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

AEROSPACE MEDICAL RESEARCH LABORATORY

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AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
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NOTICES

TECHNICAL REVIEW AND APPROVAL

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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 the AMRL RPV System Simulation and Research Program are as follows: (1) Perform RPV system design evaluation studies, i.e., evaluate alternative design configurations, assumptions, operating procedures, etc.; (2) Assess RPV system effectiveness, i.e. evaluate the expected effectiveness of a given

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) system configuration such as its overall probability of achieving a target, etc.; (3) Provide man-machine/environment interface engineering data, i.e. recommend displays etc.; (4) Test bed new technology, e.g. evaluate effectiveness of contractor designed consoles, video bandwidth compression techniques, etc. The results of the fourth simulation study are reported herein. This study included automatic RPV heading correction and position report smoothing functions in the simulation. The study employed scenarios requiring a limited number of support mission RPVs, via reprogramming, to provide coverage for a set of Strike RPVs (or manned vehicles). The study evaluates RPV system performance under the simultaneous effects of RPV Automatic Heading Correction Cross Track Threshold, Total Number of RPVs Under System Control, Ratio of Strike Set to Support Vehicle Set, and Display (Window) Sizes or Scales.

PREFACE

The authors acknowledge the assistance of the following individuals: Mr. Gene Sebasky and Mr. Dale Wartluft, Federal Systems Division, IBM; Mr. Robert F. Bachert, Sgt Jon VanDonkelaar, AMRL; Mr. Jeff Baughman, Miss Jody Kusy, Miss Suzanne Gross, and Mr. Mike Berger, University of Dayton. Each of these individuals has contributed substantially to the success of the RPV System Simulation program being conducted in this laboratory.

CONTENTS

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 fourth RPV systems simulation study (RPV Study IV) employing the AMRL RPV System Simulation Test Bed.

2.0 AMRL RPV SYSTEM SIMULATION TEST BED.

2.1.0 RPV Study IV 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 Enroute/Return Phase operators and one Terminal Phase Pilot operator (henceforth referred to as pilot). Each Enroute/Return operator monitors and operates a computer graphics terminal (IBM 2250) comprised of a graphic display (cathode ray tube, CRT), alphanumeric keyboard, lightpen, 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 simulation facility. Figure 3 provides a closer view of one Enroute/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 IV 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 Enroute/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 velocity and 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 RPV STUDY IV MISSION SCENARIO PARAMETERS

3.1.0 RPV Study II* 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** 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 large number of strike RPVs or manned aircraft. RPV Study IV continued to use this type of mission scenario.

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* Mills, R. G.; Bachert, R. B. and Aume, N. M.; Summary Report of AMRL Remotely Piloted Vehicle (RPV) System Simulation Study II Results, AMRL-TR-75-13, Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio, Feb. 1975, AD 006 142.

**Mills, R. G.; Aume, N. M. and Bachert, R. F.; Summary Report of AMRL Remotely Piloted Vehicle (RPV) System Simulation Study III Results, AMRL-TR-75-126, Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio, December 1975, AD A020064.

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

3.2.1 RPV Launch and Recovery Phases are assumed to occur "outside" the simulation.

3.2.2 Each RPV has an independent programmed flight plan that is assumed to be stored in the DCF (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 A round-trip of approximately 400 NM per RPV is simulated, with the center of the target area located 200 NM from the launch insertion and recovery coordinates. Strike RPVs held quite closely to their path lengths. E and L RPVs, due to repeated passes over targets, travelled considerably farther than the programmed path length.

3.2.5 Each RPV has an initial command velocity of 400 knots and a command altitude of 200 feet.

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

3.2.7 In RPV Study IV 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 RPVs also on 15 second intervals. The Strike group is launched last on 120 second intervals. This interval was 90 seconds in RPV Study III. The number of vehicles in each group is parametric and is determined prior to each simulated mission (see 6.2.1).

3.2.8 RPVs are launched from one of three launch areas.

3.2.9 For the RPV Study IV scenario each Strike, EW, and Low Recce group must be time-phased (coordinated arrivals) to target. Time-phasing is such that a single EW must be within a 7 NM radius of the target assigned to the coordinated Strike and a single Low Recce follows the same Strike vehicle of 2 minutes (simulating BDA). These coordination requirments will be discussed later (see 5.6.0).

3.2.10 Each Strike flight plan has a designated Hand-off coordinate (H) for Hand-off to Terminal Phase (Weapons delivery). Each strike flight plan has a designated waypoint S, prior to H, for cueing the start of Hand-off procedures. In addition to the S and H waypoints each Strike flight plan has designated Target (T, one of three targets), Hand-back (B), and Recovery (R) coordinates.

3.2.11 In RPV Study IV scenarios 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 Recovery coordinate).

3.2.12 Prior to hand-off, an RPV is given a command to climb to an altitude of 3000 ft. (in the case of Strike the small area on terrain model also required a change in command velocity to 250 knots).

3.2.13 For Strike flight plans the distance from S to H is 7.77 NM, from H to T the average distance is 1.5 NM.

3.2.14 Each RPV is given just enough fuel to complete the roundtrip mission. Strike RPVs are assigned a fuel load of 2000 pounds. EW and Low Recce RPVs are assigned a load of 4000 pounds.

3.2.15 Only Strike RPVs are handed-off to Pilot control on a first-come first-served basis.

3.2.16 It is assumed that EW and Low Recce RPVs must be handed-off but that the recipient operator is outside the simulation (e.g., EWO, photo interpreter, etc.).

3.2.17 All EW, Low Recce, and overload Strike RPVs (Strikes not handed-off to the Terminal Pilot operator) are handed-off to other Enroute/Return operators in the system but the recipient is passive (i.e., the only action on the operator's part is throwing the "accept" switches; the operator does not monitor the RPV, etc.).

3.2.18 Video imagery from the terrain model and continuous control are available to the Pilot only 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.

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

3.2.20 The simulation employed for RPV Study IV 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 a given threshold value. 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).

3.2.21 Both of the above functions (3.2.19, 3.2.20) 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 RPV Study IV. The impact of these two functions was reported in an RPV Study II supplement.*

3.3.0 Figure 4 is a basic profile of scenario requirements for RPV Study IV. In this figure one 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).

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* Mills, R. G.; Bachert, R. B. and Aume, N. M. <u>Supplementary Report of RPV System Simulation Study II: Evaluation of RPV Position Report Smoothing and Automatic Heading Correction</u>. AMRL-TR-75-87, Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio, Sept 1975, AD A-017 334.

3.4.0 Figure 4 also indicates that the EW and Low Recce shown in the figure are to rendezvous with the Strike RPV at Target T_1. Since there are less EW and Low Recce RPVs than Strikes, the EW RPV shown in the figure has previously covered a Strike at Target T_2. Also, the Low Recce has previously provided BDA for a Strike at Target T_3. In order to provide the necessary coverage at T_1 operators are required to reroute (reprogram) both support RPVs to T_1 such that the rendezvous with the incoming Strike will occur according to time-phasing requirements.

4.0 CONTROL/DISPLAY PARAMETERS

4.1.0 Each Enroute/Return operator station consists of an IBM 2250 Graphics CRT Terminals (there are four such terminals). These terminals are equipped with a 12 inch CRT, light pen, alphanumeric keyboard, and a programmable function 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 the terrain during the Strikes or the information on one of the CRT terminals during the rest of the mission.

4.3.0 Each CRT has the capability to display flight plans, track signatures, geographical reference, etc., for up to 10 RPVs simultaneously. RPV status parameters such as velocity, fuel remaining, RPV mission type, etc., can be displayed for an individual RPV. Other displayed parameters are ETA to the next designated way-point, 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 their terminals. In the case of heading changes the operator can employ any one of the three window sizes (a 10 x 10 NM to 30 x 30 NM, a 60 x 60 NM to 140 x 140 NM, (see 6.2.4 for complete details) which are centered on the RPV to be changed, and a 220 NM x 220 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. This is called a "patch", and it 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 patch, in which case the operator must introduce a new patch. Valid patches are transmitted over the command data link to the on board computer and the RPV proceeds to fly through the points prescribed in the patch.

