SIMULATION PROCEDURES FOR ANALYSIS OF MISSILE SYSTEMS

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ABSTRACT

This paper presents an overall picture of simulation analysis as it applies to testing of preproduction, prototype, and production missile systems, to include ground and ancillary equipment. Simulation concepts are defined with regard to type of weapon system to be tested, purpose, objectives, and nature of simulation analysis. Steps in constructing and validating the math model are explained. Utilization and operation of digital, analog, and hybrid computers in support of the simulation activities are also presented.

INTRODUCTION

The existing overall engineering test techniques for testing missile systems consist of simulation studies, field tests, and laboratory tests. The present concept of missile testing is consolidated (parallel) rather than sequential testing. This approach makes it essential that an analysis of test requirements be conducted at the earliest possible time with reference to system engineering tests. Simulation studies of missile systems should be utilized in various phases of missile system developmental testing: (a) in missile flight safety planning, in overall test planning, and in the development of engineering test plans; (b) in preflight and postflight analysis to supplement engineering test analysis, and to better evaluate all flight test results; (c) to extensively explore the performance of systems under widely varying sets of target and environmental conditions, and (d) to explore the effects of changes in missile system parameters on missile system performance.

Simulation of a missile system is performed through the exercise of a model that imitates the operation or motion of the relevant parts of the system under study. A math model in this case is the sum of the mathematical equations, look up tables, parameters, and initial conditions that define the real system and its operation. The math model then is coded into computer language and commands are added which tell the computer in detail at any given time what to store in its electronic memory, how to scan the tables, how to perform the mathematical operations, and which results should be listed or displayed. This programmed math model is known as the simulation program.

Simulation through use of programmed computers produces results that otherwise could only be achieved by costly actual tests or missile flights. For example, from 3,000 to 10,000 simulated firings of a short range missile can be obtained with the funds needed to fire one missile on the range. Physical tests can be imitated by use of simulation within, at, or beyond the boundaries and limitations of actual missile hardware performance.

The mathematical model of a weapon system is used to facilitate analysis procedures through its direct execution of simulation studies on analog and digital computers. A basic mathematical technique is the application of classical vector and tensor mathematics. Other important techniques include the use of automatic control system analysis concepts.

SIMULATION METHODOLOGY

The establishment of a simulation methodology team, which interfaces with project support simulation groups within the simulation organization, provides a unique capability for investigation, development, and implementation of advanced technology while at the same time providing comprehensive support for requirements, missile system simulation, and analysis.

Simulation methodology improvement activities are oriented toward the development/implementation of improved simulation techniques in support of the test and evaluation mission. Specific areas of investigation include development of program modules which can be used in configuring total weapon system simulations, organization and maintenance of simulation support libraries, implementation of simulation of event sequenced engagements and systems operations, propagation effects, and of the Advanced Continuous Simulation Language (ACSL).

TYPES OF SIMULATION STUDIES

Simulation for Missile Flight Safety

Prior to the first missile launching, safety requirements have to be established in terms of lines of fire and safety boundaries. These are determined by sets of computed trajectories. Simulation studies are based on use of design data and as much other information as may be available. From these first simulations, tentative range safety requirements and lines of fire are established.

Throughout the engineering design tests, actual missile performance data are recorded for use in refining the math model and the early trajectory predictions and thus to update the tentative safety boundaries and lines of fire. During the engineering tests, actual missile performance can be used to update the boundary limits.

Flight safety simulations are used to:

1. Determine typical flight range capabilities and impact points of the booster using a variety of atmospheric conditions and of missile booster combinations.

2. Evaluate the effects of non-normal performance such as booster, warhead, or sustainer stage failure, unusual propellant burning rate or thrust malalignment, and guidance failure or other deviation from expected performance.

3. Simulate missile trajectories using range data inputs during flight to constantly correct the predicted impact point for each of the stages of missiles launched from off range locations with impacts on range.

Simulation in Planning of Engineering Tests

Missile trajectories for a system can be developed from the physical laws of motion incorporated usually into a six degrees of freedom mathematical model of the missile system. The six degrees of freedom are represented by three translational equations and three rotational equations, with a basic assumption that the missile is a rigid body. If the missile frame flexure is considered, additional degrees of freedom in the model are added.

