 3 minute intervals. This interval was 2 minutes in RPV Study IV. The total number of vehicles is parametric and is determined prior to each mission, there being an equal number of vehicles in each group.

3.2.8 RPVs are launched from one of three launch areas.

3.2.9 For the RPV Study V scenario each Strike, EW, and Low Recce group must be time-phaseed (coordinated arrivals) to target. Time-phasing is such that as many as possible EW RPVs must be within a 5 NM radius of the target assigned to the Strike and a single Low Recce must follow the Strike vehicle after 2 minutes (simulating BDA). These coordination requirements are discussed in paragraph 5.6.0.

3.2.10 Each Strike flight plan has a designated waypoint S for cueing the start of hand-off procedures. Next comes the Hand-off (H) waypoint at which the vehicle "enters the target area" and the pilot can acquire continuous control over it as well as get TV returns from it. In addition, each Strike flight plan has a designated Target (T, one of three targets), Hand-back (B), and Recovery (R) coordinates.

3.2.11 In the RPV Study V scenario, EW and Low Recce flight plans are programmed through all three targets (labeled 1, 2 and 3). No other waypoints are designated on these flight plans (except the Recovery coordinate).

3.2.12 Prior to hand-off, an RPV is given a command to climb to an altitude of 3000 ft. For Strike RPVs, the small area on the terrain model also required a change in command velocity to 300 knots.

3.2.13 On Strike flight plans the distance from S to H is 10.0 NM, from H to T the distance is 1.5 NM.

3.2.14 Each RPV is given just enough fuel to complete the round trip mission. Strike and Low Recce RPVs are assigned a fuel load of 2200 pounds. EW RPVs are assigned a load of 3880 pounds.

3.2.15 RPVs are handed off to Pilot for continuous control to target on a first-come, first-served basis. Only Strike RPVs are handed off to Pilots.

3.2.16 EW, Low Recce, and overload Strike RPVs (Strikes not handed off to the Pilot) are handed off to other En Route/Return operators in the system but the recipient is passive (i.e., the only action taken by the operator is to throw the accept switches; the operator does not monitor the RPV, etc.)

3.2.17 Video imagery from the terrain model and continuous control are available to the Pilot during the actual Terminal Phase. Terminal Phase control will be achieved only if the Strike RPV is within an approximate ± 1500 foot wide corridor to target.

3.2.18 The simulation employed for RPV Study V included a function to smooth raw RPV position reporting data. The smooth function essentially fits a statistical, best-fit flight path to position reports. (See the Instruction Manual noted in 2.4.0 for more detail.)

3.2.19 The simulation employed for RPV Study V included a function to perform automatic RPV heading correction based on smoothed position report data. The automatic correction is ordered for an RPV when the lateral deviation or cross track error is in excess of 1000 ft. The lateral deviation of an RPV is measured relative (perpendicular distance) to its stored flight plan. (See the Instruction Manual noted in 2.4.0 for more detail).

3.2.20 Both of the above functions (3.2.18, 3.2.19) are assumed to occur at the DCF level and <u>not</u> onboard the RPV. This "smarter" RPV system was initiated in RPV Study III and was continued in all subsequent RPV Studies. The impact of these two functions was reported in the RPV Study II Supplement (Mills et al., 1975b).

3.3.0 Figure 4 is a basic profile of scenario requirements for RPV Study V. In this figure a group consisting of Strike, EW, and Low Recce flight plans are shown. The circles along flight plans and at waypoints indicate that there will be an expected RPV position error. In other words one can expect that given any desired point on an RPV flight plan, true RPV position will vary inside an ellipse (shown here as circles).

3.4.0 Figure 4 depicts a situation where the EW and Low Recce RPVs are to rendezvous with the Strike RPV at Target 1. As the experimental requirement is to provide coverage by the maximum number of EW RPVs, these vehicles are orbited in the vicinity of the target. The EW RPV shown in the figure has previously covered a Strike at Target T2. Also, the Low Recce has previously provided BDA for a Strike at Target T3 (although typically Low Recce RPVs were not orbited in RPV Study V, except to replace lost vehicles). To provide the necessary coverage at T1, operators are required to reroute (reprogram) both types of support RPVs to T1 such that rendezvous with the incoming Strike will occur according to time-phasing requirements.

4.0 CONTROL/DISPLAY PARAMETERS

4.1.0 Each En Route/Return operator station consists of an IBM 2250 Graphics CRT Terminals (see Figure 1). These terminals are equipped with a 12 inch CRT, light pen, alphanumeric keyboard, and a programmable keyboard. A small panel of switches and lights has been added to each terminal for operator control during hand-offs.

4.2.0 The Pilot station is equipped with a joystick, basic flight instruments, and a TV monitor for displaying terrain during Strikes or information from one of the CRT terminals during other portions of a mission.

4.3.0 Each CRT has the capability to display flight plans, track signatures, etc., for up to 10 RPVs simultaneously. How many and which items of information are displayed is at the operator's choosing. RPV status parameters such as velocity, fuel remaining, RPV type, etc., are displayed for one individual RPV at a time. Other displayed parameters are ETA to the next designated waypoint, flight mode for each RPV in the system, and elapsed mission time.

4.4.0 Operators can "call" displays and can make changes to RPV flight parameters using the various control devices on the terminals. For example, in the case of heading changes the operator can employ any one of the three window sizes (a 50 x 50 NM, a 100 x 100 NM which are centered on the RPV to be changed, and a 200 NM x 200 NM window which is centered on the entire geographical area). The operator then introduces a set of points (not to exceed 10) on the CRT face using the light pen. (The point-to-point distance is also displayed.) The heading change always starts from the current RPV position and must end on a point on the original flight path. If the operator's prescribed points call for an impossibly tight turn, the computer rejects the set of points, in which case the operator must introduce a new set. Valid heading change commands are transmitted over the command data link to the on-board computer and the RPV proceeds to fly though the points prescribed in the command.

4.5.0 Each attempt to communicate an instruction to an RPV is assumed to employ the command data link. The possible commands are altitude changes, velocity changes, navigation system changes, destruct, deploy chutes, and heading change. After a command is entered, it remains in the "outstanding commands" block (during this time it is displayed) until it has been transmitted to the RPV.

4.6.0 The displayed position of each RPV is in the form of a track signature consisting of a heading velocity vector and an ID number. The displayed position is computed by adding, vectorially, the position reporting system error, navigation system error, as compounded by operator error, to the true RPV position. The simulation frame time (display update) is a variable in RPV Study V (see 6.2.0 for details).

5.0 OPERATOR RESPONSIBILITIES AND PROCEDURES

5.1.0 En Route/Return operators are required to perform the following general tasks.

5.1.1 Monitor and update RPV position based on minimizing overall cross track (lateral deviation) error.

5.1.2 Coordinate all RPV arrivals to the target and recovery areas.

5.1.3 Time-phase each Strike RPV such that it achieves its "original" ETA (assigned during flight plan generation) to each designated waypoint (S, H, T, B, R). To achieve a maximum number of hand-overs to pilot, some deviations are permissible (also see 5.6.1).

5.1.4 Time-phase RPV recoveries such that EW and Low Recce RPVs arrive at R in any order, Strike achieves original ETA to R, and the arrival interval of all RPVs is as near to, but not less than, 15 seconds as possible.

5.1.5 Perform hand-offs to other operators when required.

5.1.6 Accept RPVs (on a passive basis) handed off by other operators.

5.1.7 Hand-back RPVs upon request from another operator.

5.1.8 Respond to RPV failures, e.g. by Destruct, Deploy Chutes, Replace Navigation System, etc.

5.1.9 Reprogram (recycle) RPVs to replace RPVs that are lost due to malfunction, attrition, etc.

5.1.10 Manage RPV fuel.

5.2.0 ETA adjustment for an RPV is accomplished by the operator altering RPV velocity and/or RPV heading (i.e., increasing or decreasing RPV flight path distance). Reprogramming an RPV is accomplished by causing the replacement or support RPV to go to the new target area after it has completed its assigned mission. A replacement RPV must be of the same type as the RPV lost and must be time-phased with the remaining RPVs of the group. Additionally, a replacement strike RPV must be assigned to the same target as the lost RPV.

5.3.0 The Pilot is required to perform the following general tasks.

5.3.1 Direct coordination of RPV hand-offs and arrivals to target and recovery areas during "dead-time" of en route and return phases of the mission.

5.3.2 Accept Strike RPVs from En Route/Return operators.

5.3.3 Switch into Video and Continuous Control modes when a Strike RPV is successfully handed-off.

5.3.4 Perform target acquisition and simulate line-of-sight target lock-on or weapon release (activate Trigger switch).

5.3.5 Perform hand-back of a Strike RPV following the target phase.

5.4.0 Target detection and acquisition requirements were minimal during the Terminal Phase. This is due to repeated runs to the same targets and the small area of the terrain model. At the present time, the lack of significant detection and acquisition problem is not viewed as a serious deficiency. The simulation study is concerned with the dynamic interaction of the major elements of mission phase integration, multiple RPVs, near simultaneous hand-offs, multiple operator interactions, etc.

5.5.0 A successful hand-off could occur (a Strike RPV achieves continuous control) only if the RPV was within a ± 1500 foot wide corridor on both sides of the flight path to the target.

5.6.0 There were a number of performance requirements which the RPV system was expected to achieve. These were prioritized for the operators. Operators were instructed that in order to achieve the criterion of highest priority, some accuracy might have to be sacrificed on lower priority items. Furthermore, each team (see 5.7.0) was allowed to employ its own strategy for accomplishing the criteria. The general requirement in RPV Study V was to deliver each Strike RPV to target with as many EW RPVs within a five nautical mile radius of the target as possible and followed 2.0 minutes ± 15 seconds later by a single Low Recce RPV.

