

GUIDED WEAPONS RADAR TESTING

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ABSTRACT

An overview of non-destructive real-time testing of missiles is discussed in this paper. This testing has become known as hardware-in-the-loop (HIL) simulation because it involves the actual missile hardware.

Keywords: Simulation, hardware-in-the-loop, missile testing, radar, electromagnetic environment, flight dynamics

INTRODUCTION

Non-destructive real-time performance evaluation of missile seekers has become increasingly important because it provides a very cost effective complement to actual flight testing. The testing is performed in a controlled and repeatable environment and hundreds of flight scenarios can be simulated within the cost and time frame of only a few live firings on a range. Thus the development and testing cycle can be significantly shortened.

Since the testing exercises the actual missile, the process has become known as hardware-in-the-loop (HIL) simulation. The HIL hardware and software typically creates in real-time the electromagnetic environment (targets, clutter, multipath, ECM, etc.) and the rotational kinematics that the missile would see during the flight scenario. Flight geometries and electromagnetic environments that may not be practical for live flight testing can be produced with HIL simulations. Security of the tests and results are provided by the chamber in which the HIL tests are conducted.

The following sections describe HIL simulation and show why it is important. The primary functions, major components, and typical quantitative requirements of an HIL system are discussed. The technological advances affecting HIL systems are discussed and it is shown how these advances along with the increasing performance and flexibility requirements are making it very attractive for users to purchase HIL systems (or major subsystems) rather than build them from lower level components.

WHAT IS HIL SIMULATION?

As the name implies, the actual missile hardware is placed in the testing loop. The missile, to the extent necessary or practical, operates as it would in actual flight. It is exposed to an electromagnetic environment and motions that are also as similar as necessary or practical to what would be encountered in actual flight.

There are a few aspects of the missile flight scenario that cannot be simulated for obvious practical reasons. These aspects would include linear flight motion and propulsion. These obvious limitations do not detract from the utility of HIL simulations. The other practical limitations for a specific HIL system are those imposed by:

- budget constraints,
- technology constraints,
- lack of knowledge of the environment to be simulated,
- and the people designing and building the system.

Since the guidance portion of the missile is the most critical, complex, and costly, that is where the simulation effort is focused. The inertial sensors are exercised by the angular motions provided and the electromagnetic (EM) sensors are exercised by the EM environment. The EM sensors may be RF, millimeter wave (MMW), infrared (IR), or optical. This discussion will be limited primarily to the RF and MMW regimes. However, it should be pointed out that dual-mode (RF/MMW and IR) testing will become increasingly important in the future. In addition to the guidance system, control surface actuation and forces are often part of HIL testing.

A high level schematic of missile HIL testing is shown in Figure 1. Since the missile is normally being tested as a complete system, the signal processing and control functions are being tested as well.

WHY IS HIL IMPORTANT?

Of course the real test of whether a missile system meets the requirements is an actual flight test. However, actual test firings have several drawbacks. The two most significant ones are:

- they are costly and time consuming, and
- only a few of the many possible scenarios can be tested.

For these and other reasons, HIL simulation has become a cost effective complement to flight tests. The same type of data is provided by HIL simulation as is provided by flight tests. These data include such parameters as missile linear and angular motion, sensor motion, guidance commands, control surface position, aerodynamic parameters, radar returns, etc. In the simulation, some of these parameters such as missile linear motion and aerodynamic parameters are computed rather than

