AUTOMATED CUE-SYNCHRONIZATION TEST — A REPORT FROM THE TEST FLOOR

Robert J. Sawler and Gary R. George
Link Flight Simulation Division of CAE-Link Corporation
Binghamton, New York

ABSTRACT

The validations of dynamic response and cue synchronization performance are very difficult and time-consuming tests which require special test equipment and trained personnel. These tests require the entire simulator complex in full operation and constitute a very important measure and validation of the entire simulator. They are further complicated by the fact that they must be performed at training sites all over the world by many different user and contractor engineers. It is therefore desirable and necessary to design tests and procedures that are simple and automated, which is the purpose of the Automated Cue-Synchronization Test. This paper describes the use of software inputs through the aircraft control trim circuits and the elimination of the pilot from the testing by using freeze parameters and special initializations. Advantages of the test as applied in the field and potential advantages of its use in the total simulator development process are also discussed.

INTRODUCTION

Simulators are specified for latency in terms of complete dynamic response and cue synchronization as it relates to the dynamic responses between the primary cues. In general, the primary cues of concern for aircraft simulators are motion, visual, and instrument dynamic response in the roll, pitch, yaw, and lift axes for rotary-wing simulators. Overall, the details of these specifications vary greatly. The procurement specification for the UH-60 Black Hawk Flight Simulator of the Army's Synthetic Flight Training System (SFTS) Program reads as follows:

Complete System Dynamic Response

Relative responses of the motion system, cockpit instruments, and visual system shall be coupled closely to provide integrated sensory cues. The total time lag error of the trainer shall not exceed 150 milliseconds (ms) for all cues. In addition, the difference in time lag error between any two cues shall not exceed 20 ms. Time lag error is considered to be any lag in excess of that experienced in the real aircraft. [1]

As can be determined from this specification, the time lag error is defined relative to the actual aircraft data, as opposed to the pure simulator latency, the cues to be considered for measurement are motion, visual, and instruments, and the measurement domain is implied to be time in this case. Other specifications similar to this provide guidelines for designs that insure simulation with high-fidelity cuing and correspondence of that cuing to the real-world pilot experience.

Future specifications will likely impose dynamic response requirements on other cues, including infrared and radar sensors, as well as glass cockpit displays. Helmet-mounted displays, such as those employed in the AH-64, will also be specified for latency and cue synchronization in simulation. The displays used for infrared night vision flying must respond correctly in order to give the pilot the correct feel of the aircraft. His whole perception of the world derives from the sensory cues and display imagery at his eye. [2,3]

Latency and cue synchronization discrepancies are generally suspected of contributing to degraded training of high-gain tasks, such as escort flying, and student disorientation and discomfort known as simulator sickness. [4,5,6,7]

With this important consideration, the dynamic response/cue synchronization test to verify simulator performance is a very valuable and critical test.

THE SIMULATOR DYNAMIC RESPONSE/CUE SYNCHRONIZATION PROBLEM

As in all development work, long before any testing is done to verify simulator performance, careful analysis and up-front design are performed to ensure specification compliance. For the problem of dynamic response/cue synchronization, the up-front design includes optimum sequencing of software modules to minimize the latency and provide the necessary correlation between cues. Also, developing efficient data transfers between the hardware, such as host computers and visual image generators, and maximizing the linkage efficiency for signals that have a direct relation to primary cue generation are early design considerations. Finally, the optimum execution rates for critical software modules are determined. This process is done throughout the development cycle and must be responsive to changes for software load balancing of the processing units and normal development changes as a simulator program matures.

The up-front design phase is clearly a very important time to eliminate costly problems that may arise late in a development program with the dynamic response/cue correlation of the simulator. It is much more difficult to make hardware and software changes once the system is fully integrated. Changes to an integrated system may impact many other systems and may be costly both financially and in schedule performance.

The time analysis of the dynamic system response involves adding up the delays for each cue process to determine the worst-case latencies and the relationships between the various cues. The analysis includes both the hardware and software delays of the overall system. To do a steady-state analysis in the frequency domain, the dynamics must be considered and simulator hardware modeled with complicated transfer functions. The phase relationships and gain can then be determined as a function of frequency. Non-linearities of the system can have a marked influence on the frequency response, particularly the motion base, and these nonlinearities are difficult to model analytically with the describing functions.