The major priorities of RPV V were:

5.6.1 Maximize the number of Strikes achieving target and achieving the criterion of maximum number of EWs within 5 NM radius of target and a Low Recce fly over target 2.0 ± 15 seconds minutes later.

5.6.2 Maximize the number of Strikes achieving target with coverage by a maximum number of EWs within 5 NM radius of target with slippage in the Low Recce criterion.

5.6.3 Maximize the number of Strikes achieving target with coverage by at least one EW within 5 NM radius of target and also achieving the Low Recce criterion.

5.6.4 Maximize the number of Strikes achieving target with coverage by at least one EW within 5 NM radius of target and with slippage in the Low Recce criterion.

5.6.5 Maximize the number of Strikes achieving target with EW coverage but no Low Recce coverage.

5.6.6 Maximize the number of Strikes achieving target.

5.6.7 Maximize the number of Strikes achieving original ETAs and minimize Strike lateral error.

5.7.0 Operator teams were required to do their own planning and scheduling of RPVs. The planning was done at the start of a mission. Operators were provided with computer print-outs listing original ETAs to all waypoints for each RPV flight plan. Operators were also permitted to use electronic calculators or other devices of their own choosing.

5.8.0 The three targets for a given mission were chosen randomly from a set of twenty-seven targets located on the terrain model. The targets were in the form of small white disks easily identifiable on the Pilot's video monitor. The Pilot was provided with maps and photographs of the terrain model. It was the Pilot's task to locate the three targets prior to performing the first strike and without the benefit of the terrain model. When not in the continuous-control/video-on modes of a Terminal Phase for an RPV the Pilot has access to closed circuit video from one of the En Route/ Return CRTS. The display is on the same video monitor that provides the terrain video. This display provided the Pilot with ongoing mission information, e.g., progress and ETA of a given RPV.

6.0 RPV STUDY V -- SPECIFIC OBJECTIVES AND SYSTEM PARAMETERS INVESTIGATED

6.1.0 The objective of RPV Study V was to evaluate RPV system capabilities to perform the support tasks described above and to investigate the simultaneous effects of a set of independent variables on RPV system performance. The RPV system referred to here is strictly that system postulated by the RPV systems simulation.

6.2.0 The effects of five independent variables on RPV system performance were investigated. Four of the variables involve time parameters of data transmission. The RPV system is assumed to operate in an environment where data transmission over radio frequencies has to be shared with other users, so that a time slot becomes available on a periodic basis, and only then can data be transmitted. These five independent variables are listed here.

6.2.1 Telemetry Data Transmission Time - when data can be received from an RPV (slot cycle times of 0.7, 2.1, 3.5., 4.9 and 6.3 seconds).

6.2.2 Command Data Transmission Times - when commands can be sent out to RPVs (cycle values same as above).

6.2.3 Call Delay for Modification/Window Displays - when an operator calls for a display, the display is delayed in accordance with a time factor (values same as above).

6.2.4 CRT non-immediate Information Update Time - display frame time (2.8, 5.6, 8.4, 11.2 and 14.0 seconds).

6.2.5 Number of RPVs under system control (9, 15, 21, 27 and 33).

6.2.6 RPV position reporting error was held constant at 525 ft. range error and 0.6 milliradian azimuth error. The RPV lateral deviation alarm threshold value was fixed at 1000 feet.

6.3.0 The five variables were varied in combination with each other according to a Central Composite/Fractional Factorial experimental design (Cockhran, 1957). This type of design allows one to investigate a large, multivariate, experimental space by taking a minimum number of observations. An observation constitutes a single execution of the RPV system simulation (i.e., one simulated mission).

6.4.0 In RPV Study V 32 observations (5 observations were replications) were obtained on each of four operator teams, yielding a total of 128 observations. Each observation required approximately 1 3/4 to 2 1/4 hours of execution time.

7.0 OPERATOR TEAMS

7.1.0 Operators were obtained from universities in the Dayton, Ohio area. They were required to be undergraduates for program longevity purposes and to have at least a "B" average. However, because many had been incoming freshmen at the start of the research program and there were occasional immediate needs, the grade requirement was sometimes relaxed. Teams were comprised of five operators. Four primary teams were formed. A fifth secondary team served as a back-up pool of trained operators. Data were collected on all teams.

7.2.0 Individual operators acquired a minimum of 5 months' training. Most operators had completed 6 months initial training, and had participated in one or more RPV Studies prior to RPV Study V. No member of the principal teams had less than 5 months' training. Training had been acquired during the initial portion of the program or as a member of the back-up team. Pilots were given additional training (2 weeks) in instrument flight simulators, as well as controlling the camera over the terrain model. In addition, each team executed a number of RPV V practice missions. Data collection was started after a unanimous vote of the primary teams that they were ready to start.

8.0 RPV STUDY V RESULTS

8.1.0 In order to allow readers to gain the information most relevant to their needs, interpretation of results will be kept to a minimum and will be general in nature.

8.2.0 Forty-six dependent variable measures of RPV system performance were taken in RPV Study V. The means and standard deviations are presented in Table I. This table lists each dependent variable in terms of the following categories.

8.2.1 RPV Position error Variables--relate the deviation between "True" RPV position known only to the simulation to "Ideal" RPV position (where it should have been) to various mission phases and major waypoints.

8.2.2 En Route/Terminal/Return Transition Related Variables--are primarily concerned with phase transition and Terminal Phase performance.

8.2.3 Command Data Link Usage Variables--attempt to quantify system transmission rates, etc.

8.2.4 RPV Scheduling Variables --quantify system capabilities to achieve the various time-phasing requirements of RPV Study V.

8.2.5 Miscellaneous Variables--are simply those that do not fit conveniently into a significant category.

8.2.6 Coordination Variables Involving Timing and Range Criteria--express capabilities to meet the support of Strike vehicles with EW and Low Recce RPV coverage requirements.

8.3.0 Table I presents means and standard deviations of data that have been collapsed over all teams and missions which implies that some missions yielded better and some worse results than those shown. By collapsing over missions the assumption has been made that the variables of Table I are system non-parametric. In other words the five experimental independent variables (see 6.2.0) are assumed to have had no practical effects on system performance. Under this assumption, it is possible to get a summary perspective of system performance despite the large number of measures and the complexity of the system problem. Examination of Table I can provide insight into the objectives of the missions as well as lead to additional questions. Since EW and, to a lesser extent, Low Recce RPVs underwent considerable reprogramming during a mission, position error data and scheduling data relative to the flight plans for these RPVs are not relevant; thus, these data are not included in Table I.

8.3.1 A review of the data in Table I shows that in general, ETA management and RPV position control are satisfactory. Heading correction--returning RPVs to their flight paths--was completely automated in RPV Study V, and consequently the cross track error was strictly a function of the lateral deviation threshold value of 1000 feet and warrants no further discussion.

8.3.2 The major new variables to be investigated were the timing factors of the various data transmissions (as was explained in 6.2.0). It was expected that these time factors would have some influence on the performance of the RPV system. However, a review of the data in Table I indicates that the influence is rather minimal.

8.3.3 Two new variables have been added to Table I: the number of EW RPVs within 5 NM of target at the time when the Strike RPV passes over the target. A distinction is made between RPVs that are handed off and RPVs that may or may not be handed off. These variables were necessitated by the experimental requirement to provide coverage by the maximum number of EW RPVs (see 5.6.1).

8.3.4 Figure 5 depicts some of the timing and position errors in the vicinity of the target area. The situation is the same as for Figure 4 which was described in 3.3.0; Figure 5 however, contains observed values of the systems performance variables.

8.3.5 One might note that for EW and Low Recce RPVs, the recovery rate is of the order of 2 percent, while about 15% of EW and 22% of Low Recce are lost due to malfunctions and attrition. The remainder were lost because they ran out of fuel, which may have to be considered an experimental artifact.

8.4.0 As in previous RPV Studies, to assess the effects of the five experimental variables, a regression analysis of variance was performed on each systems performance variable (as listed in Table 1). Additionally, RPV Study V used some techniques in data analysis that had not been used before. These procedures were aimed at developing a method for determining a set of values for the five experimental variables which would tend to optimize either overall systems effectiveness or a set of performance measures specified as most important.

8.4.1 The first step of the procedure was to find those dependent variables with the highest multiple regression coefficient (MRC); the MRC being a measure of how well the prediction equation fits the data. It was discovered that the data in the original form yielded low MRCs. It was determined that collapsing the data from the four teams' performance on one mission into a mean score for each mission would eliminate interteam variability and yield higher MRCs. A data set was created containing the mean data over missions and these data then were used as input to the analyses. Fifteen variables with the highest MRCs were selected and are presented in Table 2 according to the rank order of their MRCs. (The same analysis can be provided for any other variable in Table 1 and any other measurable variable on request.) Thus, the first variable is Number of Heading Commands Transmitted per Low Recce RPV for the entire Mission has the highest MRC, R = 0.9799 .

8.4.2 Table 2 lists the MRCs for the variables as well as the regression equations. These equations can be employed by engineers, etc., to assist them in the specification of system parameters or making up "expected" data profiles given selected values of the equation parameters. However, low correlation coefficients (e.g., less than R = 0.85) in combination with an experimental hyperspace (i.e., five dimensions) may cause the equations to produce unexpected or illogical results, especially if used with values outside of the ranges that were employed in the experimentation. Therefore, one should exercise caution and good reason in performing analyses with these equations.

8.4.3 The variables in Table II were reviewed to see which of the independent variables had a significant influence on them. This review showed that Telemetry time and Command link time had a significant effect on the largest number of dependent variables, followed by the Number of RPVs. Call delay time and CRT update times failed to reach a significant level of influence.

Three variables were selected for closer inspection (the following paragraphs will explain the rationale):

1. The number of heading commands per RPV transmitted overall for low Recce RPVs, with both Telemetry time and command link time

at their maximum, the number of transmissions per RPV was the lowest. It increased toward the other three possible combinations of Telemetry and Command link times; and decreased slightly with increasing number of RPVs.

