Proceedings of the 1988 Winter Simulation Conference
M. Abrams, P. Haigh, and J. Comfort (eds.)

Validation methodologies for complex, hybrid, HWIL, 6DOF missile simulations – A structured approach –

Robert M. Gravitz,
COLSA, Inc.,
6776 Odyssey Drive
Huntsville, Alabama 35898

and

William F. Waite
Riverside Research Institute, Inc.,
303 Williams Ave., Suite 125
Huntsville, Alabama 35801

ABSTRACT

Very complex simulations have been utilized in the weapons design process, on systems so fully developed as to be in the full-scale engineering or production phase of the product life cycle. With this increased use of simulations in the design, development, test and evaluation of major systems, a Program Manager must ensure the simulation tools he is relying upon are validated for the purposes they are intended.

It is our thesis that simulation validation activities must be part of a systematic, coordinated program to build confidence in simulation based analyses and in overall system analyses. In developing a coordinated, formal, validation program for complex weapon system simulations it is important that validation activities increase confidence in the decisions for which the simulation analyses are being conducted. This is particularly true of simulations utilized in the assessment and prediction of performance of weapon systems not yet fielded. Program Managers must undertake such a program to tie together simulation-based activities, such as verification, validation, field tests and the utilization of complex simulations in assessing weapon system performance under field conditions.

We will examine how one weapon system program successfully dealt with the technical considerations of developing a tailored validation program. Our focus will be the simulation validation process for a real-time, hybrid, hardware-in-the-loop, six-degree of freedom missile flight simulation, that was developed concurrent with the missile system, and which was ultimately used to conduct a performance assessment of the system's expected operational effectiveness under field conditions. We will reveal the lessons learned from the accomplishment of these tasks.

1. INTRODUCTION

1.1 Utilization of Computer Simulations in Weapon System Development

Computer simulation has proven to be an effective tool in the design, analysis, and performance assessment of complex weapons early in their life cycle. Simulations have been readily applied to concept definition and feasibility studies and are relatively common in the early phases of the product life cycle.

Recently however very complex simulations have been utilized in the weapons design process on systems so fully developed as to be in full-scale engineering development or production phase of the product life cycle. This is because exercise of a simulation during full-scale development as a surrogate system offers many advantages over use of the actual system.

1.2 Utility of Weapon System Simulations

Examples of ways in which complex simulations are providing cost, and time savings to the materiel developer are:

- *nondestructive testing of hardware in a simulation in order to minimize test hardware costs and preserve hardware for other uses;*
- *replicating field tests or trials for the purpose of conducting root cause failure analyses;*
- *determining effects of potential changes to system hardware and/or software prior to hard tooling and manufacture; and*
- *accurately predicting performance of the system under operational conditions without conducting expensive field testing.*

With this increased use of simulations in the design, development, test and evaluation of major systems, a Program Manager must ensure the simulation tools he is relying upon are validated for the purposes for which he has intended.

2. THESIS

It is our thesis that validation activities must be part of a formal, coordinated program to build confidence in simulation based analyses, and in, overall system analyses. In developing a coordinated, formal, validation program for complex weapon system simulations it is important that validation activities increase confidence in the decisions for which the simulation analyses are being conducted. This is particularly true of simulations utilized in the assessment and prediction of performance of weapon systems not yet fielded. Program Managers must undertake a program to tie together simulation-related activities, such as verification, validation, field tests and the utilization of complex simulations in assessing weapon system performance under field conditions.

We will examine how one weapon system program successfully dealt with the special considerations required in developing a coordinated, formal, validation program. Our focus will be the simulation validation process of a real-time, hybrid, hardware-in-the-loop missile flight simulation, used in a system development, and ultimately used to conduct a performance assessment of the system's expected operational effectiveness under field conditions. We will reveal the lessons learned in the accomplishment of these tasks.

3. CHAPARRAL MISSILE SYSTEM

3.1 Background

The Army recently completed an engineering development program to provide a microprocessor-based, reprogrammable, rosette scan seeker (RSS) guidance section for the Army's CHAPARRAL Missile System, an infrared (IR), short-range air defense system. The development program was concluded with a decision to proceed into production, with the Service assigning the guidance section a type classification standard designation in November 1987.

3.2 A General Description

The CHAPARRAL Missile is a supersonic, surface-to-air, passive IR homing missile. The missile is composed of a guidance section, Doppler radar fuse, blast-fragmentation warhead, rocket motor, fixed wings, and moveable canard fins (see Figure 1). The guidance section is mounted on the forward end of the missile, and consists of a seeker section, a solid-state electronics section and a fin-servo section.