The aerodynamic forces and moments for math modeling purposes are functions of missile velocity, altitude, the angle of attack, elevon deflections, and missile rotational motion. Generally, coefficients for aerodynamic forces and moments must be determined by laboratory or flight tests. Motor thrust components and gravity acceleration components expressed as forces are added to the aerodynamic force vectors which lie nearly along the body axes for supersonic missiles. As a result, the total force inputs to the three translational equations are obtained. Total moments are similarly obtained. Then the six basic equations of motion are solved simultaneously for the acceleration and velocity components along the missile body axes. These variables are used to compute total missile velocity and angles of attack. The angular accelerations and velocities are used to compute the Euler or attitude angles which, in turn, are used to compute the gravitational force components for the translational equations; and also to compute missile velocity with respect to the earth axes and, after integration, the position of the missile with respect to the earth. Further complexities are frequently encountered in modeling missile systems.

The same basic principles apply to target simulation.

Preflight Simulation

Given a missile system simulation, one can "fly" the missile on the computer before the actual flight test to predict missile performance. This information is valuable for determining where the cameras, radars, and other observational equipment should be optimally located by determining the trajectory position in advance of the firing. It is also valuable for planning location of intercept, impact points, and engagements to include in the firing program, etc.

Postflight Simulation

A postflight simulation is of value to the systems analyst in determining causes of failure or reasons for deviation in system performance. Test results can be used for verification of or improvements to the system or the model.

Simulation as an Aid in Supplementing Actual Tests

Missile flight tests are very expensive in materiel, range time, and labor. The number of firings are seldom sufficient to supply the number of samples required for a thorough statistical analysis of missile system behavior characteristics. By using simulation, firing tables for unguided missiles have been generated with a minimum number of actual flight tests, but with hundreds of simulated computer "firings". Information urgently required to make decisions during the engineering test phase can be provided by computer simulation. Likewise, when more hardware tests are required to completely analyze system behavior than there are missiles available, simulations are used to supplement and optimize the hardware testing in order to provide maximum information from the test program. A simulation program, using prior test and design data, can pre-determine the limitations of the system. Flight tests are used to verify and define more precisely these limitations. A combination of flight tests and simulation tests can be used to define the intercept areas for various targets. Simulation also permits the determination of performance against targets that are not available for field tests. An additional use is for investigation of safety hazards without risk to personnel. For example, hazards to personnel and equipment, caused by hardware failures of a system, can be simulated by introducing into the computer program perturbations of the variables that adversely affect control, as well as possible failure modes of individual subsystems.

Simulation Required as a Result of Changes in the Missile System.

Changes in the missile system frequently occur during the engineering test phase. Changes are simulated by modification of the original math model; such changes can then be investigated as to possible effects on system performance and as to whether the system has been sufficiently altered that it should be retested in the field as a new or different missile system. Conversely, the simulation may point out the need for changes in the test plans. Recommended changes to the missile system can be evaluated prior to actual change using computer simulation.

Other Simulation Requirements in Engineering Tests

In analysis of the performance of a missile it can be assumed that all of the forces acting on the missile during flight are known except for thrust and drag. By using range instrumentation data for input, the equations of motion can be solved for thrust and/or drag, yielding tables of these variables for each flight. These tables may be used to evaluate motor performance and aerodynamic capabilities for each flight.

By means of simulation, it is possible to determine intercept range, burnout time, impact range, flight trajectory, etc., for varying launch angles, motor burnout times, and other system parameters. By doing these families of trajectories various capabilities of the missile system can be determined.

The portion of space which includes all of the trajectories which successfully intercept the "target" is known as the performance envelope of the system. A study of this envelope may be used, in the engineering test phase, to show the intercept effectiveness of the system.

This envelope projected on the earth's surface can be used to help evaluate surface-to-surface missile flight systems, and to provide the input into determination of missile flight safety requirements on the range.

The simulation of missile systems can include the effects of various environments, either natural or man made, differences in deployment, and other effects which perturb system performance variables. Perturbing factors are introduced one at a time to determine the effect of each perturbing factor. Then the factors are introduced in combinations to determine combinational effects.