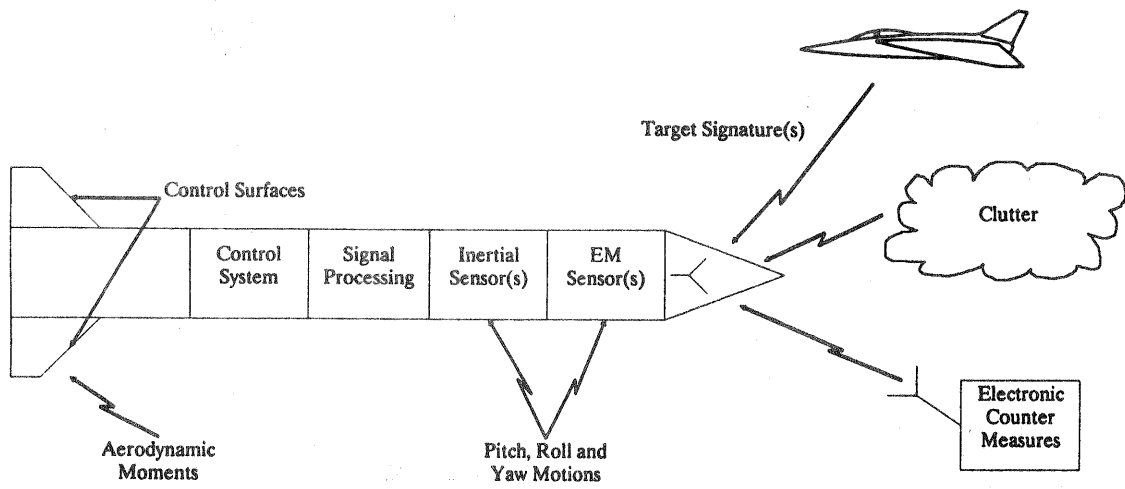


Figure 1. High Level Schematic of Missile HIL Testing

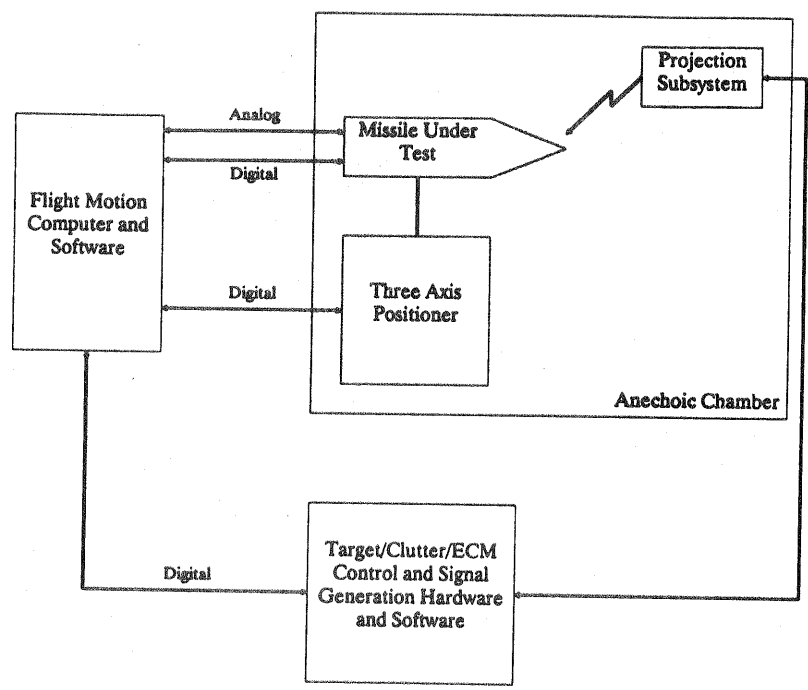


Figure 2. High Level Block Diagram of an HIL System

measured. Data from a flight test must be sent back by telemetry which adds to the complexity and cost.

HIL simulation is an economical means of:

- obtaining data in the development stage before the missile is ready to be flight tested,
- obtaining data before flight testing to maximize the value of flight tests,
- better understanding flight test results through post test simulations using the flight test results,
- obtaining data for many different scenarios,
- obtaining data for environments and scenarios that would be impossible or prohibitively expensive to produce in flight tests.

An important aspect in testing is to have controlled parameters. The environment in an HIL simulation is both controllable and repeatable. This is not true of flight tests where there are many uncontrolled variables such as meteorological conditions, clutter, and electromagnetic interference.

Security is another important factor in missile testing. Optical and electronic reconnaissance is a continuing concern for actual flight testing. Security is clearly much better within the confines of a shielded chamber.

As missile guidance systems have become more and more complex, HIL simulations have become increasingly important. With the number of variables and scenarios that need to be tested, HIL simulation as a complement to actual flight testing is really the only viable approach.

PRIMARY FUNCTIONS OF AN HIL SYSTEM

The primary purposes of an HIL System can be stated succinctly:

- to simulate the kinematics of actual flight and
- to simulate the electromagnetic environment that the missile would see in actual flight

In simulating the kinematics the obvious compromise of only imposing angular motion on the missile has to be made. The full six degree of freedom trajectory for the missile is calculated from the relevant aerodynamic and control parameters by a very high speed computer. The update rate for all of the state variables including the missile positions and rates is typically in the range of 100 to 1000 times per second. This six degree of freedom information is then used to determine the pitch, roll, and yaw motion of the missile. The angular motion is physically imposed on the missile by a high performance three axis positioner.