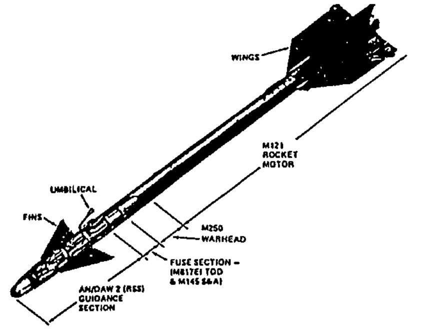


Figure 1: CHAPARRAL Missile

RSS guidance section improvements were designed to support the dual infrared seeker signal processing and included detector signal amplifiers, sensor reference circuits and, most significantly, the introduction of a digital microprocessor-based guidance and control subsystem in place of the previous analog implementation.

3.3 Embedded Software

A principal goal of this development effort was to achieve software control of such system functions as infrared-counter-countermeasure (IRCCM) logic, scene background rejection, timing, built-in-test, track-loop tailoring and missile guidance which could be reprogrammed readily in response to changing operational requirements.

The architecture elected for the CHAPARRAL microprocessor design entailed multiple processing modules operating asynchronously and in parallel. Each module consists of a Z8002A central processing unit (CPU), local bus, local program memory (ROM), local data memory (RAM), and interface control components. Integration of modules was achieved by means of a system bus, bus control logic, common memory (RAM) for storage of common data and communication between microprocessor modules, and serial input/output (I/O) control.

Reprogrammability, defined for this system as the ability to modify operational software programs without hardware disassembly, was achieved by employing electrically erasable programmable read-only-memory (EEPROM) chips as local ROM in each processing module.

3.4 Weapon System Type Classification-Standard

The Army's acceptance of the RSS guidance section for production and fielding was based upon substantive data supporting a Type Classification-Standard designation. The decision makers required information on how well the new guidance section met its operational requirements, how much better it was in comparison to the existing system, how it would be capable of defeating the defined threat aircraft, countermeasures, and tactics, and its readiness for production.

The performance of the system was assessed through laboratory tests, field tests, and simulation predictions of the systems performance in the field. The majority of data on operational effectiveness, which for this system was the probability of a single-shot kill (P_{SSK}), was based upon simulation experiments designed to map performance against a variety of targets, countermeasure conditions and tactics.

It was, therefore, extremely important to the decision makers that the credibility of the simulations be demonstrated through an arduous series of validation exercises, as part of a formal, documented, and coordinated program.

4. CHAPARRAL HARDWARE-IN-THE-LOOP SIMULATIONS

4.1 Identification and General Description

The guidance section upgrade of the CHAPARRAL missile precipitated development of several types of simulations. The principle simulation tool type was the real-time, hybrid hardware-in-the-loop (HWIL) simulation. The development of these simulations was supported by the prior development of missile flight models and all-digital simulations, and hybrid electro-optical simulations..

There were three CHAPARRAL RSS HWIL simulations, all of which were developed concurrently during the RSS engineering development program, in order to accurately model the missile's engagement scenarios against maneuvering targets in a countermeasure environment. The simulation agencies were:

•the system prime contractor (Ford Aerospace Corporation), Newport Beach, California;

•the system developer's technical advisor (Research, Development and Engineering Center, U.S. Army Missile Command, Redstone Arsenal, Alabama); and

•the system developer's advisor for counter-countermeasure design (Vulnerability Assessment Laboratory, U.S. Army Laboratory Command, White Sands Missile Range, New Mexico).

All three HWIL simulations are closed-loop, six-degree-of-freedom models (x, y, and z components of missile position in inertial space plus pitch, yaw, and roll attitude of the missile airframe), and include threat, sensor, signal processing, aerodynamics, propulsion, and actuator/servo control subsystems.

4.2 Functional Data Flow

The simulations generally follow the functional flow outlined in Figure 2. Input to the simulation is in the form of flare parameters (number, type, dispense rate, direction, start and stop time for the flare dispenser), target parameters (crossing angle, offset, range at trigger pull, altitude, speed, etc.), and target signature information (plume configuration, size, intensity, etc.).

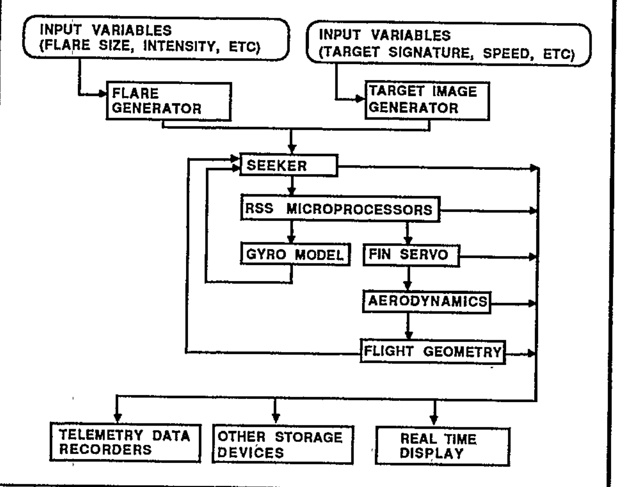


Figure 2: CHAPARRAL HWIL Functional Block Diagram

This information drives the flare generator and target image simulators to produce seeker image information. The two images are convolved with the missile instantaneous field of view to provide seeker information to the RSS multiple processing modules.