2. Number of EW RPVs per Strike within 5 NM of target, EW is or is not handed off: with a small number of RPVs, it is highest with minimum Telemetry and maximum Command link time. With a medium number of RPVs the trend is almost flat, and it reverses with a large number of RPVs (it is highest at maximum Telemetry and minimum Command link time).

3. Strike to Low Recce ATA difference at target, Low Recce is or is not handed off: with a small number of RPVs, there is an increase with longer Telemetry times. As the number of RPVs increases, the trend changes to increasing with longer Command link times.

Even though the analyses showed several statistically significant relationships and the review of the variables could discern some trends, the overall conclusion still is that the practical effect of the five independent or experimental variables is rather minimal.

8.4.4 The second step of the procedure was to obtain a correlation matrix of the dependent variables. This matrix would contain the correlation coefficient of each dependent variable with each and every other dependent variable. As this would result in an enormous (46 X 46) matrix, it was decided to select only those dependent variables which appeared in Table II, as their values are influenced to the greatest extent by the experimental variables. This submatrix was then scanned to find a set of variables which are not correlated with each other, the reasoning being that, if two variables have a high coefficient of intercorrelation, then one of them can be used to represent both. One variable was eliminated whenever a pair was discovered with a coefficient of correlation greater than 0.1. The idea was to find a small set of dependent variables with high MRCs with respect to the experimental variables, and at the same time with a low coefficient of correlation with respect to each other. These variables would then be the least interrelated and have prediction equations which fit the data most closely. The following variables were eventually selected:

1. Number of heading commands transmitted per vehicle over all mission phases, Low Recce (Variable 1 in Table II).

2. Strike and Low Recce ATA difference (minutes) at Target (Low Recce is or is not handed off) (Variable 4 in Table II).

3. Number of EW RPVs per Strike within 5 NM of target (EW is or is not handed off) (Variable 8 in Table II).

For the sake of brevity, in the following paragraphs these variables will be referred to as V1, V4, and V8. These same variables were discussed in 8.4.3.

8.4.5 The next step was to try to optimize the values of the equations to arrive at a set of values of the five independent variables. It was envisioned that some kind of general solution might be obtainable that would be optimum for overall system effectiveness.

Standard optimization procedures (setting first derivatives equal to zero) were tried but failed because some of the computed values were outside the feasible range. For instance, three of the independent variables are timing parameters and their values were found to be less than zero. Therefore, another approach was necessary to constrain these values to the range of feasibility.

One approach could be Linear Programming, but it cannot be applied because it deals only with linear conditions. However, there also exists a generalized non-linear programming problem. It is capable of handling our case which is a quadratic objective function with linear constraints. Application of this procedure yielded the following results:

	X1	X2	X3	X4	X5	
V1	5.4	6.3	2.5	2.8	33	Set 1
V4	0.7	4.0	5.4	2.8	33	Set 2
V8	0.7	6.3	6.3	2.8	9	Set 3

where X1 = telemetry time, seconds
X2 = command link time, seconds
X3 = call delay time, seconds
X4 = CRT update time, seconds
X5 = number of RPVs

(complete definitions of these variables are under 6.2.0)

8.4.6 These solutions are somewhat of a dilemma, as each one prescribes a different set of points for operation at optimum performance. In an attempt to find a single set of points, the *three system performance variables* (V1, V4, and V8) were evaluated using the equations in Table II over the three sets of values with the following results:

	Set 1	Set 2	Set 3
V1	2.62	8.87	10.14
V4	1.02	0.47	2.56
V8	2.47	1.90	3.01

This table shows that, if the RPV system were operated under the conditions of Set 1 (telemetry time = 5.4 seconds, command link time = 6.3 seconds, call delay time = 2.5 seconds, CRT update time = 2.8 seconds, and 33 RPVs in the system, which optimizes V1), there would be, on the average, 2.62 heading commands transmitted for Low Recce RPVs (V1), an ATA difference of 1.02 minutes between Strike and Low Recce RPVs (V4), and finally there would be 2.47 EWs covering the Strike RPV (V8). Similar considerations apply to Set 2 and Set 3. If one so desired, one could compute the expected values of other variables using the equations given in Table II.

It is immediately obvious that depatures from optimum affect V1 to a much greater extent than the other two variables. Thus, Set 3 can be eliminated (while it optimizes V8, it affects the other two very adversely). In having to choose between Set 1 and Set 2, Set 1 was selected as it consists of a slightly more even set of values and it avoids the 0.7 second telemetry time.

8.4.7 It is noteworthy that the CRT update time (X4) in all cases is optimal at 2.8 seconds. This is an indication that CRT update rates of less than 2.5 seconds are not necessary. Actually, update rates of 1 second or less cause the screen to cycle so rapidly as to be visually disturbing (given a long enough exposure time to such blinking, there could even be undesirable mental effects - similar to highway hypnosis). Some of the training missions used update rates of 0.7 seconds which the operators found highly unacceptable.

While 33 RPVs turned out to be the recommended number, it is realized that in a tactical situation there will be other considerations (e.g., what the targe is) that will determine the number of RPVs to be deployed.

8.5.0 Table III provides a list of confidence interval estimates for the 15 variables of table II based on 0.95 probability. In other words, 0.95 expresses the fact that one is to expect the variable to be within the tolerance values listed 95% of the time as long as the system parameter values are within the parameter continuum quantified and investigated. The intervals presented in Table IV can be quite useful in that they provide estimates on the limits of system performance. For example, for the first variable, Number of Heading Commands Transmitted per Vehicle over all mission phases, Low Recce only, one can expect the number to be greater than 6.91 but less than 8.18 95% of the time. This is not to say that some specific missions will not yield numbers outside these limits because the limits are based on 95% expectation. As a matter of fact, one would expect 5% of missions to be outside the limits. Also, the limits, while valid for present purposes, are approximate. This is due to the experimental design procedure selected for the study. However, the approximation is minor and the details of how it comes about need not be discussed here.

8.6.0 The lack of practically significant parametric effects had three major implications. First, the data in Table I and of the type in Table III are adequate for estimating expected system performance. Second, this result has been obtained in each of the previous RPV system simulation studies performed under the present program. This observation may be very important. It suggests that the RPV system as postulated herein is compensatory, i.e. it can make real-time adjustments to parametric and dynamic change, such that specific effects of outside influences tend to "wash out". It also suggests that the "acceptable" range of a parameter may be quite wide and only extreme or catastrophic changes will in fact perturb the system. Third, it is not possible at present to optimize all parameters in the strict mathematical sense. The effects are too small and the trade-offs are too complex. The attempt at optimization (8.4.5 and 8.4.6) tends to substantiate the proposition that an overall systems optimum may be difficult if not impossible to achieve, in that each systems performance variable has a different combination of independent variable values as its point of optimum operation. The only recourse then, is to apply equations to a specific parameter set. Unfortunately, systems technology does not as yet, possess the tools to deal with these latter two implications.

9.0 MAJOR CONCLUSIONS

9.1.0 The system as postulated by the AMRL RPV System Simulation Test Bed is capable of effective, multiple control and time-phasing of principal (Strike in this case) RPVs. The system is only partially successful at coordinating support RPVs (EW and Low Recce in this case) with principal RPVs. The capability of the system to perform such tasks, given selected parametric values, can be estimated by solving the regression equations presented herein or made available upon request.

9.2.0 There are, in general, no practical effects of the system independent parameters investigated. The implications of this conclusion were discussed earlier (section 8.6.0). However, the optimization procedure indicated that at certain combinations of independent variable values selected aspects of systems performance could be expected to be better than at other value combinations.

9.3.0 All other conclusions are consistent with those arrived at in the previous RPV Studies.

10.0 RPV SYSTEM SIMULATION STUDY VI - PLANS

The amount of influence of the time delays in data transmission being so small, it was decided to give the delays a large range and replicate RPV Study V with these new values of independent variables to see how much of an influence can be observed.

TABLE I

MEAN, STANDARD DEVIATION (STD DEV) PER MISSION FOR MAJOR DEPENDENT VARIABLES OF RPV STUDY V. DATA ARE ON 4 TEAMS AND 32 MISSIONS COMBINED. (DATA COMBINED OVER VEHICLE TYPE -STRIKE,ELECTRONIC WARFARE,LOW RECCE- ARE PRINTED IN STRIKE COLUMNS.)