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 patch (change heading). After a command to an RPV is entered, it remains in the "outstanding commands" block (during this time it is displayed) until it has been transmitted.

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 five seconds.

5.0 OPERATOR RESPONSIBILITIES AND PROCEDURES

5.1.0 Enroute/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 desired 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 Enroute and Return Phases of the mission.

5.3.2 Accept Strike RPVs from Enroute/Return operators.

5.3.3 Switch into Video and Continuous Control mode 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 an approximate $\pm$ 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 priorities are listed here.

5.6.1 Priority 1 -- Maximize the number of Strike RPVs handed-off successfully to the Pilot with the EW and Low Recce rendezvous criteria (see 3.2.9). This implies occasional adjustments to the prescribed ETA's, remembering to keep the squared error(difference between prescribed and actual ETA) to a minimum.

5.6.2 Priority 2 -- Maximize the number of Strike RPVs handed-off successfully to the Pilot but fail to meet the EW and Low Recce rendezvous criteria, (e.g., a Strike RPV properly handed-off but not provided with BDA coverage because it was not possible or BDA coverage provided via a Low Recce RPV 4 minutes after Strike instead of the required 2 minutes).

5.6.3 Priority 3 -- Maximize the number of Strikes achieving Priority 1 or 2 and original ETA accuracy for Strikes.

5.6.4 Priority 4 -- Maximize the number of Strikes achieving above priorities and minimal position error along flight plan.

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. Target assignment was made at the start of each mission. 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 Enroute/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 IV -- SPECIFIC OBJECTIVES AND SYSTEM PARAMETERS INVESTIGATED

6.1.0 The objective of RPV Study IV 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. These variables are listed here.

6.2.1 Number of RPVs under simultaneous control by the system (18, 21, 24, 27, or 30 RPVs). This parameter can be converted to an RPV/operator Ratio assuming four Enroute/Return operators. It can be used interchangeably with the number of RPVs parameter. However, RPV/Operator Ratio can be employed across systems of varying expected number of operators.

6.2.2 RPV Lateral Deviation Alarm Threshold Value (100, 325, 550, 775, or 1000 ft.). This threshold determines the value upon which the automatic heading correction function is triggered. It also triggers a counter (0-9) that displays the number of consecutive frames an RPV has exceeded the threshold value thus, indicating a lateral error trend. The automatic heading correction function would trigger on the fourth count. However, operators can override the function, disable it, and it is automatically disabled during an RPV turn and under certain other conditions (see the Instruction manual noted in 2.4.0).

6.2.3 Ratio of Strikes to EW and Low Recce RPVs (1.0, 2.5, 4.0, 5.5, or 7.0). This parameter is calculated by computing the ratio of the total number of Strike RPVs to the average of the total numbers of EW and Low Recce RPVs (i.e., (EW + Low Recce)/2). The average is required to account for unequal numbers of EW and Low Recce RPVs. Thus, a ratio of 7.0 indicates there is only 1 EW RPV and there is only 1 Low Recce RPV available to provide coverage for 7 Strike vehicles as they arrive sequentially in the target area.

6.2.4 The callable window displays' scaling was a variable in this study. The full size, 220 x 220 NM display remained unchanged, but the smaller scale windows could take on different values. The smallest (Mod 1) could be 10, 15, 20, 25, or 30 NM square. The intermediate (Mod 2) could be 60, 80, 100, 120, or 140 NM square. During a mission, both were held at the preselected values; these values were also printed on the ETA sheets that were available to the operators at the start of each mission.

6.2.5 RPV Position Reporting error was held constant at 525 ft. range error and 0.6 miliradian azimuth error.

6.3.0 The five variables were varied in combination with each other according to a Central Composite/Fractional Factorial experimental design.* 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., a simulated mission).

*Experimental Designs, Cochran, W. G. and Cos, G. M., New York: Wiley, 1957.

6.4.0 In RPV Study IV 32 observations (5 of them 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, RPV Studies I, II and III, or some combination thereof. No member of the principal teams had less than the 5 months training. This training had been acquired during the initial training in the program or as a member of the back-up team. Pilots had been 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 practice missions. Data collection was started after a unanimous vote of the primary teams that they were ready to start.

8.0 RPV STUDY IV 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 Approximately 100 dependent variable measures of RPV system performance were taken in RPV Study IV. The mean and standard deviation of each of these measures 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 Enroute/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 II.

8.2.5 Miscellaneous Variables--are simply those that do not fit conveniently into a large enough 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 effect 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. The examination of Table I can provide insight into the objectives of the missions as well as lead to additional questions. (Since EW and 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 presented 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. Cross track error under the various mission phases showed a general decrease as compared to RPV Study III. This can be explained by the fact that in the previous study, subjects relied entirely on the automatic heading correction to keep the RPVs on course. In RPV Study IV, they were instructed to introduce manual heading corrections if and when the situation demanded it (see variables 1, 3, 5, 7, 9, 11, and 13, Table 1). The added manual heading corrections are also reflected in the slight increase in heading commands per vehicle (variables 19, 20, and 23).

8.3.2 The major new variable investigated in RPV Study IV was the effect of various window sizes. No major overall influence was expected, and none was observed. The effect of the various sizes is mainly on visual resolution along the outbound and return legs. The size can become a limiting factor while rerouting EW and Low Recce RPVs around the targets. Very small sizes may not have enough space to make a good heading change, and at very large sizes the displayed situation may become too cluttered and cramped.

8.3.3 A note of explanation on variables 25 and 26: variable 25 pertains to the time between commands for a single RPV, while 26 pertains to the entire fleet consisting of a large number of RPVs.

8.3.4 One might note that for EW and Low Recce RPVs, the recovery rate is of the order of 2 percent, while about 16 percent 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 In order to assess the effects of the five experimental variables a regression analysis of variance was performed on each variable listed in Table 1. This analysis yielded second order regression equations, confidence interval estimates, analysis of variance, and a multiple regression coefficient (MRC) for each variable. The MRC is an indication of the extent to which the experimental variables have an influence on the measured variable. Nineteen variables with the highest MRCs were selected and are presented in Table II according to the rank order of their MRC. (The same analysis can be provided for any other variable in Table I and any other measurable variable on request.) Thus, the first variable is Number of Heading Commands Transmitted per Vehicle for the Enroute Phase (Strike only) with the highest MRC, $R = 0.9711$. It is noteworthy that the first eleven variables are concerned with various facets of heading commands. Table II 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 coefficient (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.

8.4.1 The analyses performed did not reveal the existence of of a dominant system parameter in a practical sense. Although there are a number of statistically significant relationships, with the exception of the Lateral Deviation Threshold parameter, none could be even remotely practically significant. The parameter of Ratio of Strike RPVs to EW and Low Recce RPVs had only a minimal effect on any of the performance variables, a finding that is similar to the one arrived at in RPV Study III. After a review of all performance variables, it was concluded that this Ratio could account for less than 1.0% of the total variability in most of the variables. The ratio accounted for a larger percentage (5 to 15%) of the variability in the number of altitude and velocity change commands for EW and Low Recce RPVs, and in the coverage provided for Strikes by the support RPVs. While the behavior of the above variables disallows the pinpointing of an optimum Ratio, all these variables distinctly worsen in the range of 5.0 to 7.0. Some of the variables also worsen as the Ratio approaches 1.0, which suggests that the Ratio of Strikes to EW and Low Recce RPVs should be somewhere in the range of 2.0 to 4.0. It is possible that the absolute number of support RPVs is a significant parameter, in that with very few support RPVs the loss of one can result in the loss of coverage, and with a large number of support RPVs the management of the fleet becomes confusing and difficult.