In conjunction with statistical and operational research techniques, simulations can be used to assist the hardware testing for evaluating reliability, maintainability. This is accomplished by using inputs such as maintenance and failure rates derived from actual engineering tests, together with stock level and supply limitations from materiel needs.

Test data describing warhead performance and target vulnerability can be used as an input to simulations to find kill probability (including lethality). Such data can improve the end product of an engineering test program which is an evaluation of the system tested as to its capabilities and limitations as a weapon system.

DEFINING THE SIMULATION

The present concept of missile system testing is consolidated (parallel) rather than sequential testing. Therefore, within the Army establishment, close liaison is maintained between all concerned in the production of weapon systems. This in turn permits discussions, coordination, and exchange of data required for simulations among test simulation personnel, test project personnel, developing agency personnel, and industrial contractors. Steps in definition of a simulation are:

1. Determine what kind of weapon system or subsystem is to be simulated. It may be guided or ballistic, long or short range, ground-to-ground, air-to-air, ground-to-air, or air-to-ground missile. It may be a tank-mounted, anti-tank, guided missile, or an artillery missile weapon; or the system could be a whole battlefield weapon system configuration involving various types of missile weapons or any set thereof.

2. Establish the purpose of the simulation, and the simulation objectives. Is it to find flight safety regions or to plan engineering tests? Is the simulation for preflight predictions or for post flight analysis? Is it to aid in supplementing an actual test, or is it a simulation required as a result of changes in the missile system, etc?

3. Decide which physical parameters, physical data, physical characteristics, and aspects of system behavior are involved in the simulation problem. What are the basic assumptions to be made in the model and in the analysis? The answers to these questions determine the nature of the model and

the analysis requirements.

4. Ascertain the general features and extent of the mathematical model. Should the model be a two dimensional, three degrees of freedom model, or should it be a three dimensional, six degrees of freedom model.

5. Establish the accuracy and precision which will be required for simulation output. Accuracy is dependent on the quality of the radar and telemetry data to be obtained, and depends also on accuracy of model data such as thrust curve, tables of aerodynamic coefficients, mass representation, moments of inertia, system frequencies, and other criteria. One must establish the precision that is required on simulating various signal frequencies in performance analysis data.

6. Determine the type of computer necessary to do the required analysis. In general, accurate simulation of signals which have frequency content of 50 Hz and above requires analog or hybrid equipment (autopilot and noise signals are typical) if the computer is to run in an effective analysis time-frame. One must establish the computer control unit when a hybrid computer is used. Usually the control unit is the digital computer within the hybrid system, since a digital computer has language control options and can make logical decisions which the analog components of the hybrid system cannot.

UTILIZATION AND OPERATION OF COMPUTERS

All the computers use a simulation model on the basis of the broad principles discussed earlier. At the present state of art, when frequencies are below 50 Hz a digital computer may be preferable. Otherwise, a hybrid or analog computer may be chosen.

Programs are prepared for the chosen computers and preliminary runs are made to debug the program so that the system being simulated performs according to the nominal description of the system. System parameters are adjusted so that the simulation results match well with those for corresponding missile hardware tests.

For digital computers the following additional steps should be taken:

1. Code math model into computer language.

2. Put program into computer compatible format (punched cards, magnetic tapes, etc.). In case no remote job terminal is used deliver input to digital computer operator. In case of "remote job terminal", the job is put into a remotely located card reader and the output is received at a printer located at the same remote location. This remote electronic set-up is communicating by wire with the computer located elsewhere. In case of a "demand terminal" the computer receives instructions directly by typing in program and receiving computer response at user's location. The program can in this case be interrupted, changed, and updated.

In case of analog computers, the following additional steps should be taken:

1. A program is prepared to connect the proper computer components.

2. An overall block diagram should be drawn to show the general flow of information.

3. Then the program should be mechanized by wiring the components together.

In case of the use of a hybrid computer the steps to be taken regarding digital and analog computers may be combined. In addition a decision has to be made in the beginning which part of the simulation shall be run on the digital computer (master unit) and which part of the simulation shall be run on the analog computer.