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Abstract

This report describes the development of the system identification (SysID) rack custom application code. This code is used to automate the system identification experimental processes for the National Aeronautics and Space Administration (NASA) Combined Cycle Engine Large-Scale Inlet for Mode Transition Experiments (CCE-LIMX) testbed. This series of experiments took place in the NASA Glenn Research Center (GRC) 10- by 10-Foot Supersonic Wind Tunnel (10x10 SWT) test facility. The SysID code was developed to apply command signals to testbed actuators, receive actuator feedback signals, and acquire sensor data which is used to identify the dynamics of the experimental processes. This code development and the process identification experiments were conducted during Phase-2 testing at various operating points. These points were predefined from data collected during the Phase-1 testbed characterization experiments. The developed SysID code was executed on a NASA designed and built real-time data acquisition (DAQ) and controls (SysID) rack. This report focuses on the development of the SysID rack real-time DAQ and control hardware and the custom application code used to automate the system identification process. The implementation of this reliable and efficient DAQ and controls development tool is demonstrated by presenting an example of experimental data collected to be used for system identification.

Introduction

Hypersonic air-breathing propulsion is a technology with the potential for providing reliable, safe, and affordable routine access to space (Ref. 1). NASA's research in this area is focused on a turbine-based combined-cycle (TBCC) propulsion system that consists of a turbine engine and a dual-mode ramjet (DMRJ) engine. This is a dual air breathing flow path for which a Combined Cycle Engine Large-Scale Inlet for Mode Transition Experiments (CCE-LIMX) testbed has been developed and used in the NASA Glenn Research Center (GRC) 10- by 10-Foot Supersonic Wind Tunnel (10x10 SWT). Redirecting airflow between flow paths is referred to as inlet mode transition (MT), which is the focus of the overall CCE-LIMX research effort (Refs. 1 and 2).

As part of the MT studies, a customized SysID code development was carried out to support the Phase-2 CCE-LIMX system identification experiments. The purpose of the SysID code development is to facilitate the application of actuation commands to testbed actuators, receive testbed actuation position signals, and to collect dynamic data that can be used to identify the dynamics of the experimental process. Dynamic data were collected by applying actuator step commands, sinusoidal logarithmic sweeps, and pulses to testbed actuators. The SysID code is also designed to support MT testing at various operating scenarios. For these tests, testbed actuator code allows actuators to move synchronously based on a prescribed time sequence or schedule. The MT schedules were developed during the Phase-1 experiments and were required to be automated with safety checks executed during the entire MT process. For this paper, the MT tests are not discussed.

Customized SysID code was developed to meet the Phase-1 and Phase-2 test objectives (Refs. 3 and 4). The Phase-1 experiments were conducted to assess inlet performance and obtain data to determine steady-state MT schedules. These MT schedules help to define the operating points for the Phase-2 system identification experiments. The data collected from the system identification experiments are later used to develop transfer functions (TFs) and to design feedback controls for the experimental process. This data is critical for controls development that will maintain flow path performance during the MT processes.

Three fundamental requirements were identified for the development of the real-time data acquisition (DAQ) and controls SysID rack. The first requirement was to safely and effectively position the CCE-LIMX testbed actuators for enabling dynamic system identification experiments. The SysID rack software is required to have the capability to move the testbed actuators individually or synchronously to predefined inlet geometries. The second requirement was to sample and save data at a rate of 2.5 kHz. Data to be acquired by the rack includes effector control signals applied to testbed actuators, actuator feedback positions, and readings from high-speed pressure sensors installed in the CCE-LIMX flow paths. The third requirement was to transfer actuator control from the facility control system to the SysID racks control system to carry out experiments, and vice versa. Relay banks were setup to allow for this control transfer. The experimental control process is setup so that if the 10x10 SWT facility control system is engaged, this system has control of the testbed actuators. The rack application processes are configured to initially match signal levels commanded by the facility controls. This ensures that when control is transferred from the facility to the rack, the automated testing process starts from the same operating condition initially setup by the facility. This also ensures that initially the control signals originating from the rack will maintain the CCE-LIMX actuators at their facility settings within predefined tolerance.

For the Phase-2 experiments, the facility control system performs the initialization of the testbed actuators. Then, actuator control is handed-off to the real-time SysID rack, which is specifically designed to provide the dynamic actuator positioning commands. The SysID rack was constructed with the following three hardware computational components: a host computer (Host), a Target computer (Target), and a dSPACE computer (Ref. 3). Custom code is developed for these computational platforms, which are required to support system identification experiments.