In all three models, the RSS multiprocessor hardware modules are integrated with the host simulation computers. The information provided to the RSS multiple processing modules is identical to the instantaneous-field-of-view type of information that would be provided to it by the RSS seeker as it swept the missile field-of-view in a rosette pattern. At each point in the sweep, the intensity of the IR image for each point in the sweep, in each of two color regimes of the seeker head, is transmitted to the RSS guidance section microprocessors.

The outputs from the guidance section are in the form of fin servo commands. These commands are in turn sent to the servo mechanisms which operate the fins on the CHAPARRAL missile in order to control the missile's flight path. In the HWIL simulation, these fin commands drive the fin servo model which in turn provide input to the aerodynamic model. The aerodynamic model determines the geometry of the missile/target encounter and the position of the RSS gyro with respect to the missile and the target. This information is fed back with the flare and target image models in an interactive manner to produce new seeker image information for the RSS guidance section. This loop continues until missile impact or point of closest approach. Various missile and seeker parameters, and flight trajectory information are continuously recorded by the HWIL host computers during the simulation for later playback and analysis.

4.3 Details of the Simulation Implementation

Army Missile Command HWIL Simulation. An overview of the HWIL simulation developed by the Research, Development and Engineering Center (RDEC), U.S. Army Missile Command is shown in Figure 3. The simulation uses an SEL 32/87 digital computer, two EAI SIMSTAR Parallel Signal (Hybrid) Processors, an EAI 781 analog processor, an EAI 7800 analog processor, and a complex target plume scene generator developed in-house.

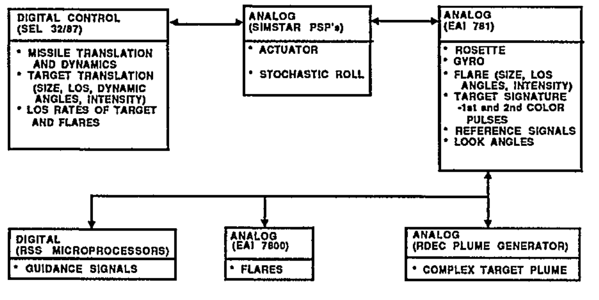


Figure 3: RDEC, MICOM HWIL Simulation

The RDEC simulation is part of a general purpose simulation facility that has the mission to support the design, development and test of all systems managed by the Missile Command, such as the STINGER, PATRIOT, HAWK and Fiber-Optic Guided Missile (FOG-M). It must be adaptable to a variety of hardware configurations and set-up conditions, and is therefore not tailored nor optimized for a specific system, such as CHAPARRAL RSS.

Ford Aerospace Corporation HWIL Simulation. Similar to the MICOM simulation, an alternative complex scene imaging device is utilized in modeling target plume signatures at FAC. It has much greater fidelity and flexibility than the one at MICOM, and is capable of superimposing weather conditions such as sun and clouds onto the target image seen by the RSS guidance section. The hardware configuration is shown in Figure 4.

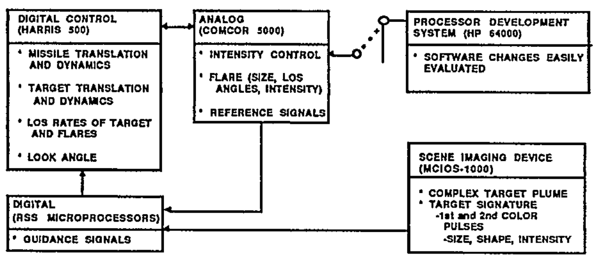


Figure 4: Ford Aerospace HWIL Simulation

The FAC simulation is tailored for the SIDEWINDER and CHAPARRAL family of missiles. It has evolved with the CHAPARRAL system and is a specialized facility optimized to replicate the RSS guidance section and missile system behaviors.

Laboratory Command HWIL Simulation. The simulation at the Vulnerability Assessment Laboratory (VAL), U.S. Army Laboratory Command is very similar to the one at Ford Aerospace. The principle difference is a unique countermeasure generator developed by VAL which is utilized in assessing performance against conventional flares, jamming devices, and unconventional countermeasures. The hardware configuration is shown in Figure 5.

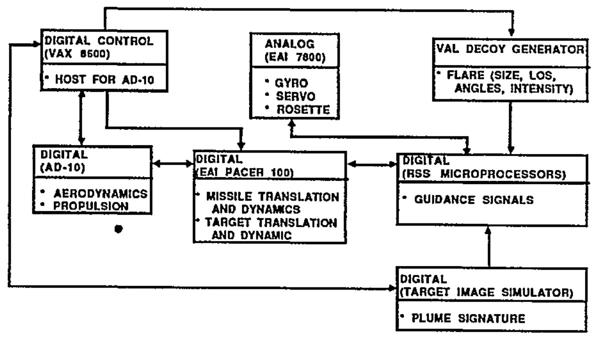


Figure 5: VAL, LABCOM HWIL Simulation

The VAL countermeasure generator has even greater fidelity and flexibility than the one at Ford Aerospace, and is crucial in evaluating system susceptibility to countermeasures.