The electromagnetic environment in which an RF or MMW missile seeker operates includes clutter, multipath, rotating parts modulation, target skin returns, and ECM. The environmental models need to be efficiently implemented so that they can be executed in real time. However, the models must provide a realistic simulation of the significant EM characteristics of the environment that can be discerned by the missile.

Target models typically need to provide range and angular extents (i.e. three dimensional models). Although statistical glint and scintillation are sometimes adequate, deterministic models that can be resolved into range and cross range scatterers are often required. Other characteristics of the target such as doppler, differential doppler, and polarization must be faithfully reproduced at least to the extent that can be discerned by the missile. In summary, the target model must provide the proper instantaneous amplitude, phase, polarization, and angle-of-arrival

for each missile seeker range and doppler resolution cell.

Clutter is normally much more extended and diffuse than is a target. However, the characteristics that need to be simulated for clutter are essentially the same as for targets. In order to simulate one target plus clutter, two independent channels are required. Often two or more independent targets are needed which requires additional channels.

In simulating ECM, the capability for both denial and deceptive jamming is important. In some cases it is desirable to incorporate the actual jamming equipment as part of the simulation configuration.

In summary, the HIL system must provide adequate simulation of the kinematics and the electromagnetic environment. This includes the pitch, roll, and yaw motions of the missile and the target(s) and clutter returns as well as ECM emissions.

MAJOR COMPONENTS OF THE HIL SYSTEM

A high level block diagram of a typical HIL system is shown in Figure 2. For the flight simulation function there is a flight motion computer and associated software and a high performance three axis positioner that is controlled by the flight motion computer. The computer also must have very high performance in terms of both I/O and computational capabilities. Some quantitative characteristics are given in the next section.

The EM environment simulation subsystem is composed of two major components:

- a projection subsystem and
- a target/clutter/ECM control and signal generation subsystem.

The projection subsystem emits this RF or MMW radiation that is received by the missile. It can be implemented in several ways including a large array, a small array that is mechanically moved, and a compact range. The large array is very complex and costly for simulating reasonable fields of view. A concept called synthetic line-of-sight is sometimes used with a small array. This allows a small array to be used, however, the missile does not undergo the same pitch, roll, and yaw motions as it would in actual flight. Also, multiple targets/clutter with different angles of arrival cannot be simulated. The approach that uses a mechanically positioned small array suffers from both positioning speed and positioning accuracy problems.

The control and signal generation subsystem is responsible for generating the appropriate signals to be radiated by the projection subsystem. It can be thought of as an elaborate programmable signal generator that receives, generates, and transmits complex electromagnetic waveforms. The appropriate directions of arrival, times of arrival, signal amplitudes and phases, and signal modulations are provided by this subsystem. For a digital implementation of this subsystem, the following functions would be performed:

- receive and downconvert the missile transmitted waveform
- digitize the downconverted waveform
- provide the proper target/clutter modulation in digital memory for each independent target or clutter channel
- produce the appropriate delay (based on range) for each target or clutter channel
- convert to analog and produce the modulated waveform at IF
- upconvert to RF
- control phase and amplitude to each part of the projection subsystem to provide proper direction of arrival

- combine the independent target and clutter channels
- supply the signals to the projection subsystem which may upconvert to MMW if it is a MMW HIL system

A large anechoic chamber (length and width on the order of 50 feet) is typically used for a wall array approach. With a small compact range approach much less space is needed.

TYPICAL QUANTITATIVE REQUIREMENTS

This section provides some typical quantitative performance requirements in order to provide a quantitative perspective on the capabilities required of an HIL system. The following are typical requirements of the flight simulation subsystem:

Update Rates	-	100 to 1000 Hertz
Position Accuracy	-	.02° to .002°
Maximum Acceleration	-	20,000°/Sec ²
Frequency Response	-	10 to 30 Hz

As can be seen from the positioning requirements, a very high performance positioner is required. Normally a very high performance hydraulic positioner is used.

The update rates imply a very high performance computer. One to ten milliseconds is not very much time to read all of the data from the missile under test and from the positioner, do all of the aerodynamic calculations, and write data to the missile and positioner. Normally a special purpose high performance computer like the AD-100 from Applied Dynamics is used. There are new RISC architectures that can provide the computational capability and could provide cost effective alternatives in the future. However, currently, there are I/O speed and response time issues that need to be addressed.