The paper is organized as follows. First, an overview of the CCE-LIMX experimental setup is provided. Next, the rack hardware components along with the software developed to support the SysID rack experiments for Phase-2 are separately described. This is followed by a description of perturbation experiments that were performed along with an example showing how the SysID custom code performed. Finally, some concluding remarks are offered.

CCE-LIMX Overview

The illustration shown in Figure 1 is a cut-away view depicting the CCE-LIMX as it was mounted in the wind tunnel. This test article has the Low-Speed Flow path (LSFP) located above the High-Speed Flow path (HSFP) and includes external and internal compression surfaces, a throat area, a subsonic diffuser, a cold-pipe, and a mass flow plug (MFP) located at the aft end of the cold-pipe. The MFP position can be continuously translated between open and closed positions to control the amount of airflow through the cold-pipe exit area. The combination of the cold-pipe and MFP are an assembly that promotes the pressurization of the subsonic diffuser like the effect of a turbine engine on the LSFP. With the airflow being redirected into the HSFP, the lower surface of the Splitter serves as a third compression ramp for the HSFP. Airflow is redirected and regulated into the HSFP using a rotatable cowl (Ref. 3). The HSFP uses its own MFP and cold-pipe to pressurize the flow path in place of a burning DMRJ.

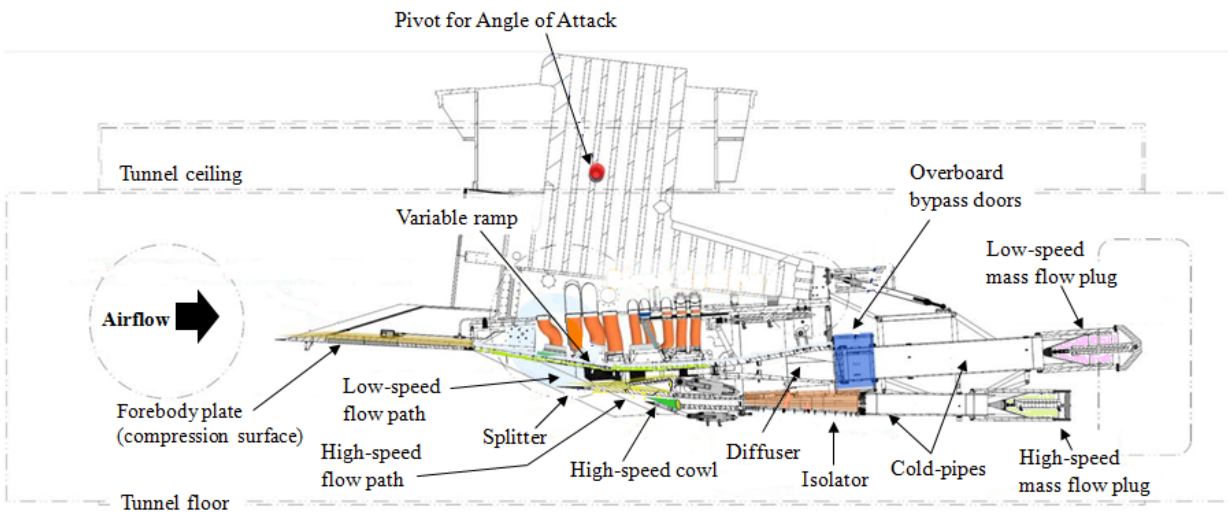

Figure 1.—Schematic of the CCE-LIMX testbed as mounted in the GRC 10x10 SWT test section.

Considering the airflow being directed into the LSFP, the throat height is mechanically linked to the compression angle of the first variable ramp surface. This surface together with the rotation of the overall mechanical structure about the angle of attack (AOA) pivot provides the means for scheduling a MT with respect to freestream Mach number. This adjustable airflow geometry allows for the flexibility to study MT at different Mach numbers. Four bypass doors are located at the aft end of the subsonic diffuser and these doors individually or together can be opened or closed to vent air from the diffuser and regulate diffuser pressure (Ref. 3).