8.4.2 The only system parameter of any significance is the Lateral Deviation Threshold. It is the parameter solely responsible for the high correlations obtained for RPV Cross Track and Command Data Link usage variables. In RPV Study III, the enroute/return operators relied entirely on the automatic heading correction to keep RPVs on course. In RPV Study IV, they were instructed to introduce manual corrections when the threshold value was large and when an RPV was observed to be deviating from its flight-path by some decision value determined by each team. Such a situation then influences two groups of variables: one relating to cross track errors and the other relating to command data link usage. It should be obvious that the basic driving function is RPV navigation error, or the tendency to drift off course. As long as this tendency is constant, attempts to keep RPVs on course will require a large number of heading commands; and an attempt to keep the number of heading commands low will result in an increased cross track error. A review of the analyses and the regression equations discloses that a large number of system performance variables (in the "number of heading commands" and in the "cross track error" categories) are determined to a great extent by the lateral deviation threshold. A review of cross track error data revealed that the magnitude of cross track error is approximately one half of the threshold value. The implication here is that the operators did not uniformly and consistently introduce manual heading corrections, but still relied largely on automatic heading corrections, although there was some manual heading correction. If a real-world RPV system is to have an automatic course correction capability, then it should be so designed as to make manual corrections unnecessary. In the design process, one should consider the desired accuracy or the maximum allowable cross track error to determine the automatic threshold value. However, the inherent error of the position reporting system also has to be considered, and the threshold should not be set so low that it is triggered frequently by the random errors produced by the position reporting system. Manual heading changes, such as for recycling support RPVs around a target, of course, are in a different category; the system must have a manual heading change capability in addition to the automatic course correction.

8.4.3 While it is possible to make a general statement about the magnitude of the cross track error as a function of automatic threshold, the number of heading commands cannot be generalized as easily, as the latter depends not only on the threshold value but also on the tendency of the RPVs to drift off course and on mission duration.

8.4.4 The largest recorded influence of the combination of display window sizes was on the Ratio of Distance Travelled to Length of Flight Path (variable 15 in Table I and variable 17 in Table II). According to the data, optimum performance can be expected with the windows approximately 20 and 70 NM square. These numbers, though, may be specific to the scenarios of RPV Study IV, and other scenarios may require different sizes. Furthermore, it was the interaction term which was statistically significant, but it accounted for only 18.09% of the variability in performance, which makes it a weak influence. It also must be pointed out that the Ratio of Distance Travelled to Length of Flight Path is not a very good variable to base judgements on. As a general rule, it can be stated that a single window size is insufficient because it lacks flexibility. There is the possibility of allowing operators to select the window size they want as they deal with real time events - and this is completely within the state-of-art of computer graphics. With such a feature, the operator would type in a number which determines the window size until such time when the operator decides to change it.

Otherwise, window sizes can be decided upon by considering how large an area has to be available (e.g., for making good heading changes for recycyling RPVs around a target) and how fine a resolution is needed (e.g., to visually detect deviations from flight path). There still should be the capability to change the window sizes if a radically different situation demands it.

8.4.5 Table III provides a list of confidence interval estimates for the 19 variables 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 for the Enroute Phase only (Strike Only), one can expect the number to be greater than 15.13 but less than 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 expectation. It is also noted that 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.

8.5.0 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, the result is consistent with all 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, i.e., IVs "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 the parameters in the strict mathematical sense. The effects are too small and the trade-offs are too complex. 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 8.5.0).

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

10.0 RPV SYSTEM SIMULATION STUDY V - PLANS

10.1.0 The fidelity of the simulation will be increased by introducing more realistic dynamic changes in RPV altitude and speed in flight plan follow mode instead of the instantaneous changes used up to now. To investigate the effects of a limited data processing capability, various delays will be introduced in the system's reactions to operator commands (such as speed and altitude changes, and heading commands). These modifications have been made possible by an increase in computer capability (from IBM 360/40 to IBM 370/155), allowing the parametric study of data transmission rate requirements and other refinements and additions to the simulation of future RPV systems.

TABLE I

MEAN, STANDARD DEVIATION (STD DEV) PER MISSION FOR MAJOR DEPENDENT VARIABLES OF RPV STUDY IV . 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)	253.204	51.957	**********	**********	**********	**********
2	GROUND SPEED (LONGITUDINAL DISTANCE FROM EXPECTED TO TRUE RPV POSITION) ERROR DURING THE ENROUTE PHASE (FEET)	234.487	38.570	**********	**********	**********	**********
3	CROSS TRACK ERROR AT THE TIME OF ARRIVAL AT THE S WAYPOINT (FEET) (STRIKE ONLY)	325.105	47.656	**********	**********	**********	**********
4	GROUND SPEED ERROR AT THE TIME OF ARRIVAL AT THE S WAYPOINT(FEET) (STRIKE ONLY)	305.500	41.881	**********	**********	**********	**********
5	CROSS TRACK ERROR FROM S WAYPOINT TO H WAYPOINT (FEET)(STRIKE ONLY)	306.837	42.333	**********	**********	**********	**********
6	GROUND SPEED ERROR FROM S WAYPOINT TO H WAYPOINT (FEET)(STRIKE ONLY)	294.765	39.193	**********	**********	**********	**********
7	CROSS TRACK ERROR AT THE TIME OF ARRIVAL AT THE H WAYPOINT (FEET)	382.485	82.246	**********	**********	**********	**********
8	GROUND SPEED ERROR AT THE TIME OF ARRIVAL AT THE H WAYPOINT (FEET)	648.020	155.636	**********	**********	**********	**********
9	CROSS TRACK ERROR FROM THE H WAYPOINT AT THE TIME THE TERMINAL PILOT OPERATOR ACTUALLY TOOK CONTROL(FEET)(STRIKE ONLY)	427.688	173.575	**********	**********	**********	**********
10	GROUND SPEED ERROR FROM H AT THE TIME THE TERMINAL PILOT OPERATOR ACTUALLY TOOK CONTROL (FEET)(STRIKE ONLY)	1780.378	840.106	**********	**********	**********	**********
11	CROSS TRACK ERROR DURING THE RETURN PHASE (FEET)	363.088	81.961	**********	**********	**********	**********
12	GROUND SPEED ERROR DURING THE RETURN PHASE (FEET)	425.665	142.813	**********	**********	**********	**********
13	CROSS TRACK ERROR FOR ENROUTE AND RETURN PHASES COMBINED (FEET)	308.447	59.072	**********	**********	**********	**********
14	GROUND SPEED ERROR FOR ENROUTE AND RETURN PHASES COMBINED (FEET)	351.571	120.040	**********	**********	**********	**********
15	RATIO OF THE DISTANCE ACTUALLY TRAVELED BY A VEHICLE TO THE LENGTH OF FLIGHT PLAN (THIRD PLACE ACCURACY)	1.002	0.003	**********	**********	**********	**********

TABLE I (CONT.)

MEAN, STANDARD DEVIATION (STD DEV) PER MISSION FOR MAJOR DEPENDENT VARIABLES OF RPV STUDY IV. 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 MEAN	STRIKE STD DEV	ELECTRONIC WARFARE MEAN	ELECTRONIC WARFARE STD DEV	LOW RECCE MEAN	LOW RECCE STD DEV
	ENROUTE-TERMINAL-RETURN TRANSITION RELATED VARIABLES						
16	PROPORTION OF VEHICLES SUCCESSFULLY HANDED OFF TO TERMINAL PILOT OPERATOR	0.923	0.040**				
17	TIME BETWEEN TERMINAL PILOT OPERATOR STRIKES (ONE STRIKE/UNIT TIME IN SECONDS)	159.033	12.099**				
18	TIME FOR TERMINAL PHASE FLIGHT (SECONDS)	17.305	1.320**				
	COMMAND DATA LINK USAGE VARIABLES						
19	NUMBER OF HEADING COMMANDS TRANSMITTED PER VEHICLE FOR THE ENROUTE PHASE ONLY	17.622	10.310	16.389	10.241	16.368	9.684
20	NUMBER OF HEADING COMMANDS TRANSMITTED PER VEHICLE OVER ALL MISSION PHASES	40.326	20.786	24.934	10.321	25.498	10.804
21	NUMBER OF VELOCITY COMMANDS TRANSMITTED PER VEHICLE OVER ALL MISSION PHASES	7.676	0.654	18.469	3.479	17.507	3.975
22	NUMBER OF ALTITUDE COMMANDS TRANSMITTED PER VEHICLE OVER ALL MISSION PHASES	1.988	0.050	4.810	1.112	4.859	1.365
23	NUMBER OF HEADING COMMANDS TRANSMITTED PER VEHICLE FOR THE RETURN PHASE ONLY	21.311	10.505	0.568	0.743	0.774	0.814
24	NUMBER OF TRANSMITTED COMMANDS PER RPV (ALL TYPES OF VEHICLES COMBINED)	51.870	17.150**				
25	TIME BETWEEN TRANSMITTED COMMANDS PER RPV (ALL TYPES OF VEHICLES COMBINED) (SECONDS)	96.597	28.192**				
26	TIME INTERVAL BETWEEN TRANSMITTED COMMANDS (ALL TYPES OF VEHICLES COMBINED) (SECONDS)	4.663	1.176**				

TABLE I (CONT.)