		STRIKE		ELECTRONIC WARFARE		LOW RECCE	
		MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
	RPV POSITION ERROR VARIABLES						
1	CROSS TRACK ERROR (PERPENDICULAR DISTANCE FROM FLIGHT PLAN TO TRUE RPV POSITION) DURING ENROUTE PHASE (FEET)	412.591	74.186	**********	**********	**********	**********
2	GROUND SPEED (LONGITUDINAL DISTANCE FROM EXPECTED TO TRUE RPV POSITION) ERROR DURING THE ENROUTE PHASE (FEET)	613.329	141.045	**********	**********	**********	**********
3	CROSS TRACK ERROR AT THE TIME OF ARRIVAL AT THE S WAYPOINT (FEET) (STRIKE ONLY)	526.229	151.820	**********	**********	**********	**********
4	GROUND SPEED ERROR AT THE TIME OF ARRIVAL AT THE S WAYPOINT(FEET) (STRIKE ONLY)	684.479	138.646	**********	**********	**********	**********
5	CROSS TRACK ERROR FROM S WAYPOINT TO H WAYPOINT (FEET)(STRIKE ONLY)	512.417	147.968	**********	**********	**********	**********
6	GROUND SPEED ERROR FROM S WAYPOINT TO H WAYPOINT (FEET)(STRIKE ONLY)	685.218	142.492	**********	**********	**********	**********
7	CROSS TRACK ERROR AT THE TIME OF ARRIVAL AT THE H WAYPOINT (FEET)	655.367	159.893	**********	**********	**********	**********
8	GROUND SPEED ERROR AT THE TIME OF ARRIVAL AT THE H WAYPOINT (FEET)	3059.025	787.437	**********	**********	**********	**********
9	CROSS TRACK ERROR FROM THE H WAYPOINT AT THE TIME THE TERMINAL PILOT OPERATOR ACTUALLY TOOK CONTROL(FEET)(STRIKE ONLY)	474.547	150.597	**********	**********	**********	**********
10	GROUND SPEED ERROR FROM H AT THE TIME THE TERMINAL PILOT OPERATOR ACTUALLY TOOK CONTROL (FEET)(STRIKE ONLY)	2327.197	690.609	**********	**********	**********	**********
11	CROSS TRACK ERROR DURING THE RETURN PHASE (FEET)	1125.232	535.767	**********	**********	**********	**********
12	GROUND SPEED ERROR DURING THE RETURN PHASE (FEET)	1282.936	533.671	**********	**********	**********	**********
13	CROSS TRACK ERROR FOR ENROUTE AND RETURN PHASES COMBINED (FEET)	560.722	400.335	**********	**********	**********	**********
14	GROUND SPEED ERROR FOR ENROUTE AND RETURN PHASES COMBINED (FEET)	1226.014	486.836	**********	**********	**********	**********
15	RATIO OF THE DISTANCE ACTUALLY TRAVELED BY A VEHICLE TO THE LENGTH OF FLIGHT PLAN (THIRD PLACE ACCURACY)	1.004	0.002	**********	**********	**********	**********

TABLE I (CONT.)

MEAN, STANDARD DEVIATION (STD DEV) PER MISSION FOR MAJOR DEPENDENT VARIABLES OF RPV STUDY V. DATA ARE ON 4 TEAMS AND 32 MISSIONS COMBINED. (DATA COMBINED OVER VEHICLE TYPE -STRIKE,ELECTRONIC WARFARE,LOW RECCE- ARE PRINTED IN STRIKE COLUMNS.)

		STRIKE		ELECTRONIC WARFARE		LOW RECCE	
		MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
	ENROUTE-TERMINAL-RETURN TRANSITION RELATED VARIABLES						
16	PROPORTION OF VEHICLES SUCCESSFULLY HANDED OFF TO TERMINAL PILOT OPERATOR	0.892	0.063	**********	**********	**********	**********
17	TIME BETWEEN TERMINAL PILOT OPERATOR STRIKES (ONE STRIKE/UNIT TIME IN SECONDS)	232.666	41.144	**********	**********	**********	**********
18	TIME FOR TERMINAL PHASE FLIGHT (SECONDS)	20.998	3.019	**********	**********	**********	**********
	COMMAND DATA LINK USAGE VARIABLES						
19	NUMBER OF HEADING COMMANDS TRANSMITTED PER VEHICLE FOR THE ENROUTE PHASE ONLY	1.511	0.771	0.731	0.302	0.506	0.276
20	NUMBER OF HEADING COMMANDS TRANSMITTED PER VEHICLE OVER ALL MISSION PHASES	13.901	2.914	9.886	1.559	7.546	1.038
21	NUMBER OF VELOCITY COMMANDS TRANSMITTED PER VEHICLE OVER ALL MISSION PHASES	7.451	1.467	6.869	0.689	4.872	0.614
22	NUMBER OF ALTITUDE COMMANDS TRANSMITTED PER VEHICLE OVER ALL MISSION PHASES	2.149	0.147	1.717	0.225	1.582	0.332
23	NUMBER OF HEADING COMMANDS TRANSMITTED PER VEHICLE FOR THE RETURN PHASE ONLY	2.868	0.917	0.038	0.070	0.055	0.065
24	NUMBER OF TRANSMITTED COMMANDS PER RPV (ALL TYPES OF VEHICLES COMBINED)	20.526	1.874	**********	**********	**********	**********
25	TIME BETWEEN TRANSMITTED COMMANDS PER RPV (ALL TYPES OF VEHICLES COMBINED) (SECONDS)	196.539	15.381	**********	**********	**********	**********
26	TIME INTERVAL BETWEEN TRANSMITTED COMMANDS (ALL TYPES OF VEHICLES COMBINED) (SECONDS)	12.864	3.242	**********	**********	**********	**********

TABLE I (CONT.)

MEAN, STANDARD DEVIATION (STD DEV) PER MISSION FOR MAJOR DEPENDENT VARIABLES OF RPV STUDY V. DATA ARE ON 4 TEAMS AND 32 MISSIONS COMBINED. (DATA COMBINED OVER VEHICLE TYPE -STRIKE, ELECTRONIC WARFARE, LOW RECCE- ARE PRINTED IN STRIKE COLUMNS.)

		STRIKE		ELECTRONIC WARFARE		LOW RECCE	
		MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
	RPV SCHEDULING VARIABLES						
27	DIFFERENCE BETWEEN ATA (ACTUAL TIME OF ARRIVAL) TO S WAYPOINT AND ETA (EXPECTED TIME OF ARRIVAL)(SECONDS)	21.231	7.415	********	********	********	********
28	DIFFERENCE BETWEEN STRIKE ETA AND ATA AT THE H WAYPOINT (SECONDS).	21.164	8.219	********	********	********	********
29	DIFFERENCE BETWEEN ATA TO TARGET AND ETA TO TARGET (SECONDS)(STRIKE ONLY)	21.723	11.598	********	********	********	********
30	DIFFERENCE BETWEEN ATA TO RECOVERY AND ETA TO RECOVERY (SECONDS) (STRIKE ONLY)	164.816	67.856	********	********	********	********
31	TIME BETWEEN RECOVERIES (ALL TYPES OF VEHICLES COMBINED) (SECONDS)	211.512	67.304	********	********	********	********
	MISCELLANEOUS VARIABLES						
32	PROPORTION OF VEHICLES RECOVERED	0.629	0.158	0.015	0.034	0.006	0.017
33	PROPORTION OF VEHICLES REPROGRAMMED (RECYCLED TO TARGET TO REPLACE LOST VEHICLES)	0.178	0.152	********	********	********	********
34	NUMBER OF HEADING COMMANDS ATTEMPTED PER VEHICLE OVER ALL MISSION PHASES	50.633	19.459	38.286	12.618	31.209	17.367
35	RATIO OF HEADING COMMANDS TRANSMITTED TO HEADING COMMANDS ATTEMPTED OVER ALL MISSION PHASES	0.390	0.154	0.329	0.087	0.372	0.149
36	PROPORTION OF VEHICLES LOST DUE TO MALFUNCTIONS AND ATTRITION	0.151	0.085	0.150	0.076	0.222	0.075

TABLE I (CONT.)

MEAN, STANDARD DEVIATION (STD DEV) PER MISSICN FCR MAJOR DEPENDENT VARIABLES OF RPV STUDY V . DATA ARE ON 4 TEAMS AND 32 MISSICNS COMBINED. (DATA CCMBINED OVER VEHICLE TYPE -STRIKE,ELECTRONIC WARFARE,LOW RECCE- ARE PRINTED IN STRIKE COLUMNS.)

		STRIKE		ELECTRONIC WARFARE		LOW RECCE	
		MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
	COORDINATION VARIABLES INVOLVING TIMING AND RANGE CRITERIA						
37	RANGE FROM STRIKE RPV TO EW RPV WHEN STRIKE RPV IS OVER TARGET (NM) (EW RPV IS OR IS NOT IN HAND OFF MODE)	4.152	2.082**				
38	RANGE FROM STRIKE RPV TO EW RPV WHEN STRIKE RPV IS OVER TARGET (NM) (EW RPV IS IN HAND OFF MODE)	2.265	C.913**				
39	PROPORTION OF STRIKES WITH EW COVERAGE (EW RPV IS WITHIN FIVE NM OF TARGET, EW RPV IS OR IS NOT IN HAND OFF MODE)	0.726	C.097**				
40	PROPORTION OF STRIKES WITH EW COVERAGE (EW RPV IS WITHIN FIVE NM OF TARGET, EW RPV IS IN HAND OFF MODE)	0.650	C.106**				
41	STRIKE AND LOW RECCE RPV ATA DIFFERENCE (MIN.) AT TARGET (CRITERION IS 2 MIN.) (LOW RECCE RPV IS OR IS NOT IN HAND OFF)	2.408	0.612**				
42	STRIKE AND LOW RECCE RPV ATA DIFFERENCE (MIN.) AT TARGET (CRITERION IS 2 MIN.) (LOW RECCE RPV IS IN HAND OFF MODE)	2.109	C.402**				
43	PROPORTION OF STRIKES WITH LOW RECCE RPV COVERAGE WITHIN 2 MIN.+-15 SEC.CRITERION (LOW RECCE RPV IS OR IS NOT IN HAND OFF)	0.421	C.130**				
44	PROPORTION OF STRIKES WITH LOW RECCE RPV COVERAGE WITHIN 2 MIN.+-15 SEC.CRITERION (LOW RECCE RPV IS IN HAND OFF MODE)	0.320	0.126**				
45	NUMBER OF EW RPVS PER STRIKE WITHIN FIVE NM OF TARGET (EW RPV IS OR IS NOT IN HAND OFF MODE)	1.284	0.267**				
46	NUMBER OF EW RPVS PER STRIKE WITHIN FIVE NM OF TARGET (EW RPV IS IN HAND OFF MODE)	C.855	C.190**				