PHYSICAL TESTING

The dynamic response/cue synchronization testing involves a considerable amount of time to perform. Prior to the Auto-Cue-Sync Test, the majority of the time spent running the tests was in the manual setups and procedures. The Auto-Cue-Sync Test was developed to significantly reduce the amount of manual work required for the testing. The actual testing philosophy has not changed: the dynamic response and cue synchronization of the simulated aircraft is still determined as the individual system response (motion, visual, instruments) to a control system input. The Auto-Cue-Sync Test methodology eliminates the "pilot in the loop," some hardware test equipment, and the associated electrical wiring. Also, the software performs many of the tasks which were previously done manually. The Auto-Cue-Sync Test methodology can be applied to both the time domain and frequency domain testing. The details of the Auto-Cue-Sync Test are discussed after a review of the physical testing procedures for the dynamic response/cue synchronization test.

The dynamic response/cue-synchronization testing initially applied on the SFTS program (AH-1S, AH-64, UH-60, CH-47) used step inputs at the controls for time domain testing. The following paragraphs describe this test methodology. The same techniques can also be applied in the frequency domain for steady-state testing with some added features, as discussed briefly later.

The test philosophy for the time domain requires that we apply a step input signal to the simulated aircraft controls and then measure the onset response of the resulting cues. The motion base response is measured using an accelerometer, the instrument response is measured using the analog drive signal, and the visual response is measured using the video output from the digital image generator (DIG). The simulator is initialized and trimmed out with contrasting video (e.g., horizon against blue sky) arranged so that it is in the correct visual window for the test axis. For example, the side window needs to be set up with a contrasting video or test pattern for the roll axis test. The analog outputs for the motion, visual, and instrument responses, along with the control position, can be put on a strip chart recorder to define the dynamic response and cue synchronization, as shown in Figure 1.

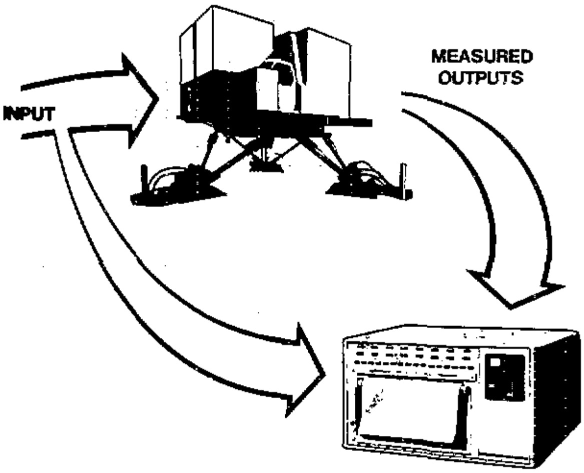

Figure 1 Cue Synchronization and Dynamic Response Test

The input command signal drives the controls to the desired position. The position of the controls is determined by the control loading hardware (high-precision follow-up potentiometer). The onset movement of the controls, determined by the follow-up potentiometers, then becomes the start time (t=o) for the dynamic response/cue synchronization test. All other response times are measured from this onset point to determine the dynamic response for each of the cues.

During the later phases of the integration process the engineering test runs, including dynamic response/cue synchronization, begin. Since dynamic response/cue synchronization testing is a total system test, it is necessary that all the systems be operational and in the general design form. Any testing done prior to this baseline may result in test data that will not be representative of actual results measured during acceptance testing. The tests can be used as an indication of performance progress to verify the previously described analysis methods.

Traditional test procedures have employed a pilot to trim out the simulated aircraft, and a test engineer to apply a function generator input signal to the appropriate controls when the pilot indicates that the initial test conditions are met. The function generator test equipment is connected to the control loading circuitry. The input signal is a square wave with a very low frequency (approximately 0.5 Hz). At that frequency, the input signal is a step command into the controls. The amplitude of the signal varies with the aircraft and the axis being tested. The amplitude is adjusted to get a good aircraft response (20 to 30 degrees for the rotational axes). The input signal is connected to the trim circuit input for the controls. Using the trim circuit as the test input allows the simulated aircraft to be maneuvered using the normal control loading system. Once the simulated aircraft is positioned into the test configuration, the manual trigger on the signal generator is selected, which generates the step input command into the applicable control loading trim circuit. By measuring the response times of the motion, visual, and instrument systems compared to the input, a good assessment of the overall system performance can be made.