The VAL simulation, like the one at the Missile Command, is part of a general purpose simulation facility that has the mission to support the design, development and test of electro-optical missile systems, countermeasures, and missile counter-countermeasures. It is adaptable to a variety of hardware configurations, and is not tailored nor optimized for a specific system, such as CHAPARRAL RSS.

5. SIMULATION CONFIDENCE

Verifying and validating simulation models is perhaps the most difficult of all the problems associated with the development and utilization of computer simulations. Verification for this system was defined as the process of corroborating that models in each simulation were correctly implemented in the computer programs. Validation was defined as corroborating that the simulation closely matched the real system.

A formal, coordinated program was conceived and implemented to build confidence in simulation based analyses and in overall system analyses. This was crucial because the HWIL simulations were to be used for a simulation-based performance assessment of system performance

5.1 Tailored Strategy to Support Decision Makers

There were a number of key decision makers, each with his own viewpoints, concerns, and issues regarding the simulation validation process. The principle ones were:

- Directorate for Operational Test and Evaluation, Office of the Secretary of Defense (DOT&E)- an independent evaluator responsible for ensuring the service has addressed the operational, as well as technical issues, in the execution of the service's test and evaluation program,

- U.S. Army Operational Test and Evaluation Agency (OTEA)- an independent evaluator responsible for assessing operational and training impacts associated with the fielding of the RSS guidance section

- U.S. Army Training and Doctrine Command (TRADOC)- and independent evaluator of the system responsible for integrating training, tactics and doctrine with the capabilities of the system to enhance combat effectiveness.

- U.S. Army Test and Evaluation Command (TECOM)-an independent tester and evaluator of technical test issues and criteria.

- U.S. Army Air Defense Artillery School, Training and Doctrine Command (USAADASCH)- represents the user in establishing performance requirements expected of the system.

- U.S. Army Logistics Evaluation Agency (LEA)-an independent evaluator of logistics impacts and the adequacy of integrated logistics support.

Each of these agencies had to be satisfied that sufficient data was available to substantiate and document the validation process, that the data generated supported his own independent analysis and assessment, and was in a format which they could use in presentations within their organizations to develop confidence in the simulations.

5.2 Confidence Building Measures

The simulation validation strategy for CHAPARRAL consisted of a series of inter-related activities which included RSS system development by FAC, concurrent and independent simulation development activities by FAC, RDEC, and VAL, pre-flight and post-flight simulation exercises, the use of field tests (target acquisition, tracking and flight tests), and root-cause flight failure analyses. All of these activities formed a basis for confidence in the missile flight simulations, and in the missile system.

5.3 Formal Simulation Validation

In order to validate the HWIL simulations for the RSS guidance section the CHAPARRAL Project Management Office developed a Simulation Validation Plan. This was accomplished through a forum known as the CHAPARRAL Simulation Integration Working Group (SIWG). The SIWG had representatives from each of the simulation principle investigators, and the other government agencies involved in the development program.. The plan set forth formal simulation validation exercises to be undertaken by each of the principal simulators to demonstrate to the development community the accuracy and predictive power of their HWIL simulations. The planning called first for verification of the component programs and subroutines of each HWIL simulation, which were then to be followed by validation of each HWIL system against actual missile flight tests.

The basic context in which these confidence building activities were executed is depicted in the diagram in Figure 6 below:

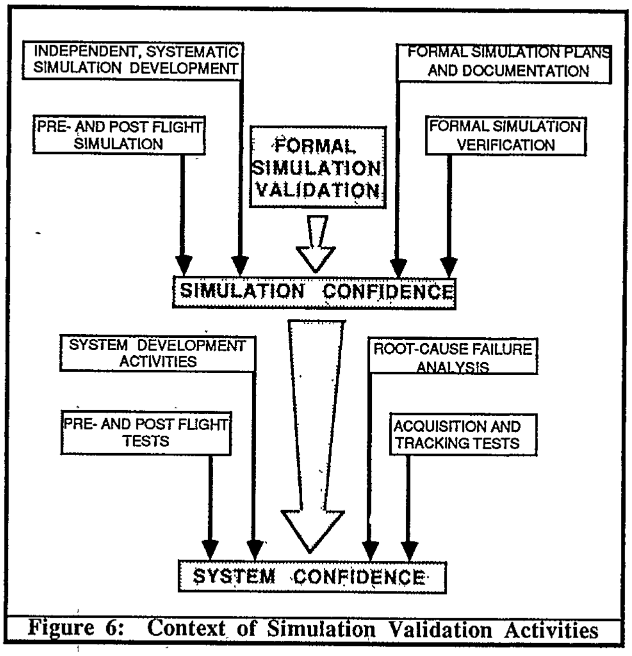


Figure 6: Context of Simulation Validation Activities

Simulation Validation and Flight Tests. The formal validation of the CHAPARRAL RSS HWIL simulations involved the comparing of simulation output to recorded flight data acquired in the government's product qualification tests conducted at White Sands Missile Range.