TABLE II

REGRESSION EQUATION AND MULTIPLE CORRELATION COEFFICIENT FOR EACH OF 15 SELECTED DEPENDENT RPV SYSTEM MEASURES. (X1 = TELEMETRY DATA TRANSMISSION TIME,X2 = COMMAND DATA TRANSMISSION TIME,X3 = CALL DELAY FOR MODIFICATION/ WINDOW DISPLAYS,X4 = CRT NON-IMMEDIATE INFORMATION REFRESH TIME,X5 = NUMBER OF RPV'S IN SYSTEM,E INDICATES POWER OF TEN.)

```
1 NUMBER OF HEADING COMMANDS TRANSMITTED   =     0.1721927E 02        +( -0.3551305E 00)X1    +( -0.1014427E 01)X2
  PER VEHICLE OVER ALL MISSION PHASES         +( -0.1542880E 01)X3    +( -0.4720240E 00)X4    +( -0.2217600E 00)X5
  (LOW RECCE ONLY)                            +(  0.2257085E 00)X1X1  +( -0.2545663E 00)X1X2  +(  0.2653061E-02)X1X3
                                              +( -0.6492984E-01)X1X4  +( -0.1020982E-01)X1X5  +(  0.1482659E 00)X2X2
                                              +( -0.1167500E-01)X2X3  +(  0.1049617E 00)X2X4  +( -0.1244196E-01)X2X5
                                              +(  0.1163781E 00)X3X3  +(  0.5051017E-02)X3X4  +(  0.3583780E-01)X3X5
                                              +( -0.1654830E-02)X4X4  +(  0.1791690E-01)X4X5  +(  0.6771148E-03)X5X5

  MULTIPLE CORRELATION COEFFICIENT = 0.9799

2 TIME INTERVAL BETWEEN TRANSMITTED        =     0.2017342E 02        +(  0.2191303E 01)X1    +(  0.3948818E 00)X2
  COMMANDS (ALL TYPES OF VEHICLES             +( -0.1804872E 00)X3    +(  0.1608455E 01)X4    +( -0.1366527E 01)X5
  COMBINED) (SECONDS)                         +( -0.1022490E 00)X1X1  +(  0.2035426E 00)X1X2  +( -0.2913584E-01)X1X3
                                              +( -0.6552643E-01)X1X4  +( -0.4406473E-01)X1X5  +( -0.2497616E 00)X2X2
                                              +(  0.2180772E 00)X2X3  +( -0.3250159E-01)X2X4  +(  0.2315609E-01)X2X5
                                              +( -0.1086138E 00)X3X3  +(  0.2276626E-01)X3X4  +(  0.7270087E-02)X3X5
                                              +( -0.4758352E-01)X4X4  +( -0.2436421E-01)X4X5  +(  0.2614631E-01)X5X5

  MULTIPLE CORRELATION COEFFICIENT = 0.9771

3 NUMBER OF HEADING COMMANDS TRANSMITTED   =     0.1177108E 02        +( -0.6060375E 00)X1    +( -0.8711208E 00)X2
  PER VEHICLE OVER ALL MISSION PHASES         +(  0.3388567E 01)X3    +( -0.2488115E 00)X4    +( -0.4245509E 00)X5
  (EW ONLY)                                   +(  0.1339666E 00)X1X1  +( -0.3950509E 00)X1X2  +(  0.2239222E 00)X1X3
                                              +( -0.6643170E-01)X1X4  +(  0.1595536E-01)X1X5  +(  0.1704099E 00)X2X2
                                              +( -0.2444707E 00)X2X3  +(  0.4659120E-01)X2X4  +(  0.5447917E-01)X2X5
                                              +(  0.2919179E-01)X3X3  +( -0.1736097E 00)X3X4  +( -0.9209669E-01)X3X5
                                              +(  0.3121536E-01)X4X4  +(  0.2062723E-01)X4X5  +(  0.8973703E-02)X5X5

  MULTIPLE CORRELATION COEFFICIENT = 0.9637

4 STRIKE AND LOW RECCE RPV ATA DIFFERENCE  =     0.5433557E 01        +(  0.3635374E 00)X1    +( -0.7217632E 00)X2
  (MIN.) AT TARGET    (LOW RECCE RPV          +( -0.7697513E 00)X3    +( -0.2064804E 00)X4    +( -0.1226335E 00)X5
  IS OR IS NOT IN HAND OFF)                   +( -0.8115143E-02)X1X1  +( -0.3586288E-01)X1X2  +(  0.1566422E 00)X1X3
                                              +( -0.4180006E-01)X1X4  +( -0.1360640E-01)X1X5  +(  0.3125348E-01)X2X2
                                              +(  0.2374681E-01)X2X3  +(  0.5913744E-01)X2X4  +(  0.1220015E-01)X2X5
                                              +(  0.1229244E 00)X3X3  +( -0.5310746E-01)X3X4  +( -0.1409747E-01)X3X5
                                              +( -0.1765712E-02)X4X4  +(  0.1913132E-01)X4X5  +(  0.9786615E-03)X5X5

  MULTIPLE CORRELATION COEFFICIENT = 0.9564

5 PROPORTION OF VEHICLES LOST DUE TO       =     0.2854466E 00        +( -0.5588630E-01)X1    +(  0.1096192E-01)X2
  MALFUNCTIONS AND ATTRITION                  +( -0.4133868E-01)X3    +( -0.3860930E-03)X4    +( -0.9403549E-02)X5
  (EW ONLY)                                   +(  0.7537729E-02)X1X1  +(  0.1240434E-02)X1X2  +( -0.1151467E-01)X1X3
                                              +(  0.2662628E-03)X1X4  +(  0.1777530E-02)X1X5  +( -0.5735736E-02)X2X2
                                              +(  0.2604273E-01)X2X3  +( -0.5757332E-02)X2X4  +( -0.1530506E-02)X2X5
                                              +(  0.1100597E-02)X3X3  +(  0.3808392E-02)X3X4  +( -0.1694196E-02)X3X5
                                              +( -0.2955415E-03)X4X4  +(  0.7235862E-03)X4X5  +(  0.3828597E-03)X5X5

  MULTIPLE CORRELATION COEFFICIENT = 0.9519
```

TABLE II (CONT.)

REGRESSION EQUATION AND MULTIPLE CORRELATION COEFFICIENT FOR EACH OF 15 SELECTED DEPENDENT RPV SYSTEM MEASURES.
(X1 = TELEMETRY DATA TRANSMISSION TIME,X2 = COMMAND DATA TRANSMISSION TIME,X3 = CALL DELAY FOR MODIFICATION/ WINDOW DISPLAYS,X4 = CRT NON-IMMEDIATE INFORMATION REFRESH TIME,X5 = NUMBER OF RPV'S IN SYSTEM,E INDICATES POWER OF TEN.)

```
 6 NUMBER OF TRANSMITTED COMMANDS PER        =      0.3670108E 02      +( -0.9142278E 00)X1    +( -0.1505481E 01)X2
   RPV (ALL TYPES OF VEHICLES                    +(  0.6596261E-01)X3   +( -0.1538427E 01)X4    +( -0.3761474E 00)X5
   COMBINED)                                     +(  0.2304186E 00)X1X1 +( -0.4150702E 00)X1X2  +(  0.1269005E 00)X1X3
                                                 +( -0.6959458E-01)X1X4 +(  0.7674105E-02)X1X5  +(  0.3807502E 00)X2X2
                                                 +( -0.1306823E 00)X2X3 +(  0.1242985E-01)X2X4  +( -0.2494048E-02)X2X5
                                                 +(  0.8844155E-01)X3X3 +( -0.2896365E-01)X3X4  +( -0.1850446E-01)X3X5
                                                 +(  0.4374783E-01)X4X4 +(  0.4717113E-01)X4X5  +(  0.5641098E-03)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.9510

 7 RATIO OF HEADING COMMANDS TRANSMITTED     =      0.4050415E 00      +(  0.6027963E-01)X1    +( -0.8770841E-01)X2
   TO HEADING COMMANDS ATTEMPTED OVER ALL        +(  0.1345820E-01)X3   +( -0.6409157E-02)X4    +(  0.1807787E-01)X5
   MISSION PHASES (STRIKE ONLY)                  +(  0.2277829E-01)X1X1 +( -0.6246173E-01)X1X2  +( -0.9336732E-02)X1X3
                                                 +( -0.2834821E-02)X1X4 +(  0.9568450E-03)X1X5  +(  0.3347345E-01)X2X2
                                                 +( -0.1734694E-02)X2X3 +(  0.4473850E-02)X2X4  +( -0.2366071E-03)X2X5
                                                 +( -0.4689816E-02)X3X3 +(  0.5742982E-02)X3X4  +(  0.7842260E-03)X3X5
                                                 +( -0.5568807E-03)X4X4 +( -0.6473213E-03)X4X5  +( -0.5685289E-03)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.9500

 8 NUMBER OF EW RPVS PER STRIKE WITHIN FIVE =      -0.7453344E 00      +(  0.3553713E-01)X1    +(  0.3249211E 00)X2
   NM OF TRAGET  (EW RPV IS OR IS NOT            +(  0.5609270E 00)X3   +(  0.1428605E 00)X4    +( -0.4348745E-01)X5
   IN HAND OFF MODE)                             +(  0.7026900E-02)X1X1 +( -0.1813457E-01)X1X2  +( -0.3967793E-01)X1X3
                                                 +( -0.6742664E-02)X1X4 +(  0.6584074E-02)X1X5  +(  0.8500114E-02)X2X2
                                                 +( -0.2437819E-01)X2X3 +( -0.2130580E-01)X2X4  +( -0.2682292E-02)X2X5
                                                 +(  0.9150624E-02)X3X3 +( -0.2115912E-01)X3X4  +( -0.1191741E-01)X3X5
                                                 +( -0.1148249E-02)X4X4 +(  0.1558408E-02)X4X5  +(  0.2210006E-02)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.9471

 9 NUMBER OF HEADING COMMANDS TRANSMITTED    =      0.3807365E 02      +( -0.1057187E 01)X1    +( -0.2159647E 01)X2
   PER VEHICLE OVER ALL MISSION PHASES           +( -0.1544937E 01)X3   +( -0.2599002E 01)X4    +( -0.1441970E 00)X5
   (STRIKE ONLY)                                 +(  0.3369452E 00)X1X1 +( -0.6930261E 00)X1X2  +( -0.6023597E-02)X1X3
                                                 +(  0.4393017E-01)X1X4 +( -0.1793973E-01)X1X5  +(  0.6672130E 00)X2X2
                                                 +( -0.1481091E 00)X2X3 +(  0.1022176E 00)X2X4  +( -0.6299478E-01)X2X5
                                                 +( -0.1837372E-01)X3X3 +(  0.1764461E 00)X3X4  +(  0.3166295E-01)X3X5
                                                 +(  0.1135045E-01)X4X4 +(  0.5282775E-01)X4X5  +( -0.3939234E-02)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.9348

10 PROPORTION OF VEHICLES LOST DUE TO        =      0.3402056E 00      +(  0.1257041E 00)X1    +( -0.5235538E-01)X2
   MALFUNCTIONS AND ATTRITION                    +( -0.7660538E-01)X3   +(  0.9585030E-01)X4    +( -0.5536998E-01)X5
   (STRIKE ONLY)                                 +(  0.7571890E-03)X1X1 +( -0.3896684E-02)X1X2  +( -0.1452806E-01)X1X3
                                                 +( -0.6731503E-02)X1X4 +(  0.4136905E-03)X1X5  +( -0.1063949E-01)X2X2
                                                 +(  0.1523557E-01)X2X3 +( -0.2480867E-02)X2X4  +(  0.4376487E-02)X2X5
                                                 +( -0.1525974E-02)X3X3 +(  0.2834821E-02)X3X4  +(  0.2562500E-02)X3X5
                                                 +( -0.2090677E-02)X4X4 +( -0.1819196E-02)X4X5  +(  0.9242108E-03)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.9158
```