During experiments, a CCE-LIMX test configuration, also known as the operating point, is described by the freestream conditions and the inlet geometry that is defined by the positions of the nine actuators of interest (Splitter, Variable Ramp, High-speed Cowl, High-speed MFP, Low-speed MFP, and 4 bypass doors). Rotating the inlet about the AOA pivot point, will increase or decrease forebody compression. The AOA is a variable that affects inlet air flow and is used to define theoretical freestream conditions (Ref. 3). For this SysID development, the AOA actuator is preset prior to the start of MT experiments, and it is not considered to be an inlet operating actuator as are the other nine actuators. Data collection includes freestream conditions, actuator positions, and inlet aerodynamics. Freestream conditions include AOA, Mach number, total pressure, and total temperature. Actuator positions are determined based on voltage measurements from resistive potentiometers. For aerodynamic analysis of the flow paths, twenty high-speed pressure sensors are positioned throughout the HSFP and the LSFP (Refs. 3 and 4).

SysID Rack Development

Based on the Phase-2 requirements for which the SysID rack was developed, the rack system serves four functions. First, it serves as a code development platform to develop custom code that defines collective interaction among the three SysID system components. Second, it provides the operator a means to specify the parameters that define/configure a given experiment. Third, it serves to display real-time data during an experiment and, fourth, it serves to archive the collected data at the conclusion of each experiment.

The custom code for the Phase-1 experiments consisted of MT logic, where the main task objective was to be able to apply syncronized signals to testbed actuators for proper positioning of aerodynamic surfaces while avoiding undesired contact. Whereas, the Phase-2 code development focused on application processes that apply dynamic signals to testbed actuators.

The commercial-off-the-shelf (COTS) components are a Host laptop computer that is connected to a real-time Target computer via Ethernet cable, and in turn the Target computer is connected to a real-time dSAPCE computer system by way of analog input-output hardware and cables (Ref. 3). The Host, Target, and dSPACE computer hardware components and their custom code are discussed in the following two sections.

The block diagram in Figure 2 illustrates the interconnections (and signal flow) between the SysID rack computational components and the testbed component of interest. The path of CCE-LIMX actuator control signals initiated from the Host commands are represented by the blue arrows. The paths of SysID rack feedback signals for recording by the Target system are identified by the green arrows. From left-to-right, the Host is the operator gateway to the SysID rack and the experiments. Arrows shown pointing in and out of the "Host" block represent the Ethernet communication path between the Host and Target. The blue right arrow, which extends from the "Target" block, represents the coaxial cables interface between the Target digital-to-analog (D/A) ports and the dSPACE analog-to-digital (A/D) ports. For recording purposes, Target A/D ports receive control signal from the dSPACE D/A ports, shown by the green arrow pointing into the "Target" block, without using signal conditioning filters.

The graphic image for the "Hardware under test" component shown in Figure 2 includes one of the testbed bypass door actuators and it is used to illustrate how a hardware test component is interfaced. A bypass door's hardware components are introduced and discussed in more detail later in this document. The blue arrow pointing into the "Hardware under test" block is representative of the interface between the dSPACE D/A ports and the CCE-LIMX Hydraulic Machine Controller (HMC) setpoint ports. Shown in the figure, is a graphic image for the test facility signal conditioning filters that serve to filter and condition the experiment signals between the testbed actuator and the Target.