THE AUTOMATED CUE-SYNCHRONIZATION TEST

Initial on-site testing of dynamic response/cue synchronization of the AH-64 Combat Mission Simulator (CMS) has shown that there are a number of deficiencies in the traditional test methodology, including: 1) difficulty in test initialization, 2) wide variance in the data recorded, and 3) difficulty in performing a timely test. These deficiencies are eliminated by the Automated Cue-Synchronization Test.

The traditional "pilot in the loop" techniques introduce many unrepeatable variables. If, for example, the pilot of a helicopter simulator is trying to hover at a position in the visual database that is defined as the initial condition, it is very unlikely, for the next run of the test, that the pilot can relocate the aircraft back to that exact database location and aircraft configuration. With the pilot in the loop, the aircraft may not be trimmed out, causing the aircraft to drift in any direction, thus resulting in different orientations of the aircraft, biasing of the test results, and large data spreads with every test run. The amount of time and effort spent on initializing the aircraft can easily involve many hours, often with very frustrating results. With all the variables in the initial conditions and data gathering techniques, it becomes necessary for many test samples to be performed in each axis under test. The need to simplify the data recording of these tests was easily recognized.

With this in mind, the Automated Cue-Synchronization Test philosophies were established. The concept behind the automated testing is to focus on the specific data required to determine the dynamic response of the simulated aircraft in the specific axis under test. In order to get repeatable data, a programmable initial condition (IC) set is used to configure and orient the aircraft to an exact location in the visual database for each test run. The programmable IC set allows control of the aircraft parameters such as weight, CG, weapons load, payload, attitude, fuel load, etc. Other environmental conditions may be set to specific levels, such as visibility, scene illumination, cloud tops, wind/gust velocity, and turbulence levels. The initial conditions create a flexible, yet repeatable starting point and aircraft configuration for each test run.

Another feature used in the Auto-Cue-Sync Test is the parameter freeze sets which are available on the instructional features of the SFTS simulators. The parameter freeze functions provide the ability to hold constant ("freeze") different types of aircraft parameters. The control of the parameter freeze function is user-selectable, and the parameters can be selected individually or a combination of parameters simultaneously. The parameters may include pitch, roll, and yaw attitude, heading, airspeed, and vertical speed. The Auto-Cue-Sync Test uses different combinations of these parameters to freeze the aircraft configuration except for the axis being tested. The selection of the applicable freezes is completely automated by the Auto-Cue-Sync Test software. The user does not have to be concerned with the aircraft configuration because the software does all of the work.

Once the conditions of the simulated aircraft are established, the details of the Auto-Cue-Sync Test can be addressed. The development of the Auto-Cue-Sync Test is done one axis at a time, keeping in mind the data required to determine the dynamic response of the aircraft in that specific axis. For example, in the pitch axis test, attention is focused on the simulated aircraft response along this axis. The parameter freeze functions are utilized to hold the simulated aircraft still in all other axes, while allowing full maneuverability in just the pitch axis. This ensures the same starting conditions for each test run, and eliminates any biasing of the test results due to the simulated aircraft drifting in the other axes.

Once these testing techniques are defined for all of the axes to be tested, the next step is to put all the methodologies together into one test. The Auto-Cue-Sync Test organizes the actual running of all the tests. It greatly simplifies the testing by replacing the hardware signal generator with a software signal generator. The software routine generates a square wave pulse identical to the one produced by the hardware signal generator. The software pulse is then introduced into the control loading trim circuit software. This greatly simplifies the running of the test by eliminating all of the electrical connections and the need for the hardware signal generator test equipment. Also, electronic loading effects of the signal generator on the hardware, which cause control position drift, are eliminated. The software square wave pulse is input into the control loading software system at the same place the hardware signal is. This makes the software pulse a one-for-one replacement of the hardware signal, with very successful results.

The Auto-Cue-Sync Test continues to improve the testing by controlling the entire testing process. The software of the Auto-Cue-Sync Test controls many of the difficult tasks which were previously done manually by the testing personnel. These tasks include the setup of the initial conditions, the setup of the applicable parameter freezes, the generation of the square wave pulse, and the input of the signal into the control loading systems. The Auto-Cue-Sync Test software, via the use of digital outputs (DO's) from the computer, also operates the strip chart recorders which record the test results. Once the test run is complete, the Auto-Cue-Sync Test software automatically resets the aircraft back to the initial conditions and is ready to do another test run. These additional features are particularly important when there is a limited number of personnel on site for test support.