TABLE II (CONT.)

REGRESSION EQUATION AND MULTIPLE CORRELATION COEFFICIENT FOR EACH OF 15 SELECTED DEPENDENT RPV SYSTEM MEASURES.
(X1 = TELEMETRY DATA TRANSMISSION TIME,X2 = COMMAND DATA TRANSMISSION TIME,X3 = CALL DELAY FOR MODIFICATION/ WINDOW DISPLAYS,X4 = CRT NON-IMMEDIATE INFORMATION REFRESH TIME,X5 = NUMBER OF RPV'S IN SYSTEM,E INDICATES POWER OF TEN.)

```
11 PROPORTION OF VEHICLES SUCCESSFULLY     =     0.1114185E 01      +( -0.2570966E 00)X1    +( -0.2532576E-01)X2
   HANDED OFF TO TERMINAL PILOT         +(  0.3617722E-01)X3    +(  0.2170157E-01)X4    +(  0.1277942E-01)X5
   (STRIKE ONLY)                        +(  0.4785482E-02)X1X1  +(  0.1098214E-01)X1X2  +(  0.9215560E-02)X1X3
                                        +(  0.3721301E-02)X1X4  +(  0.4629463E-02)X1X5  +(  0.2255334E-03)X2X2
                                        +( -0.2123724E-02)X2X3  +( -0.1753827E-03)X2X4  +( -0.1651786E-03)X2X5
                                        +(  0.2508697E-02)X3X3  +(  0.7079081E-03)X3X4  +( -0.3720238E-02)X3X5
                                        +( -0.1651206E-02)X4X4  +( -0.4955356E-03)X4X5  +( -0.2165404E-03)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.9180

12 PROPORTION OF VEHICLES RECOVERED        =     0.1761147E 00      +( -0.5986824E-01)X1    +( -0.2374324E-01)X2
   (EW ONLY)                            +(  0.9190851E-01)X3    +( -0.2820427E-01)X4    +( -0.1297790E-02)X5
                                        +(  0.1780456E-02)X1X1  +(  0.6377548E-02)X1X2  +( -0.3188776E-02)X1X3
                                        +(  0.1594388E-02)X1X4  +(  0.7440476E-03)X1X5  +( -0.2773075E-02)X2X2
                                        +( -0.3188776E-02)X2X3  +(  0.1594388E-02)X2X4  +(  0.7440476E-03)X2X5
                                        +( -0.4962852E-03)X3X3  +( -0.3188776E-02)X3X4  +( -0.1488095E-02)X3X5
                                        +(  0.4451240E-03)X4X4  +(  0.7440476E-03)X4X5  +( -0.1509785E-03)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.9027

13 TIME BETWEEN TERMINAL PILOT STRIKES     =     0.3578948E 03      +(  0.1074053E 03)X1    +(  0.1009616E 02)X2
   (SECONDS)                            +( -0.1366956E 02)X3    +( -0.1171003E 02)X4    +( -0.2143268E 02)X5
                                        +( -0.1683217E 01)X1X1  +( -0.3866952E 01)X1X2  +( -0.7030580E 01)X1X3
                                        +(  0.2577136E 00)X1X4  +( -0.2372949E 01)X1X5  +( -0.2733658E 01)X2X2
                                        +( -0.1854892E 01)X2X3  +(  0.2263039E 01)X2X4  +(  0.3214613E 00)X2X5
                                        +( -0.7768147E 00)X3X3  +(  0.1400121E 01)X3X4  +(  0.1941304E 01)X3X5
                                        +( -0.4582056E 00)X4X4  +(  0.1060885E 00)X4X5  +(  0.4197474E 00)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.9022

14 RATIO OF HEADING COMMANDS TRANSMITTED   =     0.2381705E-01      +(  0.1455464E 00)X1    +( -0.4461431E-01)X2
   TO HEADING COMMANDS ATTEMPTED OVER ALL +(  0.1055434E 00)X3    +( -0.1039076E-01)X4    +( -0.4470672E-02)X5
   MISSION PHASES (EW ONLY)             +(  0.6745707E-02)X1X1  +( -0.3376913E-01)X1X2  +( -0.6205354E-02)X1X3
                                        +( -0.1253189E-02)X1X4  +( -0.9479166E-03)X1X5  +(  0.1117811E-01)X2X2
                                        +( -0.2551020E-02)X2X3  +(  0.5618621E-02)X2X4  +(  0.7261904E-03)X2X5
                                        +( -0.4217301E-02)X3X3  +( -0.3258929E-02)X3X4  +( -0.7738094E-04)X3X5
                                        +(  0.6819631E-03)X4X4  +( -0.1532738E-03)X4X5  +(  0.1301136E-03)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8976

15 RATIO OF DISTANCE ACTUALLY TRAVELLED    =     0.1003310E 01      +( -0.2268939E-02)X1    +(  0.6804653E-03)X2
   BY A STRIKE RPV TO THE LENGTH        +( -0.4891774E-03)X3    +(  0.1485660E-02)X4    +(  0.1117424E-04)X5
   OF FLIGHT PLAN                       +(  0.6435528E-04)X1X1  +( -0.8928571E-04)X1X2  +(  0.2614795E-03)X1X3
                                        +(  0.2869897E-04)X1X4  +(  0.3422618E-04)X1X5  +( -0.3768552E-04)X2X2
                                        +(  0.1084184E-03)X2X3  +( -0.9247448E-04)X2X4  +(  0.1934523E-04)X2X5
                                        +( -0.8232838E-04)X3X3  +( -0.2551019E-04)X3X4  +( -0.8928570E-05)X3X5
                                        +( -0.2855403E-04)X4X4  +( -0.3869047E-04)X4X5  +(  0.2462120E-05)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8892
```

TABLE III

95% CONFIDENCE INTERVALS FOR EACH OF 15 SELECTED DEPENDENT

RPV SYSTEM VARIABLES

	Measure	Minimum Limit	Maximum Limit
1)	Number of heading commands transmitted per vehicle over all mission phases (Low Recce only)	6.91	8.18
2)	Time interval between transmitted commands (all types of vehicles combined) (seconds)	10.74	14.99
3)	Number of heading commands transmitted per vehicle over all mission phases (EW only)	8.60	11.17
4)	Strike and Low Recce ATA difference (min.) at target (Low Recce is or is not handed off)	1.58	2.71
5)	Proportion of vehicles lost due to malfunctions and attrition (EW only)	0.078	0.222
6)	Number of transmitted commands per RPV (all types of vehicles combined) (seconds)	18.74	22.31
7)	Ratio of heading commands transmitted to heading commands attempted over all mission phases	0.242	0.538
8)	Number of EW RPVs per Strike within 5 NM of target (EW RPV is or is not handed off)	1.02	1.55
9)	Number of heading commands transmitted per vehicle over all mission phases Strike only)	10.71	17.09
10)	Proportion of vehicles lost due to malfunctions and attrition (Strike only)	0.048	0.254

TABLE III CONTINUED

	Measure	Minimum Limit	Maximum Limit
11)	Proportion of vehicles successfully handed off to terminal pilot	0.815	0.969
12)	Proportion of vehicles recovered (EW only)	0.000	0.060
13)	Time between terminal pilot strikes (seconds)	177.95	287.43
14)	Ratio of heading commands transmitted to heading commands attempted over all mission phases (EW only)	0.210	0.448
15)	Ratio of the distance actually travelled by a strike vehicle to the length of flight plan	1.034	1.038