MEAN, STANDARD DEVIATION (STD DEV) PER MISSION FOR MAJOR DEPENDENT VARIABLES OF RPV STUDY IV . 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)	25.570	5.228**				
28	DIFFERENCE BETWEEN STRIKE ETA AND ATA AT THE H WAYPOINT (SECONDS).	29.135	5.069**				
29	DIFFERENCE BETWEEN ATA TO TARGET AND ETA TO TARGET (SECONDS)(STRIKE ONLY)	28.305	10.596***				
30	DIFFERENCE BETWEEN ATA TO RECOVERY AND ETA TO RECOVERY (SECONDS) (STRIKE ONLY)	9.148	6.254**				
31	TIME BETWEEN RECOVERIES (ALL TYPES OF VEHICLES COMBINED) (SECONDS)	181.341	44.473***				
	MISCELLANEOUS VARIABLES						
32	PROPORTION OF VEHICLES RECOVERED	0.740	0.075	0.020	0.057	0.018	0.038
33	PROPORTION OF VEHICLES REPROGRAMMED (RECYCLED TO TARGET TO REPLACE LOST VEHICLES)	0.190	0.081**				
34	NUMBER OF HEADING COMMANDS ATTEMPTED PER VEHICLE OVER ALL MISSION PHASES	41.651	20.902	29.559	10.636	29.458	11.176
35	RATIO OF HEADING COMMANDS TRANSMITTED TO HEADING COMMANDS ATTEMPTED OVER ALL MISSION PHASES	0.964	0.025	0.833	0.050	0.852	0.057
36	PROPORTION OF VEHICLES LOST DUE TO MALFUNCTIONS AND ATTRITION	0.093	0.036	0.169	0.097	0.158	0.093

TABLE I (CONT.)

MEAN, STANDARD DEVIATION (STD DEV) PER MISSION FOR MAJOR DEPENDENT VARIABLES OF RPV STUDY IV. 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
	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)	2.676	0.704***				
38	RANGE FROM STRIKE RPV TO EW RPV WHEN STRIKE RPV IS OVER TARGET (NM) (EW RPV IS IN HAND OFF MODE)	1.568	0.415***				
39	PROPORTION OF STRIKES WITH EW COVERAGE (EW RPV IS WITHIN SEVEN NM OF TARGET, EW RPV IS OR IS NOT IN HAND OFF MODE)	0.886	0.063***				
40	PROPORTION OF STRIKES WITH EW COVERAGE (EW RPV IS WITHIN SEVEN NM OF TARGET, EW RPV IS IN HAND OFF MODE)	0.671	0.087***				
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)	3.068	0.492***				
42	STRIKE AND LOW RECCE RPV ATA DIFFERENCE (MIN.) AT TARGET (CRITERION IS 2 MIN.) (LOW RECCE RPV IS IN HAND OFF MODE)	2.856	0.468***				
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)	0.601	0.095***				
44	PROPORTION OF STRIKES WITH LOW RECCE RPV COVERAGE WITHIN 2 MIN.+-15 SEC.CRITERION (LOW RECCE RPV IS IN HAND OFF MODE)	0.458	0.098***				

TABLE II

REGRESSION EQUATION AND MULTIPLE CORRELATION COEFFICIENT FOR EACH OF 19 SELECTED DEPENDENT RPV SYSTEM MEASURES. (X1 = DISPLAY MODX1 SIZE,X2 = DISPLAY MODX2 SIZE,X3 = RATIO OF STRIKE RPVS TO EW AND LOW RECCE RPVS,X4 = THRESHOLD VALUE THAT TRIGGERS AUTOMATIC HEADING CORRECTION, X5 = TOTAL NUMBER OF RPVS IN THE SYSTEM, E INDICATES POWER OF TEN.)

```
1 NUMBER OF HEADING COMMANDS TRANSMITTED   =      0.1522254E 03         +( -0.1041541E 01)X1     +( -0.4107696E 00)X2
  PER VEHICLE FOR THE ENROUTE PHASE ONLY      +(  0.7480751E 00)X3     +( -0.1388940E 00)X4     +( -0.4783080E 01)X5
  (STRIKE ONLY)                               +(  0.3236043E-01)X1X1 +(  0.7499843E-03)X1X2 +( -0.3243021E-01)X1X3
                                              +( -0.1337958E-03)X1X4 +( -0.1909687E-02)X1X5 +(  0.1509832E-02)X2X2
                                              +( -0.2255729E-03)X2X3 +( -0.1933020E-04)X2X4 +(  0.3741276E-02)X2X5
                                              +(  0.2750645E 00)X3X3 +(  0.1296343E-03)X3X4 +( -0.9513849E-01)X3X5
                                              +(  0.7111163E-04)X4X4 +(  0.6851873E-03)X4X5 +(  0.9057027E-01)X5X5
  MULTIPLE CORRELATION COEFFICIENT = 0.9711

2 NUMBER OF HEADING COMMANDS TRANSMITTED   =      0.2660159E 03         +( -0.9650946E-01)X1     +( -0.6317925E 00)X2
  PER VEHICLE OVER ALL MISSION PHASES         +( -0.5030521E 00)X3     +( -0.2741511E 00)X4     +( -0.8233013E 01)X5
  (S RPVS ONLY)                               +(  0.7091779E-01)X1X1 +( -0.1120317E-01)X1X2 +( -0.1175002E 00)X1X3
                                              +(  0.3162012E-03)X1X4 +( -0.5388865E-01)X1X5 +(  0.2391349E-02)X2X2
                                              +(  0.3265630E-01)X2X3 +( -0.1682878E-03)X2X4 +(  0.1261289E-01)X2X5
                                              +(  0.5682842E 00)X3X3 +(  0.1788579E-02)X3X4 +( -0.2217594E 00)X3X5
                                              +(  0.1405381E-03)X4X4 +(  0.1082563E-02)X4X5 +(  0.1729054E 00)X5X5
  MULTIPLE CORRELATION COEFFICIENT = 0.9510

3 NUMBER OF HEADING COMMANDS ATTEMPTED     =      0.2474060E 03         +(  0.5561655E 00)X1     +( -0.4403253E 00)X2
  PER VEHICLE OVER ALL MISSION PHASES         +(  0.2348661E 00)X3     +( -0.2694263E 00)X4     +( -0.8095629E 01)X5
  (S RPVS ONLY)                               +(  0.6466204E-01)X1X1 +( -0.1433859E-01)X1X2 +( -0.9805536E-01)X1X3
                                              +(  0.1916611E-03)X1X4 +( -0.5847229E-01)X1X5 +(  0.1848997E-02)X2X2
                                              +(  0.2767354E-01)X2X3 +( -0.1298618E-03)X2X4 +(  0.1182302E-01)X2X5
                                              +(  0.5356176E 00)X3X3 +(  0.1174380E-02)X3X4 +( -0.2202556E 00)X3X5
                                              +(  0.1357899E-03)X4X4 +(  0.1111875E-02)X4X5 +(  0.1731929E 00)X5X5
  MULTIPLE CORRELATION COEFFICIENT = 0.9508

4 NUMBER OF TRANSMITTED COMMANDS PER RPV   =      0.1954926E 03         +(  0.7447629E 00)X1     +( -0.4656941E 00)X2
  (ALL TYPES OF VEHICLES COMBINED)            +( -0.1779264E 01)X3     +( -0.1874394E 00)X4     +( -0.5220556E 01)X5
                                              +(  0.4450549E-01)X1X1 +( -0.6684046E-02)X1X2 +( -0.9061891E-01)X1X3
                                              +(  0.2026014E-03)X1X4 +( -0.6725633E-01)X1X5 +(  0.1206077E-02)X2X2
                                              +(  0.3453214E-01)X2X3 +( -0.1678969E-03)X2X4 +(  0.1234716E-01)X2X5
                                              +(  0.6495970E 00)X3X3 +( -0.4063656E-03)X3X4 +( -0.1304198E 00)X3X5
                                              +(  0.1137991E-03)X4X4 +( -0.1353356E-03)X4X5 +(  0.1268479E 00)X5X5
  MULTIPLE CORRELATION COEFFICIENT = 0.9494

5 NUMBER OF HEADING COMMANDS TRANSMITTED   =      0.1492603E 03         +(  0.3953254E-01)X1     +( -0.2880213E 00)X2
  PER VEHICLE FOR RETURN PHASE ONLY           +( -0.1716231E 01)X3     +( -0.1375407E 00)X4     +( -0.5353640E 01)X5
  (S RPVS ONLY)                               +(  0.2947347E-01)X1X1 +( -0.6531216E-02)X1X2 +( -0.1361125E-01)X1X3
                                              +(  0.4652776E-03)X1X4 +( -0.3930562E-01)X1X5 +(  0.2795914E-03)X2X2
                                              +(  0.4616123E-02)X2X3 +( -0.3367985E-04)X2X4 +(  0.1564240E-01)X2X5
                                              +(  0.3579510E 00)X3X3 +(  0.8441387E-03)X3X4 +( -0.5161944E-01)X3X5
                                              +(  0.6737115E-04)X4X4 +(  0.2245324E-03)X4X5 +(  0.9792972E-01)X5X5
  MULTIPLE CORRELATION COEFFICIENT = 0.9423
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TABLE II (CONT.)

REGRESSION EQUATION AND MULTIPLE CORRELATION COEFFICIENT FOR EACH OF 19 SELECTED DEPENDENT RPV SYSTEM MEASURES. (X1 = DISPLAY MODX1 SIZE,X2 = DISPLAY MODX2 SIZE,X3 = RATIO OF STRIKE RPVS TO EW AND LOW RECCE RPVS,X4 = THRESHOLD VALUE THAT TRIGGERS AUTOMATIC HEADING CORRECTION, X5 = TOTAL NUMBER OF RPVS IN THE SYSTEM, E INDICATES POWER OF TEN.)