Another area of concern is the visual system response. Measuring the video output is, in itself, a unique problem. Since the exact positioning of the visual representation is very important for consistent results, the previously mentioned initialization/freeze techniques greatly improve the results by producing more repeatable data. The output video signal direct from the digital image generator (DIG) window channel is a high-frequency signal, which for test measurements is applied to a bandwidth-limited strip chart recorder, resulting in a highly attenuated signal at the recorder. All the sync and blanking pulses are on the video signal, causing a cluttered trace at the recorder.

An option to this measurement technique was the use of a photometer and a test pattern in the visual database. This technique has been used by another investigator.[8] In almost all cases, the photometer method resulted in better measurements than the raw video method, even with the inherent photometer hardware time delays.

The visual test pattern was a large white vertical block with a black spot in the center. The contrast change for the photometer was between the white and black, while the raw video used the white edge of the test pattern and blue sky. For comparison purposes the raw video signal is retained with the test data gathered.

The Auto-Cue-Sync Test step input can easily be programmed into any other input signal, including sinusoidal for steady-state analysis. Testing of the dynamic response in the frequency domain will be the method of the future. Some recent simulator specifications have defined dynamic response/cue synchronization in the frequency domain. This type of testing was performed on the AH-64 CMS and UH-60 FWS recently to demonstrate that application of the Auto-Cue-Sync Test.

The Cue Synchronization/Dynamic Response Test generates a command signal into the simulator control system, and then measures the response of the instruments and the visual and motion systems. This testing process is diagrammed in Figure 2.

RESULTS AND FURTHER IMPROVEMENTS

One of the first results of the use of this test was the consistency of data. As previously mentioned, using the "pilot in the loop" and the function generator results in a large data spread. The Auto-Cue-Sync Test, on the other hand, results in good dynamic response data, and provides better confidence in the overall results.

The use of the visual test patterns provides signals which are easier to read. The perceivable onset measured is considerably better than previous results. This is an important fact in dynamic response testing, showing that the results can be influenced tremendously by the actual test methods.

Although the test is still complicated in that it tests all simulator functions, the new test methodology simplifies user application of the test. It is easier to perform the tests, as well as produce better results. The total test run time is reduced, which is very important in time-critical acceptance schedules.