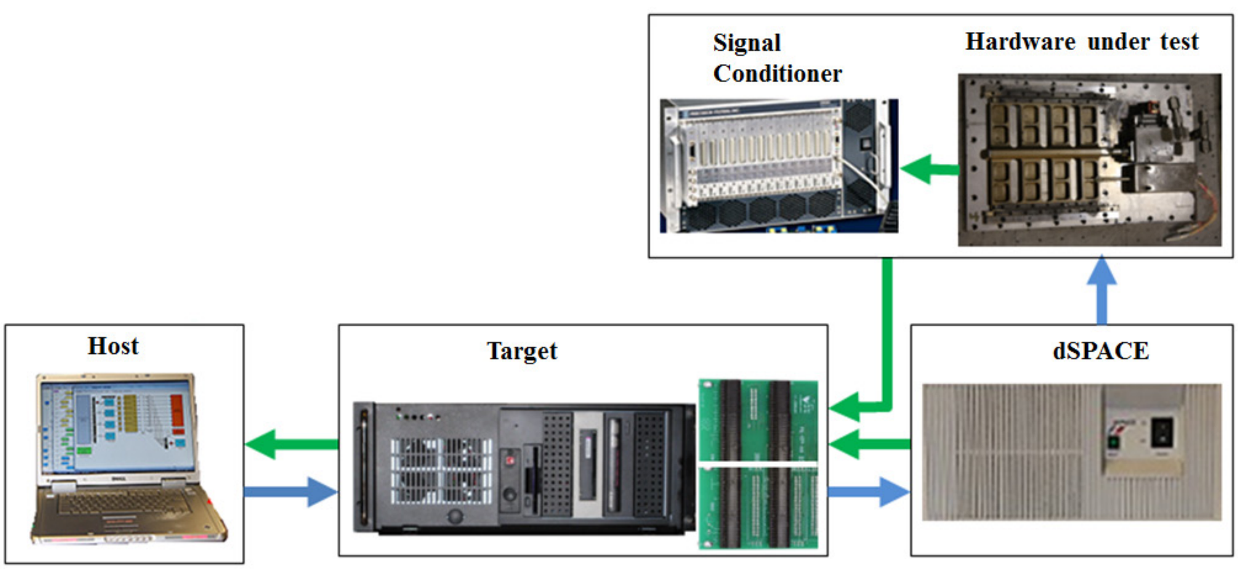

Figure 2.—SysID rack hardware computational component interfaces and signal flow illustration.

Hardware Components

The host computer, the rack mounted Target computer, and the dSPACE computer employed custom code that was developed to facilitate the process for performing the system identification experiments. Each of these computational components, along with how they are integrated, will be described in this section.

The Host laptop computer is the platform that is used to develop all the custom application code for the Host, Target, and dSPACE computers. For the Phase-2 experiments, the Host also served as the operator interface for the SysID rack. Using the Host computer, an operator communicates experiment instructions to the Target and uploads data from Target memory to a data file on the Host. From the Host, custom code is downloaded to the Target computer. Additionally, from the Host, custom application code is downloaded to the dSPACE computer via a fiber optic cable (not shown in Figure 2); thereafter, this cable is removed and not required for real-time experimentation. The system is setup so that once the dSPACE process is down-loaded and started, the experiment can proceed without requiring further interaction or information from the Host.

The purpose of the real-time Target computer is to receive experiment instructions from the Host prior to starting an experiment, calculate and apply control signals on D/A converter ports, receive feedback signals on A/D converter ports, and to sample and save data. The Target applies these control signals and receives feedback control signals through the dSPACE system, where it also receives sensor signals from the signal conditioners. The Target is interfaced with the dSPACE system by way of Target A/D and D/A boards, and coaxial cabling.

The dSPACE system is a high performance real-time digital control computer system that is used to perform hardware-in-the-loop (HIL) functions. This system is termed the Safety dSPACE system or S-dSPACE. The S-dSPACE A/D ports receive control signals from the Target D/A ports, and calculates control signal applications to the CCE-LIMX Hydraulic (HMC) setpoint ports, by way of D/A boards, coaxial cable, and relay banks. The purpose of the S-dSPACE system is to serve as a signal buffer between the signals calculated by the Target, for actuator positioning, and the CCE-LIMX HMCs. Signal buffering is needed to prevent errant signals from the Target being applied to the actuator HMC setpoint ports.

Finally, data from the Target can be transmitted to the Host. This data may include information pertaining to Target operating conditions and values of feedback signals for display on the Host. During an experiment, data read from the Target A/D ports are recorded in a file that is saved on the Target hard drive. After each experiment, these data files can be uploaded to the Host using a custom data delivery process designed into the Host process code. This upload must take place before starting the next experiment. Otherwise, data from the previous experiment will be lost.

Software Components

This section describes the SysID rack software developed to perform system identification experiments in a real-time environment. The custom designed process code that is developed to meet the requirements includes the following: The Host model, Target model, and a S-dSPACE model. The Host model is developed in the MATLAB Simulink® (The MathWorks, Inc.) environment. This model is designed to configure experiments via the host. Using a graphical user interface (GUI), an operator is enabled to interact with the model real-time hardware through software instruction and to transmit that information to the Target. It is also designed to display data during the execution of an experiment and to upload saved data at the conclusion of the experiment. The Host GUI is also known as the CCE GUI. The CCE GUI consists of custom software and is conveniently used by the experiment operator to issue commands, collect information, and monitor progress during an experiment. This GUI includes text labels, character entry fields, check boxes, simulated push-buttons, graphics, and color changing indicators. Use of the CCE GUI streamlines the process for setting up the Host model and communicating desired experiments to the Target. The Target model runs under the Target's real-time operating system. It is designed to run experiments by calculating control signals and applying them to the Target D/A ports, read data from the Target A/D ports, and save the data into a file. The Target model can run any of the required SysID experiments—pulse, step change, staircase, or sine sweep tests. The S-dSPACE model is designed to apply control signals to the testbed hardware, acting as a buffer between that hardware and the Target. The buffer is intended to safeguard against any errors generated by the Target that may cause undesired changes in the state of the testbed actuators.