The SIWG identified four flights for intensive data comparison. These exercises were assigned to each simulation agency as outlined in Table 1, below:

Table 1: Validation Exercises

AGENCY:	FLIGHT TEST NUMBER:			
	3	7	10	14
FORD	•	•	•	•
MICOM		•		•
LABCOM		•	•	•

The objectives and parameters for each flight were different, and are outlined below. This variety in validation flights was crucial in establishing the accuracy of the simulations for various missile and target scenarios.

Table 2: Flight Parameters and Objectives

OBJECTIVES:	FLIGHT TEST NUMBER			
	3	7	10	14
TARGET TYPE	MQM-34D	MQM-34D	MQM-34D	QF-86
FLARE TYPE	BENIGN	MJU-8	M-206	M-206
TARGET SPEED	250MPS	200MPS	200MPS	250MPS
TARGET ALTITUDE	150M	500M	500M	150M
TARGET ASPECT	20°	160°	180°	135°

Validation Strategy. The composite strategy used in the validation of the simulations to support the type classification decisions consisted of:

- *executing the simulation in order to obtain a 10 run set of output data based upon nominal input values for each of the flight variables, and the comparison of that simulation data to the actual recorded flight data by means of a direct overlay;*

- *executing the simulation in order to obtain a 30 run set of output data based upon Monte Carlo input for those endogenous values, post-processing of data to establish the mean and standard deviation for each of the flight variables, and comparison of that simulation data to the actual recorded flight data by means of direct overlay and statistical treatment of the data; and*

- *examination of the data in order to determine if it met the evaluation criteria outlined for validation of the simulations.*

This basic strategy is outlined in Figure 7, below.

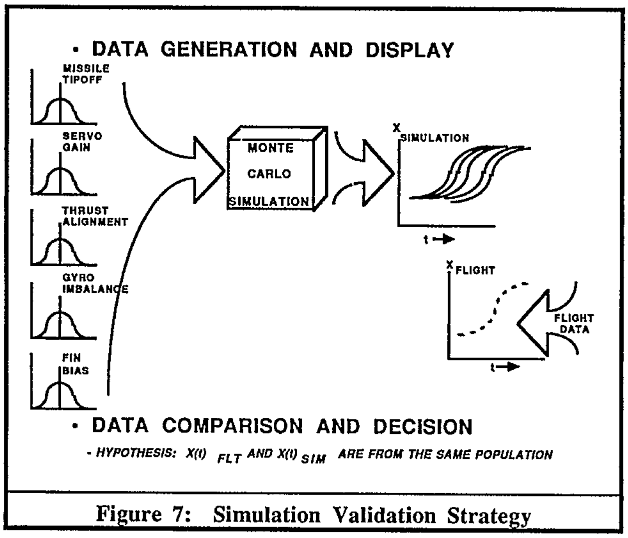
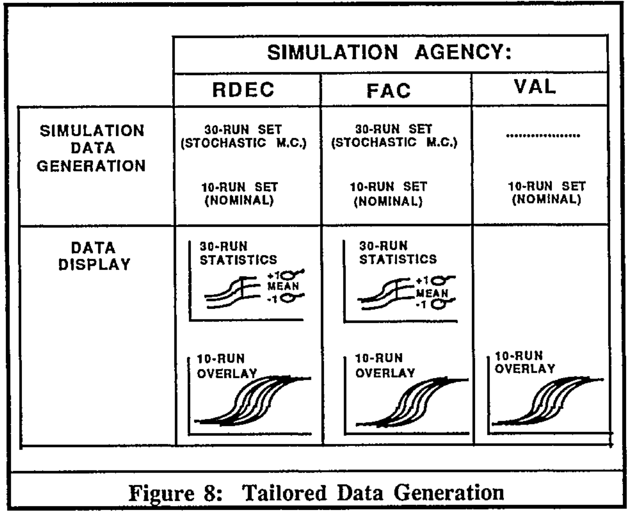


Figure 7: Simulation Validation Strategy

Tailored Data Generation Procedures. Each simulation implementation and research facility had its own particular capabilities and constraints. These factors, coupled with the different simulation mechanizations utilized by the three independent simulation activities, required the basic data generation procedures to be tailored for each simulation agency. The generation of simulation validation data, data displays, and post processing were configured to ensure accomplishment of the validation exercises within these constraints, yet still satisfy the need to support the decision making process. This tailoring of the data generation procedures is outlined in Figure 8 below.