The following are typical requirements for target signature simulation:

Frequencies	-	2-18 GHz, 35 GHz, 94 GHz
Range	-	50 meters to 10 kilometers
Range Rate	-	Up to 1500 meters/second
Position Accuracy	-	.05°
PRF's	-	Up to 250 kilohertz
Waveforms	-	Pulsed, stepped frequency, and FM/CW
Target Types	-	Complex, extended in range and angle with differential doppler

As can be seen from these quantitative requirements, a lot of performance and flexibility is required from the control and signal generation hardware and software.

TECHNOLOGICAL ADVANCES AFFECTING HIL SYSTEMS

The major technological advances that have had an effect on HIL systems during the 1980's are in the areas of digital hardware, analog-to-digital (A-D) converters, digital-to-analog (D-A) converters, and signal processing. As an example of such changes, Figure 3 (reproduced from the 12 January 1989 issue of *Electronic Design*) shows how A-D converters have increased in speed over an 18 year time frame. The speed of A-D converters is continuing to increase. The new top-of-the-line digital oscilloscopes are achieving sampling rates of one GHz and beyond. There have also been corresponding increases in speeds of D-A converters.

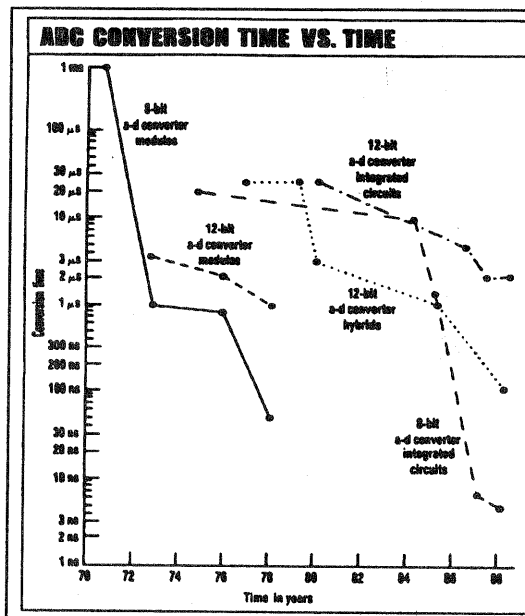


Figure 3. As A-D converters have moved from modules to hybrids to ICs, both conversion times and costs have dropped orders of magnitude.

The tremendous progress in both speed and cost of digital hardware together with the increasing A-D and D-A speeds has allowed higher and higher bandwidth signals to be captured, processed, and converted to analog form. These changes are now to the point that the target/clutter/ECM simulation can be implemented in digital form. This provides significant advantages over the older analog or hybrid implementations in cost, capability, and flexibility. The flexibility that is provided by a digital implementation is very important for HIL simulations. Different target, clutter, and/or ECM characteristics can be provided via software rather than through making hardware changes.

Another important technological advance is in the area of frequency synthesizers. Accuracy and frequency switching time have improved dramatically. Switching times on the order of a microsecond are available today and even faster ones, albeit even more expensive ones, are becoming available. Fast switching times are required for providing HIL simulations for missiles with frequency agile seekers.

Another important area of technology for HIL simulations is the compact range. A compact range approach allows an HIL system to be implemented in a much smaller and much less costly chamber than, for example, an "array-on-the-wall" approach which requires a large anechoic chamber.

SUMMARY

An overview of non-destructive real-time testing of missiles has been presented. This HIL simulation was defined and the reasons for its importance were given. The primary functions, major components, and typical quantitative requirements were discussed. Some of the significant advances in technology affecting HIL systems were presented.

This new technology along with the needs and desires for higher performance and more flexibility has produced a situation where digital implementations are attractive and cost effective. The

capability, flexibility, and cost of a properly designed digital implementation are some reasons why it is attractive for users to purchase HIL systems (or major sub-systems) rather than to attempt to build them from lower level components. There are also significant system integration and development cost issues that make it more attractive to purchase rather than build.

Furthermore, the use of a compact range drastically reduces the building volume (and thus cost) required to do HIL simulation. As time progresses more and more users will realize that they can afford HIL systems and thus the use of HIL simulation will continue to increase.