Host Model

The Host model process is programmed to perform the following functions:

- Receive experiment setup and control information via the GUI from an operator.
- Translate input values from the GUI in engineering units (EUs) to the Target model, in units of volts.
- Transmit experimental configuration and control information to the Target model.
- Receive Target model feedback signals and translate them from voltage signals to EUs.
- Periodically display select signals from the Target model.

A block diagram of the Host model is illustrated in Figure 3. In this figure, the "Data Trigger" block (far upper right) includes process code that performs the following tasks. It instructs the Target process to start data recordings, stop data recordings, or transmit recorded data to the Host. Immediately below this block, are seven rectangular blocks. The blocks receive input values that are used to copy signal information required for a system identification test. These blocks are also virtually linked to the Target model.

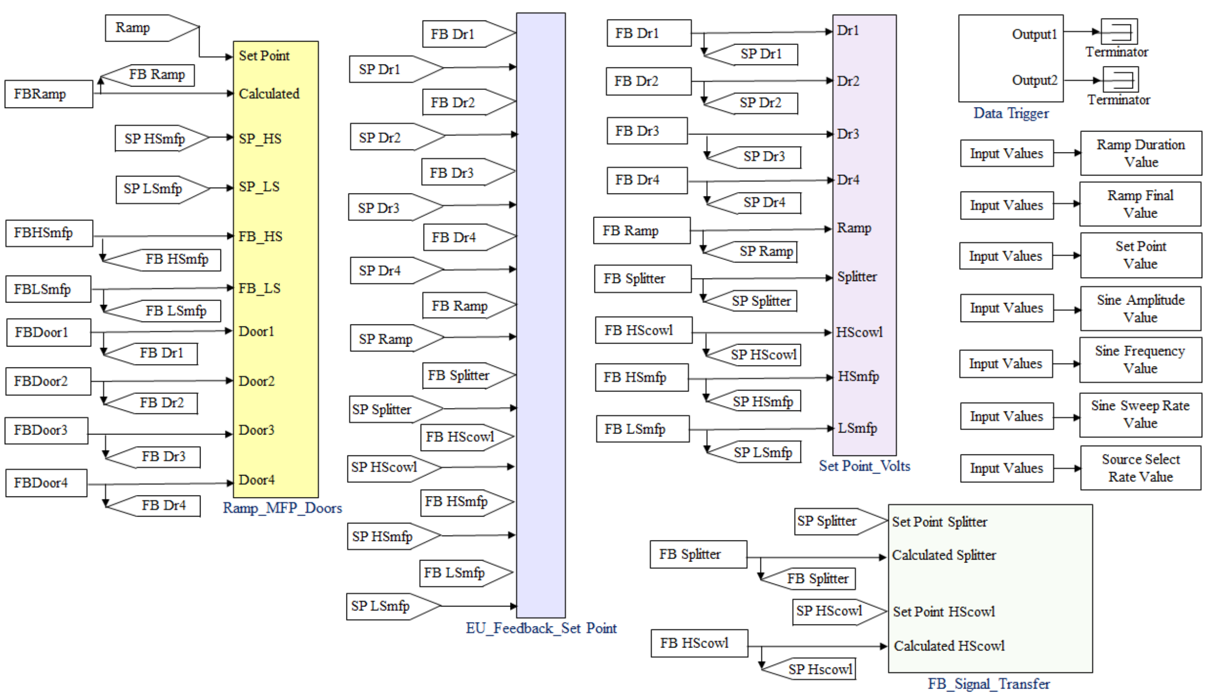

Figure 3.—The Host model. This model application code process is used to display setpoint and feedback signal data, convert volts to EU and EU to volts, start and stop experiments, and save experiment data.