```
 6 TIME BETWEEN TRANSMITTED COMMANDS PER     =    -0.1133477E 03        +(  0.8507950E 00)X1    +(  0.8049955E 00)X2
   RPV (ALL TYPES OF VEHICLES COMBINED)      +(  0.4842334E 01)X3    +(  0.1743507E 00)X4    +(  0.5946787E 01)X5
   (SECONDS)                                 +( -0.6804132E-01)X1X1 +(  0.1928094E-01)X1X2 +(  0.9337288E-01)X1X3
                                             +( -0.7997222E-04)X1X4 +( -0.1657250E-01)X1X5 +( -0.1818459E-02)X2X2
                                             +( -0.1811688E-01)X2X3 +(  0.2330007E-03)X2X4 +( -0.3614703E-01)X2X5
                                             +( -0.5810732E 00)X3X3 +( -0.1061943E-01)X3X4 +(  0.3502639E-01)X3X5
                                             +( -0.2814220E-04)X4X4 +(  0.5198843E-03)X4X5 +( -0.3663428E-01)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8950

 7 TIME INTERVAL BETWEEN TRANSMITTED         =     0.3059530E 01        +( -0.1573499E-01)X1    +( -0.1833714E-01)X2
   COMMANDS (ALL TYPES OF VEHICLES           +( -0.1003031E 00)X3    +(  0.1087408E-01)X4    +(  0.1170039E-01)X5
   COMBINED) (SECONDS)                       +( -0.3819670E-02)X1X1 +(  0.7874998E-03)X1X2 +(  0.6111667E-02)X1X3
                                             +(  0.7155556E-05)X1X4 +(  0.2956667E-02)X1X5 +(  0.1305518E-03)X2X2
                                             +( -0.6961457E-03)X2X3 +(  0.9081249E-05)X2X4 +( -0.9524478E-03)X2X5
                                             +( -0.3802412E-01)X3X3 +( -0.4986573E-03)X3X4 +(  0.2206319E-01)X3X5
                                             +( -0.1474898E-05)X4X4 +( -0.1220509E-03)X4X5 +( -0.2720960E-02)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8789

 8 NUMBER OF HEADING COMMANDS TRANSMITTED    =     0.2078145E 03        +(  0.2615963E 00)X1    +( -0.8081779E 00)X2
   PER VEHICLE OVER ALL MISSION PHASES       +( -0.1617906E 02)X3    +( -0.1307828E 00)X4    +( -0.6220800E 01)X5
   (EW RPVS ONLY)                            +(  0.3896027E-01)X1X1 +( -0.3596375E-02)X1X2 +( -0.1459374E 00)X1X3
                                             +(  0.5664360E-03)X1X4 +( -0.5005208E-01)X1X5 +( -0.4545170E-04)X2X2
                                             +(  0.5471354E-01)X2X3 +(  0.3084513E-04)X2X4 +(  0.2787760E-01)X2X5
                                             +(  0.3159932E 00)X3X3 +(  0.2045528E-02)X3X4 +(  0.4014457E 00)X3X5
                                             +(  0.7417791E-04)X4X4 +( -0.7982268E-03)X4X5 +(  0.7830387E-01)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8616

 9 NUMBER OF HEADING COMMANDS TRANSMITTED    =     0.2236240E 03        +(  0.1605819E 01)X1    +( -0.9468812E 00)X2
   PER VEHICLE FOR THE ENROUTE PHASE ONLY    +( -0.1403474E 02)X3    +( -0.1175963E 00)X4    +( -0.9229195E 01)X5
   (EW RPVS ONLY)                            +(  0.4513256E-01)X1X1 +( -0.5992200E-02)X1X2 +( -0.2112844E 00)X1X3
                                             +( -0.1905057E-03)X1X4 +( -0.7821196E-01)X1X5 +(  0.7114096E-03)X2X2
                                             +(  0.5688380E-01)X2X3 +( -0.7899340E-04)X2X4 +(  0.3200081E-01)X2X5
                                             +(  0.2873506E 00)X3X3 +(  0.3125773E-02)X3X4 +(  0.3037622E 00)X3X5
                                             +(  0.7444817E-04)X4X4 +( -0.3892754E-03)X4X5 +(  0.1431349E 00)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8607

10 NUMBER OF HEADING COMMANDS TRANSMITTED    =    -0.7148741E 01        +( -0.1320829E 01)X1    +(  0.4110054E-01)X2
   PER VEHICLE FOR THE ENROUTE PHASE ONLY    +(  0.1014614E 02)X3    +( -0.5778110E-01)X4    +(  0.2601746E 01)X5
   (LR RPVS ONLY)                            +(  0.3795432E-02)X1X1 +(  0.1261716E-01)X1X2 +(  0.8454788E-01)X1X3
                                             +(  0.1076389E-03)X1X4 +( -0.2091979E-01)X1X5 +( -0.9541917E-03)X2X2
                                             +(  0.4296873E-02)X2X3 +( -0.3211874E-04)X2X4 +( -0.2712708E-02)X2X5
                                             +( -0.5157854E-01)X3X3 +(  0.5208240E-03)X3X4 +( -0.5159138E 00)X3X5
                                             +(  0.6695773E-04)X4X4 +( -0.2455634E-02)X4X5 +(  0.4312377E-01)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8448
```

TABLE II (CONT.)

REGRESSION EQUATION AND MULTIPLE CORRELATION COEFFICIENT FOR EACH OF 19 SELECTED DEPENDENT RPV SYSTEM MEASURES. (X1 = DISPLAY MODX1 SIZE,X2 = DISPLAY MODX2 SIZE,X3 = RATIO OF STRIKE RPVS TO EW AND LOW RECCE RPVS,X4 = THRESHOLD VALUE THAT TRIGGERS AUTOMATIC HEADING CORRECTION, X5 = TOTAL NUMBER OF RPVS IN THE SYSTEM, E INDICATES POWER OF TEN.)