	SIMULATION AGENCY:		
	RDEC	FAC	VAL
SIMULATION DATA GENERATION	30-RUN SET (STOCHASTIC M.C.) 10-RUN SET (NOMINAL)	30-RUN SET (STOCHASTIC M.C.) 10-RUN SET (NOMINAL)	.... 10-RUN SET (NOMINAL)
DATA DISPLAY	30-RUN STATISTICS +1σ MEAN -1σ 10-RUN OVERLAY	30-RUN STATISTICS +1σ MEAN -1σ 10-RUN OVERLAY	10-RUN OVERLAY

Figure 8: Tailored Data Generation

Validation Data Requirements. There were multiple classes of data provided to the decision makers for them to establish for themselves the validity of each RSS HWIL simulation and overall confidence in the models, and for the purposes for which they were used.

The validation of the simulations against flight data was based a variety of instruments and measures, such as:

- *Direct overlay of data plots of simulation and Fight data;*
- *Pearson Product Moment Correlation Coefficients;*
- *Analysis of Variance;*
- *Comparison of the values of key, selected simulation and flight variables, such as flight time and miss distance; and*
- *Examination of the maximum absolute deviation between the values of key, selected simulation and flight variables.*

Exogenous Variables. There were several variables that impacted on system performance that were identified by the Simulation Working Group. Examples of the exogenous variables considered are: target position vs. time, target signature, countermeasure condition, countermeasure signature, missile roll, rocket motor thrust vs. time. In the process of validating the simulation for a given flight test, these variables were constrained to match the recorded data from the field test. This enabled the simulation output (endogenous variables and status variables) to better match the field data.

Monte Carlo Variables. Commonly occurring, random error sources which had to be compensated by missile guidance and control systems were identified. These variables were not measured during flight, but nominal values and distributions were known from previous tests and they were treated as a Monte Carlo input to the simulation (exogenous) variables. Examples of these variables are: servo gain, gyro imbalance, fin bias, thrust misalignment, and missile tip-off.

Endogenous and Status Variables (Output). These variables described missile system performance and/or guidance section status and operations. From an engineering viewpoint it was necessary to ensure that these variables reflected accurately not only overall system performance, but the components of the system as well. Examples of these variables are missile altitude vs. time, missile downrange and crossrange position vs. time, missile speed vs. time, miss distance, log amplifier gain settings, electronic field of view, gain reduction, lead and total bias vector, and other telemetry variables.

5.4 Validation Results

Each model was evaluated by the decision makers in the context of the data available to support the validation process. Examples of the data, utilizing different evaluation measures, are outlined below:

Direct overlay of data plots This data was the easiest to communicate to lay persons, and was important in establishing confidence in the simulations by the independent system evaluators due to its qualitative nature. All three simulations demonstrated a close match of predicted to actual flight data.

Examples of the type of overlay data provided to the evaluation community are portrayed in Figure 9 below.

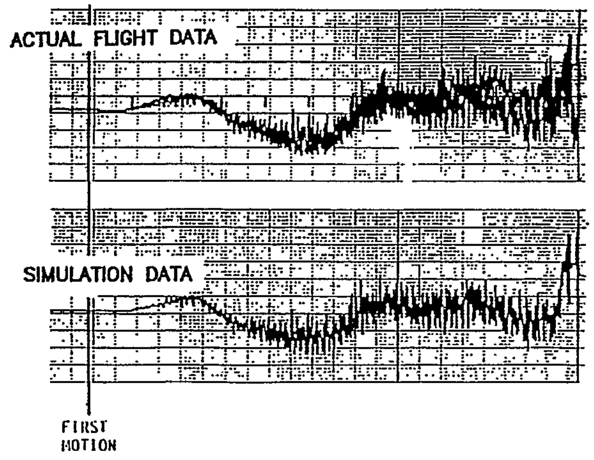


Figure 9: Direct Overlay - Fin Command Up/Down

Correlation Coefficients. The Pearson Product Moment Correlation Coefficients were calculated for each of several pairs of simulation and flight test data. These correlation coefficients proved to be strong indicators that the simulation output had the same trend as the actual flight data. The calculation of these coefficients was based upon the approach outlined in Figure 10 below:

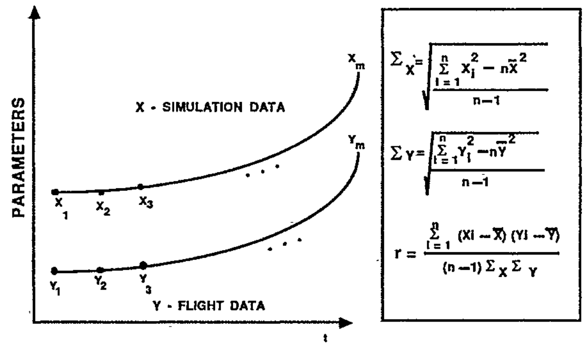


Figure 10: Determination of Pearson Product Moment Correlation Coefficients

An example of the typical results and data displays generated for just one of the flight parameters for one of the validation flights is shown in Table 3 below.