The block labeled “SetPoint_Volts” receives copies of the Target model feedback setpoint values for the actuator positions. By including these arrays of virtual blocks in the Host model, it also provides for the capability to display the calculated Target model setpoint values on the Host GUI. Actuator position feedback signals are also mapped from the Target to the blocks labeled “Ramp_MFP_Doors” and “FB_Signals_Transfer” block shown in Figure 3. Prior to transferring actuator control from the facility control system to the SysID rack, the “EU_Feedback_Set Point” block compares facility actuator feedback and the experiment feedback signals in volts. That is, comparing the signals between the designated setpoint (SP) and the corresponding feedback (FB) input blocks.

The configuration in Figure 4 shows a subset of the internal code contained in the “EU_Feedback_Set Point” block. This block configuration is available to the operator and is used during the transfer process. The signals applied to the input ports (shown in the figure as In1 and In2) are routed to the input ports of the “CALIBRATION COEFFICIENTS” block. The block’s custom code converts voltage signals to EUs for display purposes. The conversion process uses calibration polynomials that were previously determined by computing a best fit of data collected. This data was collected by applying a voltage to the HMC setpoint port and measuring the position voltage signal from the actuator feedback potentiometer. After the voltage conversion process takes place, an actuator’s EU setpoint value and a corresponding EU feedback value are compared. If the difference between these two values is greater than the specified bias constant (shown in the figure as 0.2 units), then the block at the output of the “Compare” block will illuminate red indicating the values are beyond a safe range (unsafe to transfer control). Otherwise, the block color will be green (safe to transfer control). This block is used to alert the operator to significant discrepancies between any setpoint and feedback state. Control room protocol requires this information while performing a transfer. Therefore, upon settling at a tunnel operating condition and indicators are green, the HMC setpoint signal control can be transferred from the 10x10 SWT facility controllers to the SysID rack.

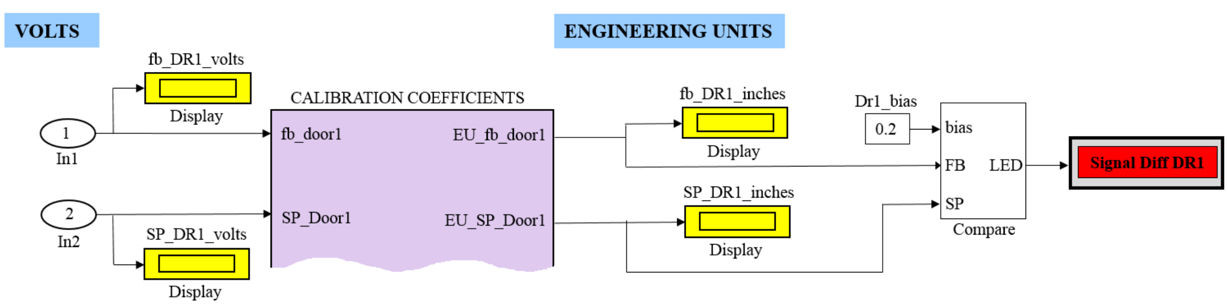

Figure 4.—SysID Rack experiment Host model EU_Feedback_Set Point subsystem block.

Host Model GUI

The CCE GUI shown in Figure 5 consists of radio buttons and text fields. The selection and entries shown are used to initialize the Host model, which is required prior to performing an experiment. The Host model is initialized with calibration coefficients, and actuator range and rate of motion limits. Values that define these parameters are read into the GUI from a document that was generated with Microsoft Excel® (Microsoft Corporation) software. Depressing the “Rack Test Cond” button (lower right) causes the file to be loaded and transferred to the Host. Depressing the button labeled “Test data out file” causes the system to recognize the name of the Excel spreadsheet file (ExpDoc_20110318.xlsx in this example) used to store experiment setup information. After each experiment, this document is appended with information specific to the latest conducted experiment. Information pertaining to the next test will be automatically entered in a new row that is created in the document to store data. After opening the GUI and completing the tasks associated with the spreadsheet files, the actual voltage values on the Target D/A ports are unknown. For this reason, prior to a system identification test, it is necessary to manually specify the actuator hardware default positions. The default positions should be entered into the section titled, “Default Position” section (upper right). Pressing the “Move all to default pos” button causes the movement of these actuators to the positions specified. This step needs to be done before either the Host Model or the GUI can be considered properly initialized.