```
11 NUMBER OF HEADING COMMANDS ATTEMPTED     =     0.2566340E 03       +( -0.7458138E 00)X1     +( -0.1069017E 01)X2
   PER VEHICLE OVER ALL MISSION PHASES         +( -0.2029771E 02)X3      +( -0.1450859E 00)X4     +( -0.6826769E 01)X5
   (EW RPVS ONLY)                              +(  0.4380307E-01)X1X1 +( -0.5260624E-03)X1X2 +( -0.1361113E 00)X1X3
                                               +(  0.9560194E-03)X1X4 +( -0.4548604E-01)X1X5 +(  0.6191050E-04)X2X2
                                               +(  0.6293416E-01)X2X3 +(  0.9259167E-04)X2X4 +(  0.3259542E-01)X2X5
                                               +(  0.5387827E 00)X3X3 +(  0.1128083E-02)X3X4 +(  0.4798604E 00)X3X5
                                               +(  0.6931632E-04)X4X4 +( -0.4621898E-03)X4X5 +(  0.6826091E-01)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8379

12 CROSS TRACK ERROR (PERPENDICULAR DIST.   =     0.7967264E 02       +( -0.1084026E 02)X1     +( -0.9182451E 00)X2
   FROM FLIGHT PLAN TO TRUE RPV POSITION)      +( -0.8390437E 01)X3      +( -0.2330760E-01)X4     +(  0.2395584E 02)X5
   DURING ENROUTE PHASE (FEET)(STRIKE ONLY)    +(  0.1563182E 00)X1X1 +(  0.4510600E-01)X1X2 +(  0.2898133E 00)X1X3
                                               +(  0.1486222E-02)X1X4 +( -0.1074133E 00)X1X5 +(  0.6919883E-02)X2X2
                                               +(  0.1858833E 00)X2X3 +(  0.9369110E-03)X2X4 +( -0.1154250E 00)X2X5
                                               +(  0.1757134E 01)X3X3 +(  0.2264800E-01)X3X4 +( -0.1882689E 01)X3X5
                                               +(  0.3704226E-03)X4X4 +( -0.1530415E-01)X4X5 +(  0.1124838E 00)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8227

13 NUMBER OF HEADING COMMANDS ATTEMPTED     =    -0.2115825E 02       +( -0.2672398E 01)X1     +(  0.3465947E 00)X2
   PER VEHICLE OVER ALL MISSION PHASES         +(  0.4328287E 01)X3      +( -0.5344933E-01)X4     +(  0.5218604E 01)X5
   (LR RPVS ONLY)                              +(  0.1129357E-01)X1X1 +(  0.1861975E-01)X1X2 +(  0.1354167E 00)X1X3
                                               +( -0.1388944E-03)X1X4 +( -0.5555414E-02)X1X5 +( -0.2067589E-02)X2X2
                                               +(  0.1649312E-01)X2X3 +( -0.9722222E-04)X2X4 +( -0.1059042E-01)X2X5
                                               +(  0.7238646E 00)X3X3 +(  0.1782407E-02)X3X4 +( -0.5920139E 00)X3X5
                                               +(  0.7224374E-04)X4X4 +( -0.2820222E-02)X4X5 +(  0.1001651E-01)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8216

14 NUMBER OF HEADING COMMANDS TRANSMITTED   =    -0.1692751E 02       +( -0.2372535E 01)X1     +(  0.1411101E 00)X2
   PER VEHICLE OVER ALL MISSION PHASES         +(  0.5809146E 01)X3      +( -0.5770470E-01)X4     +(  0.5042083E 01)X5
   (LR RPVS ONLY)                              +(  0.1006060E-01)X1X1 +(  0.1889323E-01)X1X2 +(  0.1192710E 00)X1X3
                                               +(  0.6134305E-04)X1X4 +( -0.1397573E-01)X1X5 +( -0.1734494E-02)X2X2
                                               +(  0.1089411E-01)X2X3 +( -0.1131358E-03)X2X4 +( -0.4795961E-02)X2X5
                                               +(  0.4451178E 00)X3X3 +(  0.2025458E-02)X3X4 +( -0.5489010E 00)X3X5
                                               +(  0.7580152E-04)X4X4 +( -0.2907021E-02)X4X5 +(  0.3293340E-02)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.8178

15 CROSS TRACK ERROR FOR ENROUTE AND RETURN =     0.1225981E 04       +( -0.1057045E 01)X1     +( -0.1053785E 02)X2
   PHASES COMBINED(FEET)                       +(  0.5323557E 02)X3      +( -0.1591309E-01)X4     +( -0.4444595E 02)X5
                                               +( -0.6334251E-01)X1X1 +(  0.1501380E 00)X1X2 +( -0.1519239E 01)X1X3
                                               +(  0.6029330E-02)X1X4 +( -0.3802533E 00)X1X5 +(  0.3982659E-01)X2X2
                                               +(  0.1100100E 00)X2X3 +(  0.2059600E-02)X2X4 +( -0.6814665E-01)X2X5
                                               +(  0.7584605E 00)X3X3 +( -0.2082400E-01)X3X4 +( -0.1343088E 01)X3X5
                                               +(  0.4612748E-03)X4X4 +( -0.2204563E-01)X4X5 +(  0.1500692E 01)X5X5
   MULTIPLE CORRELATION COEFFICIENT = 0.6838
```

TABLE II (CONT.)

REGRESSION EQUATION AND MULTIPLE CORRELATION COEFFICIENT FOR EACH OF 19 SELECTED DEPENDENT RPV SYSTEM MEASURES. (X1 = DISPLAY MODX1 SIZE, X2 = DISPLAY MODX2 SIZE, X3 = RATIO OF STRIKE RPVS TO EW AND LOW RECCE RPVS, X4 = THRESHOLD VALUE THAT TRIGGERS AUTOMATIC HEADING CORRECTION, X5 = TOTAL NUMBER OF RPVS IN THE SYSTEM, E INDICATES POWER OF TEN.)