Table 3: PQT-G2 Pearson Correlation Coefficients

PARAMETER: CROSS RANGE POSITION

RUN NUMBER	MICOM	FAC
1	.946543	.99897
2	.951043	.99981
3	.999201	.99964
4	.998634	.99993
5	.999195	.99995
6	.999863	.99995
7	.997101	.99899
8	.997981	.99936
9	.995366	.99993
10	.999652	.99992
11	.999917	.99994
12	.999489	.99983
13	.999681	.99920
14	.999572	.99532
15	.996305	.99719
16	.994946	.99992
17	.999747	.99996
19	.999704	.99815
20	.999756	.99537
21	.999650	.99993
22	.999359	.99859
23	.997071	.99992
24	.999713	.99754
25	.999886	.99933
26	.998665	.99866
27	.992963	.99962
28	.999745	.99463
29	.999942	.99954
30	.999422	.99986

Analysis of Variance. Another means of establishing the credibility of the simulations was through analysis of variance, examining the distribution of the simulation's status and output variables, and determining the percent of time the data for each variable fell within one or three sigma bands.

Table 4: PQT-G2 Analysis of Variance

Parameter Name: Cross Range

Percent within 1 Sigma Band		Percent within 3 Sigma Band	
MICOM	FAC	MICOM	FAC
85.58	88.46	86.26	89.01

Comparison of Selected Variables. Certain variables were examined in an absolute context, such as flight time and miss distance. This was an easy test of how accurate the simulations were for important system level variables.

Table 5: Comparison of Key Variables of PQT-G2 Flight and Simulation Predicted Value

SIMULATION AGENCY: MICOM

VALIDATION PARAMETER:	FLIGHT TIME (S)	MISS DISTANCE (M)
ACTUAL	5.675	0.27
PREDICTED	5.654	1.52
DEVIATION	0.021	1.25

Maximum Absolute Deviation. Other variables were examined in the context of the maximum deviation along the entire flight trajectory between the flight recorded data, and the simulation mean predicted value

Table 6: PQT-G2 Maximum Deviation

PARAMETER NAME: CROSS RANGE

MICOM	FAC
15.0 METERS	7.73 METERS

6. SIMULATION UTILIZATION

The simulations were used for a variety of tasks, in addition to system performance assessments. These included:

6.1 Guidance System (Algorithm) Development

A principal use of the HWIL simulation was the development and refinement of flight algorithms which enhanced missile performance in an infrared countermeasure environment. Ford Aerospace, through the software development station integral to their HWIL simulation, was able to quickly and easily adapt the operational flight software resident in the EEPROMS of the guidance section in order to address and correct problems encountered during the government's qualification tests.

6.2 Preflight Performance Predictions

Prior to flight tests conducted in the government qualification tests, the HWIL simulations provided data on expected flight performance for the specific scenario planned, as well as excursions of variations that might have occurred if the scenario was not executed exactly as planned. This utilization was a distinct confidence building measure which fostered support in simulation based analysis. It also increased confidence in the system performing well during the flight tests. If the HWIL simulations indicated sensitivities in performance for a specific target/scenario then additional analysis was conducted to identify its nature and scope. This often resulted in software refinements prior to execution of the flight test.

6.3 Post-flight Failure Analysis/Evaluation

After any flight failure the HWIL simulations were used in an attempt to replicate the failure in the lab. Before proceeding with additional flights a determination based upon simulation results, as well as flight telemetry data, would be made on the nature of the failure; software related or hardware related, or a combination of both. Additionally, as knowledge was gained from flight data, the simulations would be upgraded to better model field conditions.

6.4 System Performance Assessment

Supported by the limited flight test program, the HWIL simulations were used to assess system performance in a variety of countermeasure conditions, across all possible missile/target ranges and aspects, and involved thousands of computer runs. This was crucial in documenting system capability and readiness for proceeding into production and fielding. The simulation based performance assessment conducted by the three independent agencies provided the crucial data used by the Army's system evaluators to determine if the RSS missile met its P_{SSK} requirements.

7. General Observations and Lessons Learned-

It is extremely important that system simulation be brought in early in system design. System simulation can affect design, save time, and money, while reducing risk. But the simulation has to be developed concurrent with the system, and if possible lead the program through the product life cycle. This means spending time and money early in a program. Money spent early on simulation can preclude excursions which prove to be dead-end paths that contribute nothing but the expenditure of precious resources, and, if serious enough, could result in cancellation of the program.