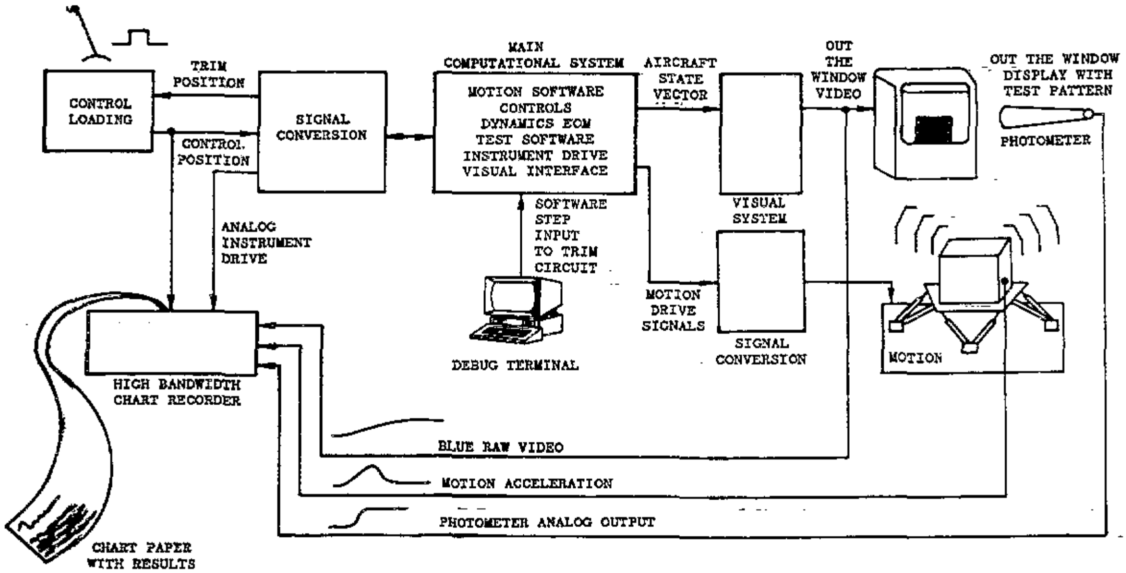

Figure 2 Cue Synchronization and Dynamic Response Test Block Diagram

The fact that the test time has been reduced allows for the dynamic response test to be used as a simulator verification tool during integration time. This Auto-Cue-Sync Test allows for timely test runs to verify simulator performance in regard to both software and hardware. It provides a means for performance evaluation and "benchmarking" during the total development cycle. The systems engineer can use the test to verify full compliance to specification, as well as find unexpected problems with primary cuing drives that can be corrected or compensated for early in the development program.

Improvements to the Auto-Cue-Sync Test include the elimination of the aerodynamic filtering effect. A method described by Butrimas and Browder [9] of replacing the equations of motion outputs by scaled controlled inputs will result in better perceivable onset data. This procedure is planned by Link in upcoming simulator projects.

A problem that has been noted on the initial condition setup is slight residual control inputs when the aircraft should be completely stabilized. These small inputs result in test data which can be biased. A solution to this problem is for the test software to zero the aircraft rates and accelerations before introducing the step input so that the simulated aircraft is in a completely stabilized state.

CONCLUSION

The Auto-Cue-Sync Test has made dynamic response/cue synchronization testing more efficient with more consistent results and a more user-friendly procedure. The fact that fewer test personnel are necessary and that the time to execute the test is greatly reduced makes the task easier for both the contractor and user engineers.

The Auto-Cue-Sync Test incorporates many innovative ideas and reduces a very complicated manual test procedure to a few very simple commands at the computer terminal. The test parameters are easily manipulated through software, which allows for experimentation and effortless adjustment. By reducing the complexity of the test procedure, it provides both the user and the contractor with pertinent, reliable, and repeatable dynamic response/cue synchronization data for simulator acceptance. The simplicity of this test also encourages its use as a simulator development tool. This allows any discrepancies to be corrected early in the design and prevents problems in the final product. For the user, the simplicity of this test greatly reduces the amount of "manual" work in the setup and running of these tests. It eliminates the inconsistencies and the large data spread due to the "pilot in the loop" inputs. It also reduces the many areas in the manual testing procedure which may have allowed for different interpretations of how the test is supposed to be run, and how to determine the results.

With the repeatability of the tests, the number of test runs can be significantly reduced while producing quality results. With the many improvements that the Auto-Cue-Sync Test provides, it allows both the contractor and the user to feel more confident that the test results obtained are representative of the actual simulator cue correlation and system dynamic response. This Auto-Cue-Sync Test has been implemented on the AH-64 CMS, the UH-60 FWS, and the AH-1S FWS with great success. The ability to use this test in the early development stages of the design provides the system engineers more control over the cue correlation and system dynamic response of the simulation system during the development period. Ultimately, with better cue correlation, the pilots will receive superior simulator training.

The Auto-Cue-Sync Test is a first attempt to simplify a difficult test in response to needs both in the field and at the contractor's development site. An industrywide standard is needed to define dynamic response/cue synchronization testing procedures. This standard should be one that simplifies the testing while still obtaining necessary data, similar to the Auto-Cue-Sync. Future development of techniques which automate testing are necessary for measuring latencies and for cuing between simulators on complex networks such as described by George [10] and Thorpe [11].

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ABOUT THE AUTHORS

Robert J. Sawler is a Senior Systems Engineer with the Link Flight Simulation Division of CAE-Link Corporation in Binghamton, New York. He is currently working on the development and implementation of the MST microprocessor-controlled six-degree-of-freedom motion system. He was lead motion engineer for all SFTS helicopter programs and has eight years of experience in the Motion and Control Systems department. He has a Masters of Electrical Engineering degree from Syracuse University and a BS in Electrical Engineering from Rutgers University.

Gary R. George is a Staff Engineer with the Link Flight Simulation Division of CAE-Link Corporation in Binghamton, New York, with 11 years of experience. He is currently assigned to cue synchronization requirements for the Army SFTS and SOF simulator programs. He has 1800 hours in the AH-64 Combat Mission Simulator supporting mission testing and training. He has done significant field testing and research of cue synchronization. He holds an MSME from SUNY and an MSEE from Syracuse University. He has published several papers on various simulation topics, including networking and mission testing.