FIGURE I

HUMAN ENGINEERING SYSTEMS SIMULATION FACILITY CONFIGURATION FOR RPV SYSTEM SIMULATION

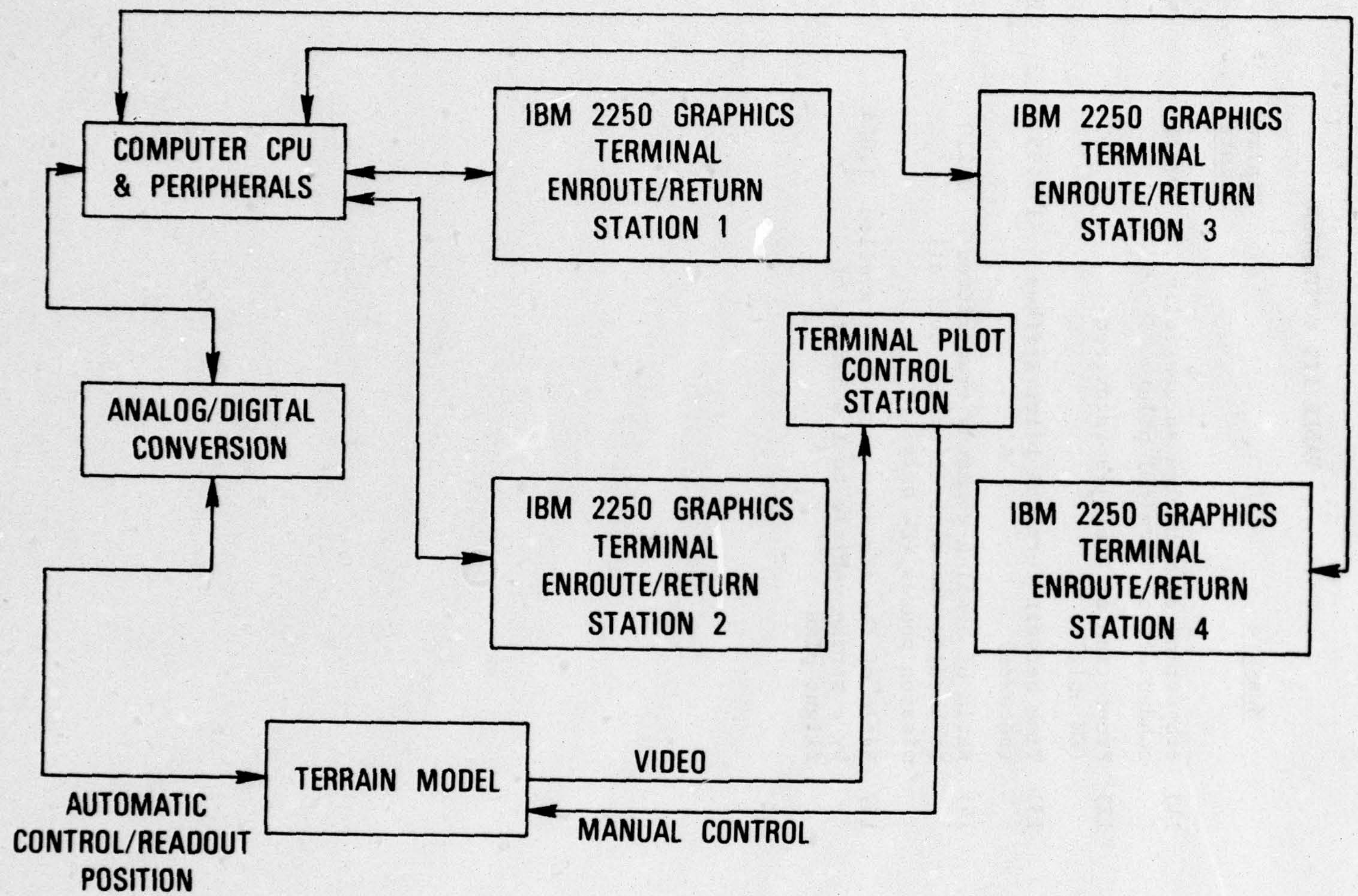


FIGURE 2 - Team of Five Operators Performing in the AMRL RPV System Simulation

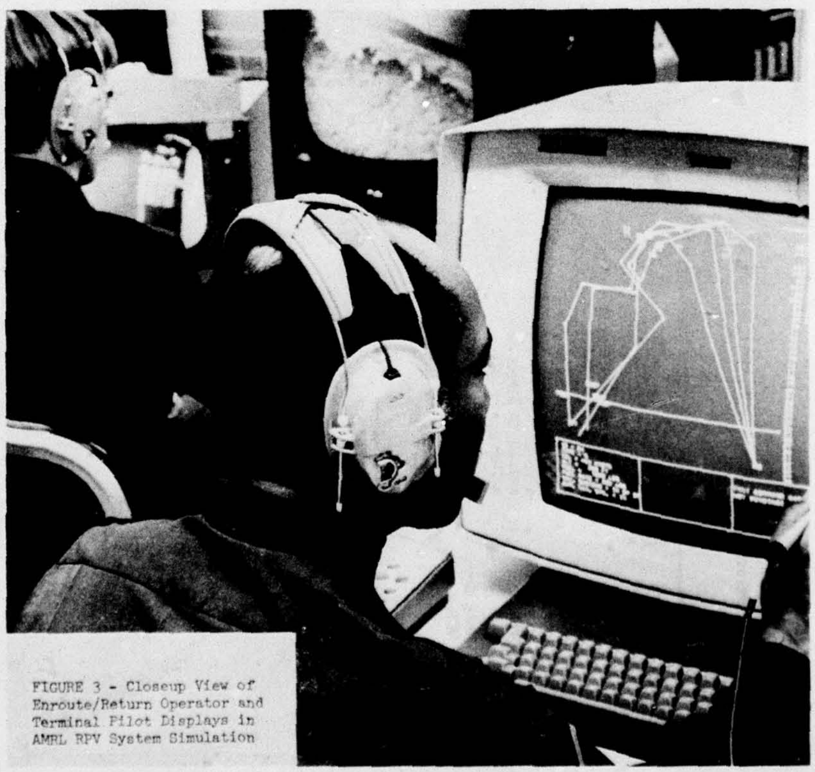


FIGURE 3 - Closeup View of Enroute/Return Operator and Terminal Pilot Displays in AMRL RPV System Simulation

FIGURE 4

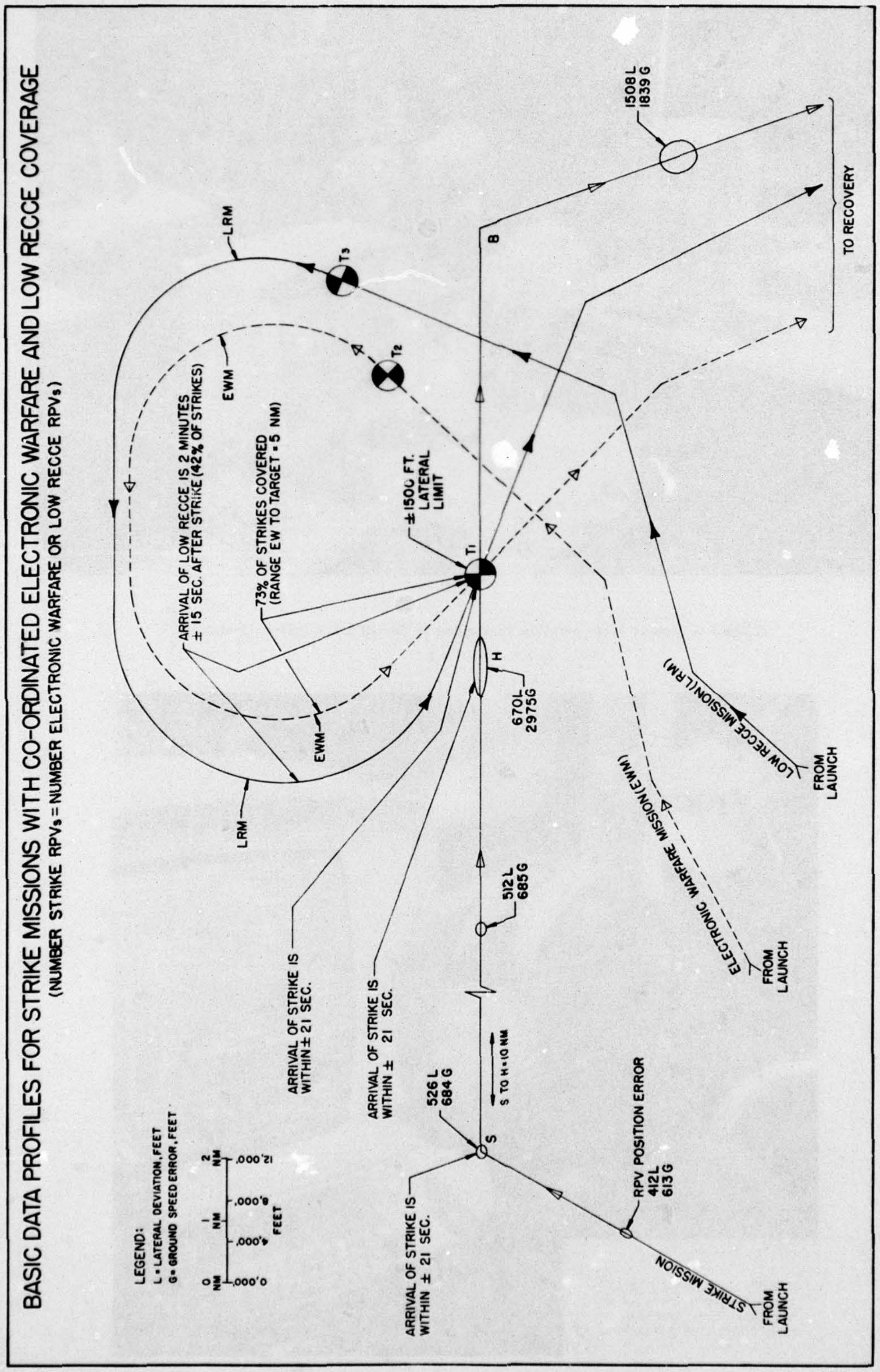

BASIC DATA PROFILES FOR STRIKE MISSIONS WITH CO-ORDINATED ELECTRONIC WARFARE AND LOW RECCE COVERAGE
(NUMBER STRIKE RPVs = NUMBER ELECTRONIC WARFARE OR LOW RECCE RPVs)
LEGEND:
L = LATERAL DEVIATION, FEET
G = GROUND SPEED ERROR, FEET
0 NM
1 NM
2 NM
0,000
4,000
8,000
12,000
FEET
ARRIVAL OF STRIKE IS WITHIN ± 21 SEC.
ARRIVAL OF STRIKE IS WITHIN ± 21 SEC.
ARRIVAL OF STRIKE IS WITHIN ± 21 SEC.
526 L
684 G
S
S TO H = 10 NM
512 L
685 G
670 L
2975 G
H
RPV POSITION ERROR
412 L
613 G
STRIKE MISSION
FROM LAUNCH
ELECTRONIC WARFARE MISSION (EWM)
FROM LAUNCH
LOW RECCE MISSION (LRM)
FROM LAUNCH
LRM
EWM
EWM
LRM
ARRIVAL OF LOW RECCE IS 2 MINUTES ± 15 SEC. AFTER STRIKE (42% OF STRIKES)
73% OF STRIKES COVERED (RANGE EW TO TARGET = 5 NM)
± 1500 FT. LATERAL LIMIT
T1
T2
T3
B
1508 L
1839 G
TO RECOVERY