```
16 PROPORTION OF VEHICLES RECOVERED        =      0.3714580E 01        +( -0.8627248E-01)X1     +( -0.1769942E-01)X2
   (EW RPVS ONLY)                             +( -0.7039800E-02)X3     +( -0.1989992E-02)X4     +( -0.1178792E 00)X5
                                              +(  0.1799205E-03)X1X1   +(  0.2734219E-03)X1X2   +( -0.5206249E-03)X1X3
                                              +(  0.1735971E-04)X1X4   +(  0.1822812E-02)X1X5   +(  0.1124503E-04)X2X2
                                              +( -0.3905727E-03)X2X3   +(  0.6076041E-05)X2X4   +(  0.3254947E-03)X2X5
                                              +(  0.6628282E-02)X3X3   +( -0.1156944E-04)X3X4   +(  0.8684027E-03)X3X5
                                              +(  0.8884956E-07)X4X4   +(  0.4050693E-04)X4X5   +(  0.4997789E-03)X5X5

   MULTIPLE CORRELATION COEFFICIENT = 0.6696

17 RATIO OF THE DISTANCE ACTUALLY TRAVELED =      0.9701177E 00        +(  0.1126783E-02)X1     +(  0.3319569E-03)X2
   BY A VEHICLE TO THE LENGTH OF FLIGHT       +(  0.1049758E-02)X3     +(  0.2718363E-05)X4     +(  0.1705861E-03)X5
   PLAN (THIRD PLACE ACCURACY)                +( -0.1670454E-05)X1X1   +( -0.6421875E-05)X1X2   +( -0.3958333E-05)X1X3
                                              +( -0.2569444E-06)X1X4   +( -0.9895833E-05)X1X5   +( -0.7684659E-06)X2X2
                                              +(  0.2604167E-06)X2X3   +( -0.4201389E-07)X2X4   +( -0.1223958E-05)X2X5
                                              +( -0.5467171E-04)X3X3   +(  0.1990741E-06)X3X4   +( -0.2465278E-04)X3X5
                                              +( -0.4219977E-08)X4X4   +(  0.4050926E-06)X4X5   +(  0.5681817E-06)X5X5

   MULTIPLE CORRELATION COEFFICIENT = 0.6595

18 CROSS TRACK ERROR FROM THE H WAYPOINT   =      0.3476491E 04        +( -0.1007153E 03)X1     +( -0.4551395E 02)X2
   AT THE TIME THE TERMINAL PILOT OPERATOR    +(  0.1365204E 03)X3     +( -0.2694596E 01)X4     +(  0.3713039E 02)X5
   ACTUALLY TOOK CONTROL(FEET)(STRIKE ONLY)   +(  0.4376840E 00)X1X1   +(  0.9281214E 00)X1X2   +( -0.3411766E 01)X1X3
                                              +(  0.6610394E-01)X1X4   +( -0.1322462E 01)X1X5   +(  0.1622646E 00)X2X2
                                              +( -0.1050035E 01)X2X3   +(  0.1877221E-01)X2X4   +( -0.3534158E 00)X2X5
                                              +(  0.7768888E 00)X3X3   +( -0.9623003E-01)X3X4   +(  0.3018678E 01)X3X5
                                              +(  0.1208832E-02)X4X4   +( -0.4950837E-01)X4X5   +(  0.7160889E 00)X5X5

   MULTIPLE CORRELATION COEFFICIENT = 0.6586

19 GROUND SPEED ERROR FROM H AT THE TIME   =      0.2923239E 05        +( -0.1144293E 04)X1     +( -0.2862683E 03)X2
   THE TERMINAL PILOT OPERATOR ACTUALLY       +(  0.9079998E 03)X3     +(  0.7656372E 01)X4     +( -0.4484014E 03)X5
   TOOK CONTROL (FEET) (STRIKE ONLY)          +(  0.1658147E 01)X1X1   +(  0.6443260E 01)X1X2   +( -0.1485901E 02)X1X3
                                              +(  0.5516080E-01)X1X4   +(  0.1868941E 02)X1X5   +(  0.4969960E 00)X2X2
                                              +( -0.5707789E 01)X2X3   +(  0.1615253E-01)X2X4   +(  0.3119388E 01)X2X5
                                              +(  0.8304035E 01)X3X3   +( -0.7590486E 00)X3X4   +(  0.8433467E 01)X3X5
                                              +(  0.4918635E-02)X4X4   +( -0.4953483E 00)X4X5   +( -0.1070812E 01)X5X5