Equally important is agreement among the simulators, and the system evaluators that utilize the computer based performance assessment data, on the criteria for establishing how good a simulation is, or must be. A great deal of time was spent in validating the RSS simulation against all the telemetry variables. This established confidence among the simulation agencies that the HWIL simulations accurately predicted system behaviors and performance, and for all the right reasons. It was then necessary to communicate this confidence to the system evaluators which were users of the simulation data. A special effort was made to share data with the evaluators and demonstrate the accuracy of the simulations through the formal validation exercises. The Simulation Integration Working Group was the forum used for this exposition as well as other, less formal, simulation based activities.

8. CONCLUSION

Conducting a systematic program of simulation confidence building for the Chaparral RSS Development Program has been a successful and valuable enterprise. In particular, the procedures associated with a formal, tailored and documented simulation validation strategy provided the Program with decisive support required for the critical RSS Type-Classification Decisions. The general utility of simulation-based systems analysis in support of the RSS Program is indicated below.

8.1 Strengths:

The validated hybrid, HWIL simulations were an important analytical tool for project management. The specific strengths of simulation demonstrated in the development and utilization of the CHAPARRAL RSS simulation were:

- *Although these simulations were expensive, and time consuming to develop and maintain, there were tremendous savings to the program due to the reduced number of flights tests required to qualify the system for full-scale production and deployment*

- *It allowed the Program Manager, and system evaluators, to estimate the performance of the system under a projected set of operating conditions.*

- *Alternative system designs, and operational flight software could be compared by simulation to see which best met specified requirements.*

- *In a simulation, better control could be exercised over experimental conditions than with the system itself under field conditions.*

- *It allowed for replication of field conditions in order to detect, fault isolate and correct system problems.*

8.2 Limitations:

Simulation of weapon systems in the full-scale development phase of the product life cycle is not without drawbacks and problems. Limitations encountered with the CHAPARRAL RSS simulations which are common in a HWIL environment were:

- *Several independent runs of a simulation were required for each particular set of conditions. For CHAPARRAL, several thousand runs were required, and it therefore took several months to complete the entire performance assessment.*

- *Due to the stochastic nature of the HWIL and the large number of trials required in a Monte Carlo model, it is possible for laymen to perceive a greater precision in the results than is warranted or justified. Therefore, it is necessary to take a proactive approach and incorporate measures in your validation program to ensure the limits, as well as strengths, of the simulations and simulation data are communicated to its users.*

REFERENCES

"CHAPARRAL-RSS Simulation Validation Plan," CHAPARRAL/FAAR Project Office, U.S. Army Missile Command, January 1987.

"CHAPARRAL-RSS Simulation Validation Reports," CHAPARRAL/FAAR Project Office, U.S. Army Missile Command, June 1987.

Law, Averill M., and David W. Kelton, Simulation Modeling and Analysis, McGraw-Hill, Inc., 1982.

Naylor, Thomas H., and et al, Computer Simulation Techniques, John Wiley and Sons, Inc., 1968.

Richard, Henri J. and William F. Waite, "Flight Data Injection into a HWIL Simulation," Proceedings of the 1980 Summer Computer Simulation Conference, The Society for Computer Simulation, AFIPS Press, 1980.

Street, Donald R., "Comparison of Three CHAPARRAL Performance Assessment Models," Weapon Systems Analysis Division, CAS, Inc., Report Number CR871302, 1987.

Waite, William F., "Hardware-In-The-Loop Simulation For Quality Assurance," Proceedings of the 1981 Summer Computer Simulation Conference, The Society for Computer Simulation AFIPS Press, 1981.

Waite, William F., "Simulations For System Design Modifications," Proceedings of the 1983 Summer Computer Simulation Conference, Volume 1, The Society for Computer Simulation, AFIPS Press, 1983.

Waite, William F., et. al., "Hardware-In-The Loop Simulation of Systems Having Embedded Computers," Proceedings of the 1985 Summer Computer Simulation Conference, The Society for Computer Simulation, AFIPS Press, 1985.

BIOGRAPHY

Robert M. Gravitz is a Senior Systems Analyst at COLSA, Inc. in Huntsville, Al. Mr. Gravitz supports the CHAPARRAL Rosette Scan Seeker (RSS) simulation and engineering test programs, as well as the Fiber-Optic Guided Missile (FOG-M) design, fabrication, and integration efforts underway at the U.S. Army Missile Command. He has an MS in Systems Management from the Florida Institute of Technology, and a BS degree from the University of Florida.

COLSA, Inc., P.O. Box 1068, 6726 Odyssey Drive, Huntsville, AL 35806; (205) 830-5412, Ext. 1579.

William F. Waite is the Assistant Manager of the Huntsville office of Riverside Research Institute. He supports the Chaparral and FAADS Project Offices at the U.S. Army Missile Command in defining and executing strategies for simulation-based systems analysis. He is involved with SDI systems simulation activities, including SDI architecture modeling and National Test Bed planning and simulation procedures definition. He has an MS degree in Physics from Penn State University, and an MAS from the University of Alabama.

Riverside Research Institute, 303 Williams Ave., Suite 125, Huntsville, AL 35801; (205) 536-5500.