FIGURE 5

BASIC DATA PROFILES FOR STRIKE MISSIONS WITH CO-ORDINATED ELECTRONIC WARFARE AND LOW RECCE COVERAGE
(NUMBER STRIKE RPVs >NUMBER ELECTRONIC WARFARE OR LOW RECCE RPVs)

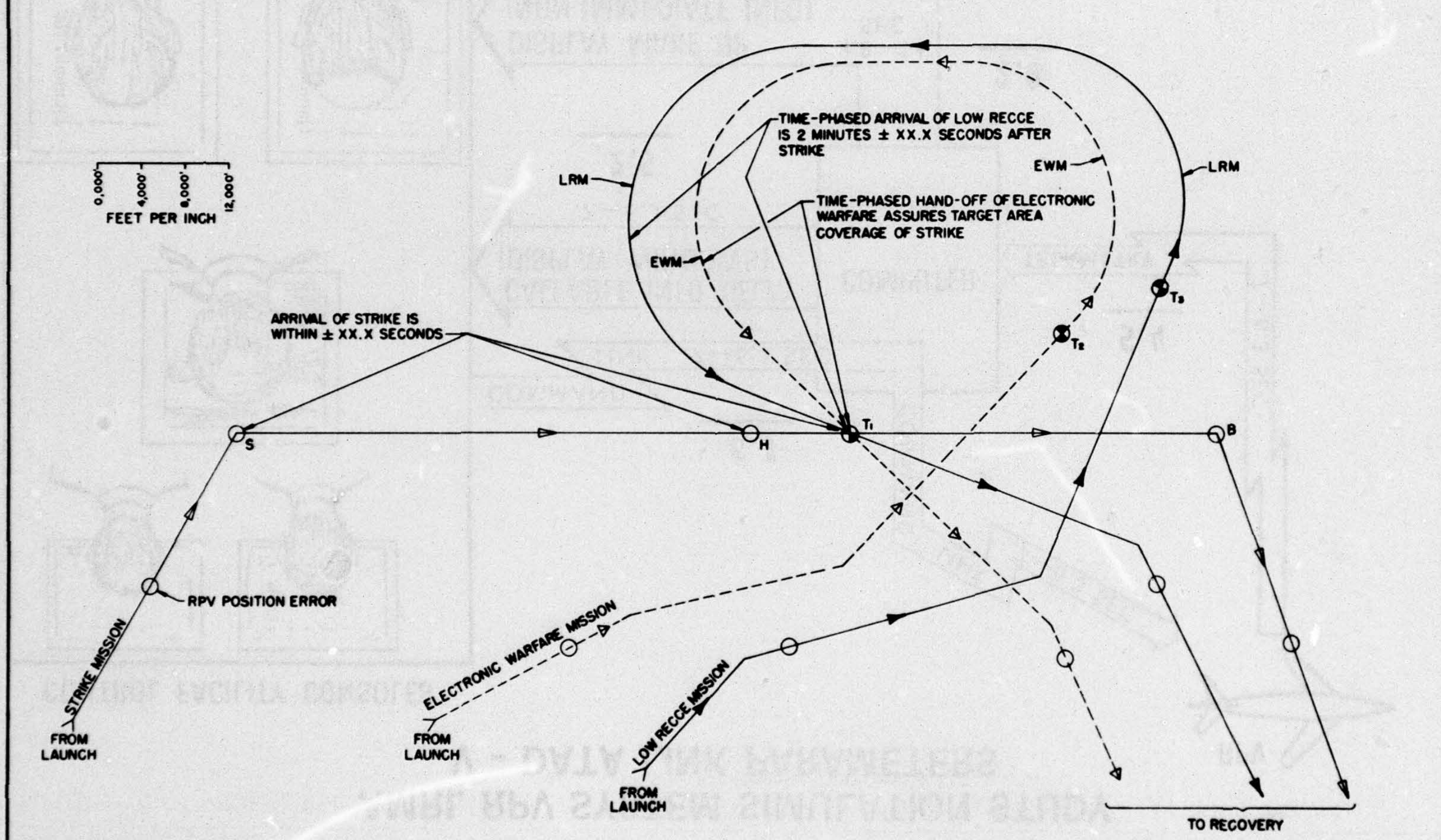
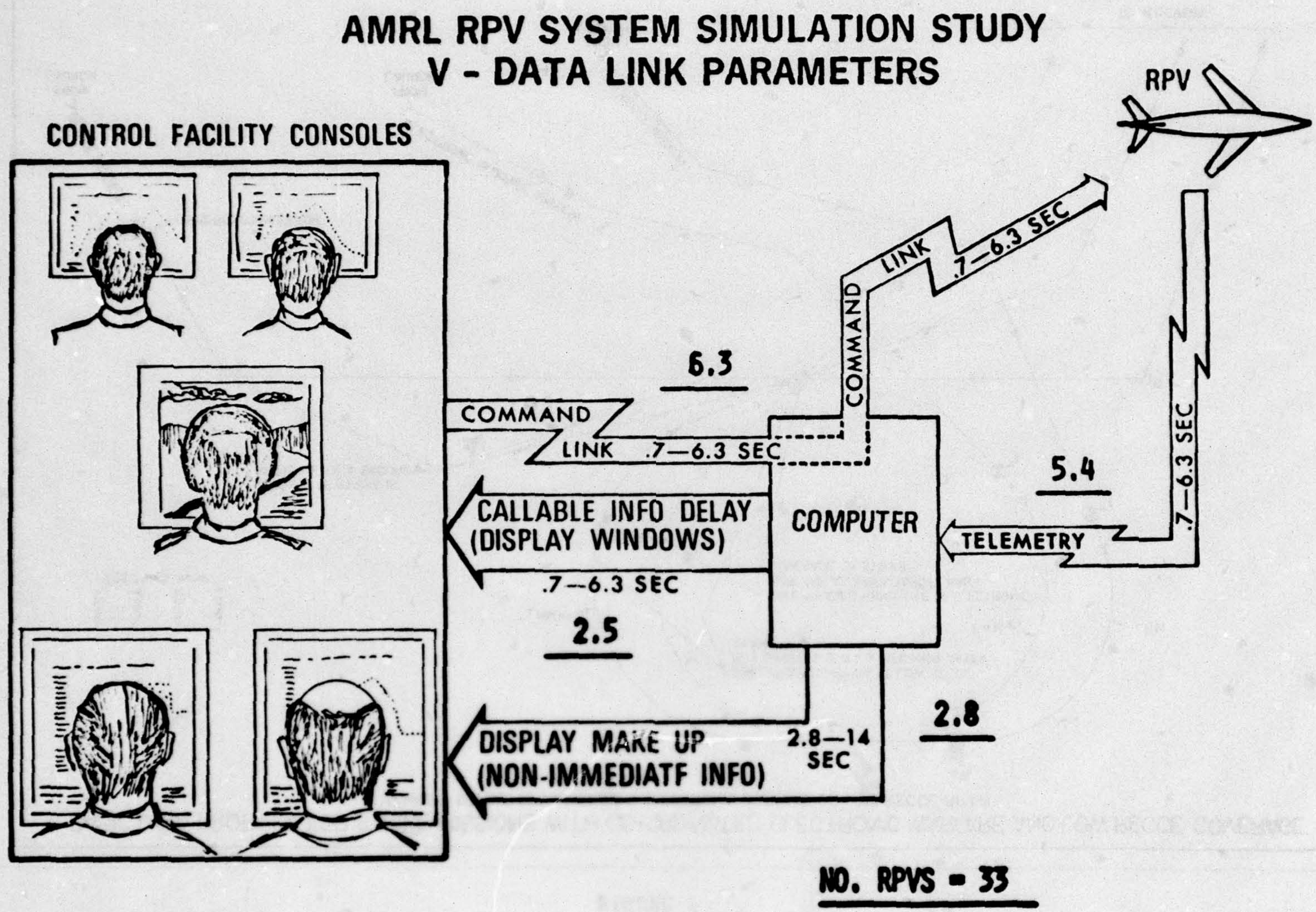


FIGURE 6


AMRL RPV SYSTEM SIMULATION STUDY
V - DATA LINK PARAMETERS
CONTROL FACILITY CONSOLES
RPV
COMMAND LINK .7—6.3 SEC
6.3
COMMAND LINK .7—6.3 SEC
CALLABLE INFO DELAY (DISPLAY WINDOWS)
.7—6.3 SEC
2.5
COMPUTER
5.4
TELEMETRY
.7—6.3 SEC
DISPLAY MAKE UP (NON-IMMEDIATF INFO)
2.8—14 SEC
2.8
NO. RPVS = 33

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