   MULTIPLE CORRELATION COEFFICIENT = 0.6461
```

TABLE III

95% CONFIDENCE INTERVALS FOR EACH OF 19 SELECTED DEPENDENT

RPV SYSTEM VARIABLES

Measure	Minimum Limit	Maximum Limit
1) Number of heading commands transmitted per vehicle for the enroute phase (strikes only)	15.13	20.11
2) Number of heading commands transmitted per vehicle over all mission phases (strikes only)	33.71	46.95
3) Number of heading commands attempted per vehicle over all mission phases (strikes only)	34.99	48.31
4) Number of transmitted commands per RPV, all types of vehicles	46.29	57.45
5) Number of heading commands transmitted per vehicle for the return phase (strikes only)	17.67	24.95
6) Time between transmitted commands per RPV, all types of vehicles (seconds)	82.88	110.32
7) Time interval between transmitted commands, all types of vehicles (seconds)	4.04	5.28
8) Number of heading commands transmitted per vehicle over all mission phases (EW only)	18.98	30.88
9) Number of heading commands transmitted per vehicle for enroute phase (EW only)	10.47	22.31
10) Number of heading commands transmitted per vehicle for enroute phase (Low Recce only)	10.47	22.27
11)Number of heading commands attempted per vehicle over all mission phases (EW only)	22.81	36.31

TABLE III CONTINUED

	Measure	Minimum Limit	Maximum Limit
12)	Cross track error during enroute phase (strikes only)	218.03	288.37
13)	Number of heading commands attempted per vehicle over all mission phases (Low Recce only)	22.02	36.90
14)	Number of heading commands transmitted per vehicle over all mission phases (Low Recce only)	18.16	32.84
15)	Cross track error for enroute and return phases (strikes only)	249.37	367.53
16)	Proportion of vehicles recovered (EW only)	0.000	0.075
17)	Ratio of distance actually traveled to the length of flight path	1.0012	1.0028
18)	Cross track error from H waypoint when pilot took control	243.16	612.22
19)	Ground speed error from H waypoint when pilot took control	907.86	2652.90

FIGURE I

HUMAN ENGINEERING SYSTEMS SIMULATION FACILITY CONFIGURATION FOR RPV III SYSTEM SIMULATION

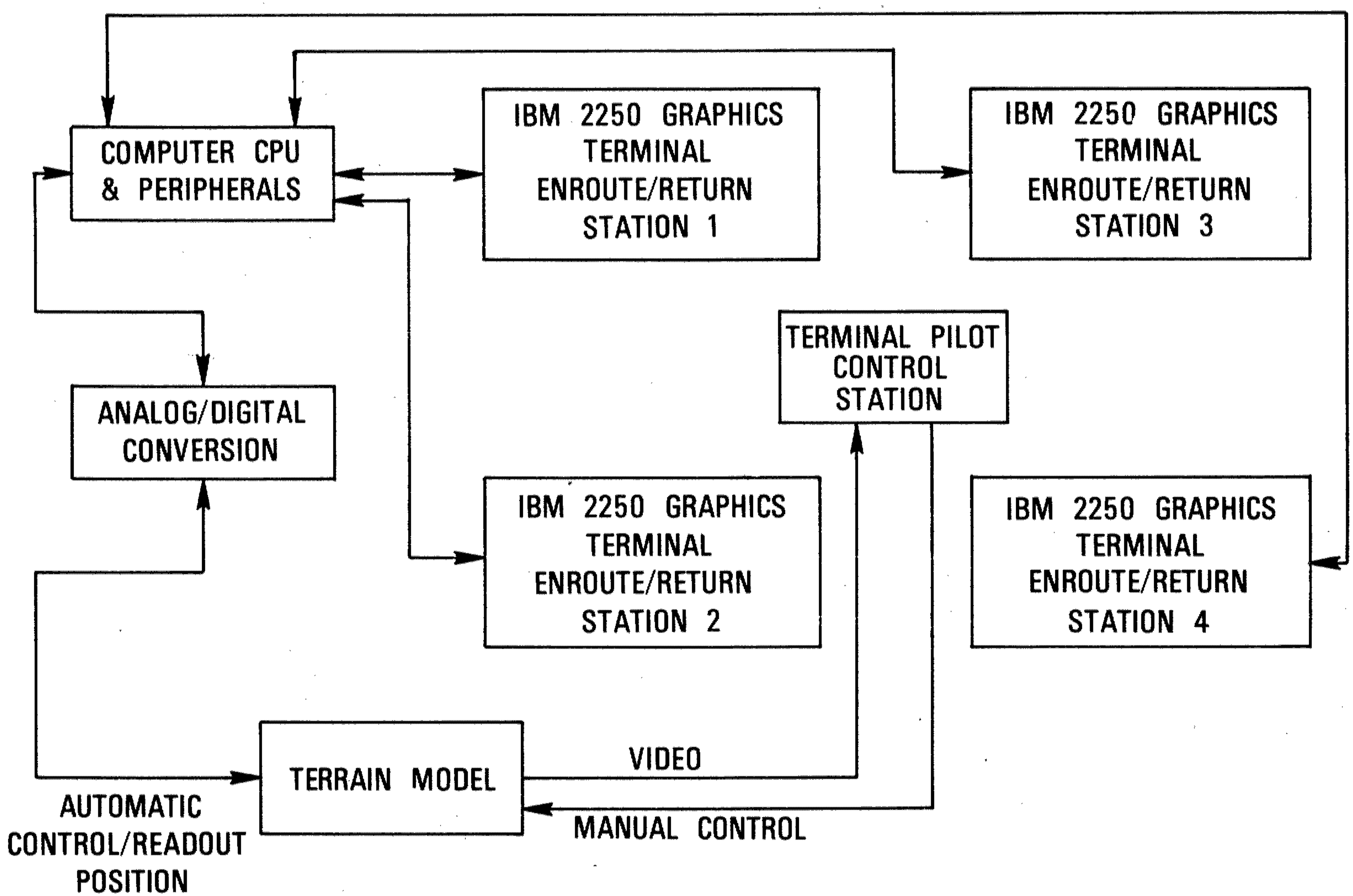


FIGURE 2 - Team of Five Operators Performing in the AMRL RPV System Simulation

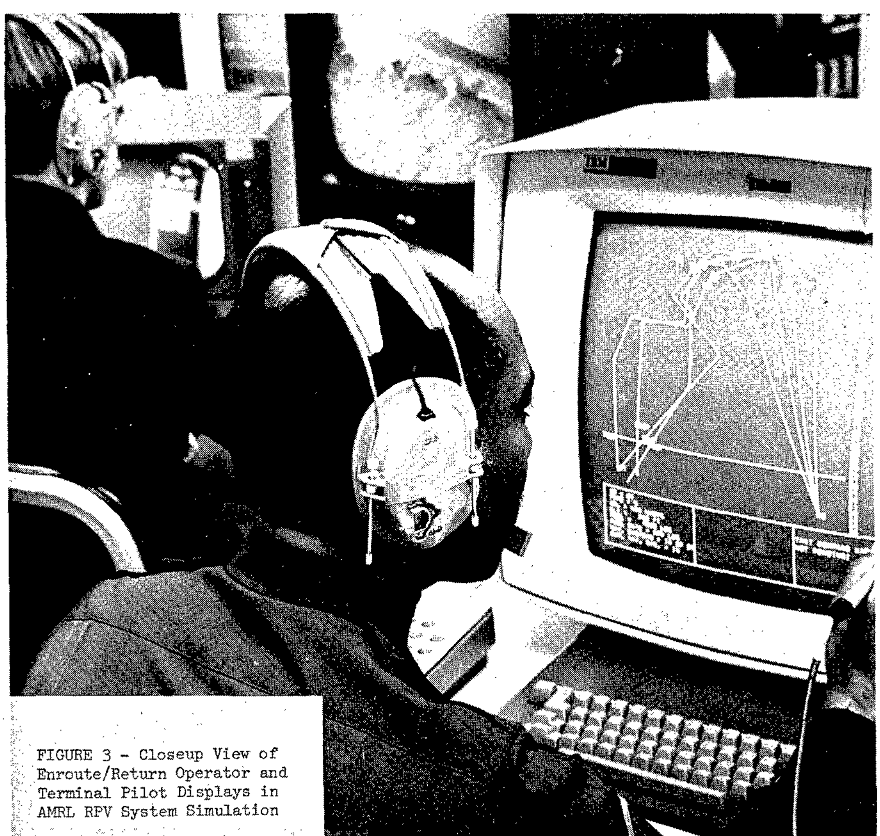
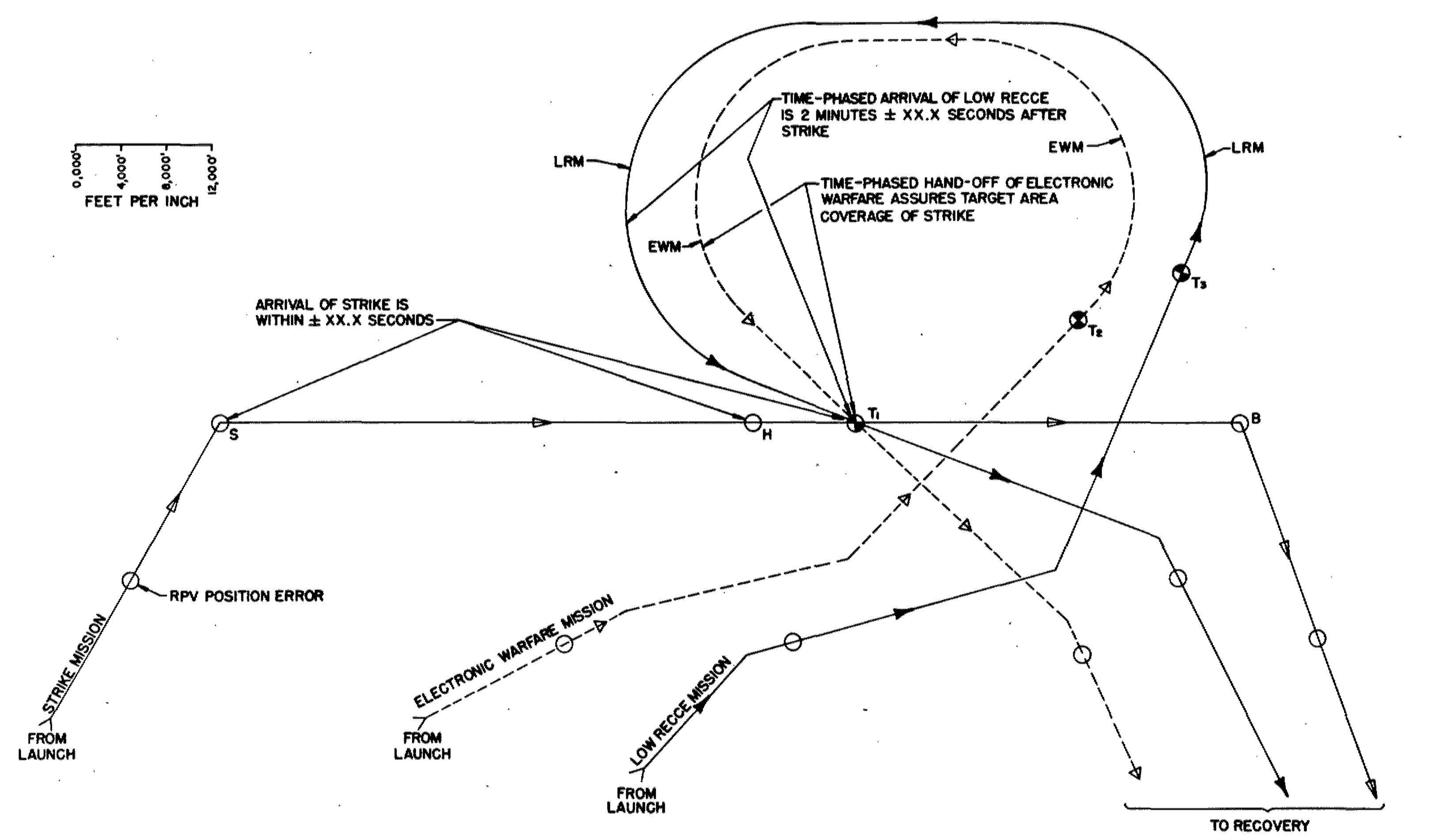


FIGURE 3 - Closeup View of Enroute/Return Operator and Terminal Pilot Displays in AMRL RPV System Simulation

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)



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