Four types of tests can be selected for SysID experiments: step, staircase, sine pulse, or sine sweep. As shown, the GUI is set up so that a step and sine sweep test can be applied to a single or to a combination of actuators if desired. Normally, only one actuator is perturbed at a time for SysID testing. Staircase perturbations are setup for the bypass doors and the HS Plug, and sine pulse perturbations are only set up for the bypass doors. Each test has unique parameters that need to be set along with the choice of the actuator for which the test is intended. The step size and amplitude fields define the perturbation amplitudes, in either degrees or inches, with respect to the default positions. The time fields have units of seconds and the frequency fields have units of Hertz.

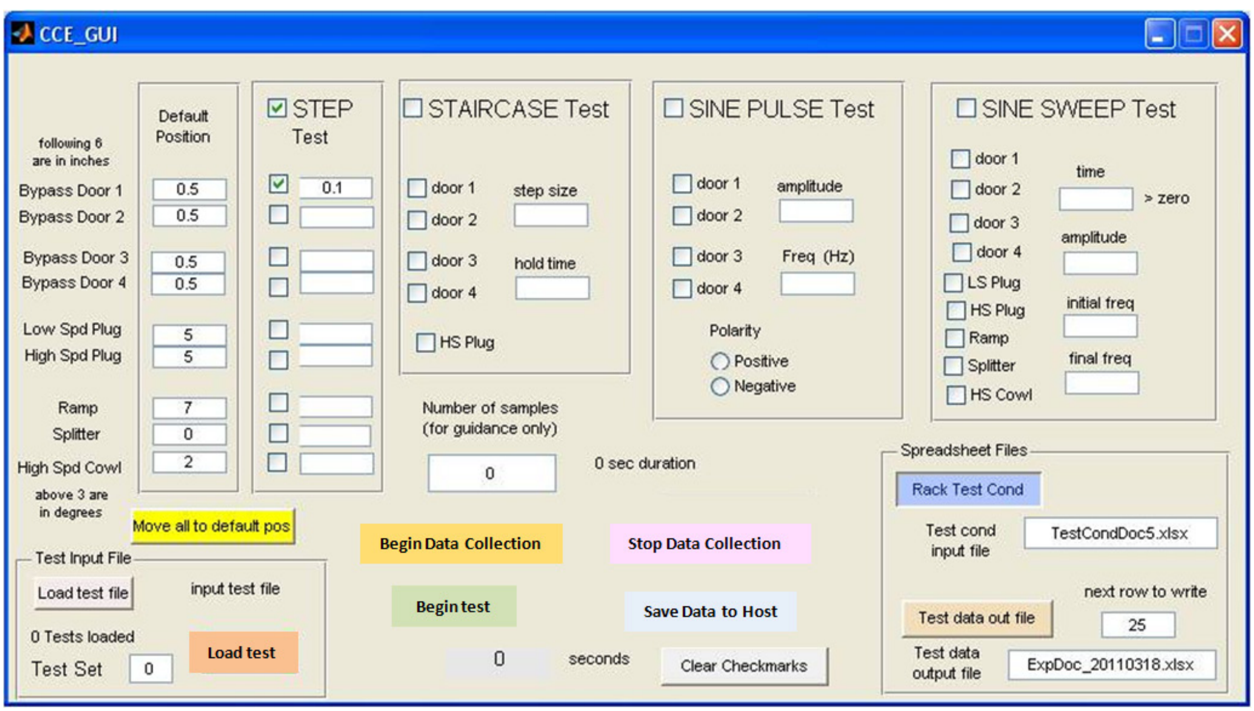

Figure 5.—The SysID experiments GUI (CCE_GUI).

The “Load test file” in the “Test Input File” area shown in Figure 5 (lower left), is used to supply the GUI with predefined experiment setup conditions. These conditions are used to populate the other required test areas. This file may include conditions for multiple experiments, where the number selected in the “Test Set” window specifies the particular experiment to be loaded upon depressing the “Load test” button.

The final functional area of the GUI controls test initiation and data collection. The “Begin Data Collection” button (mid bottom) will start data recording. This button is linked to the “Data Trigger” block shown Figure 3. The “Begin test” button initiates the sequence of events necessary to perform the selected perturbation test. The “Stop Data Collection” button (also linked to the “Data Trigger block”) will cause the data recorders to cease collecting data. It also directs the saved data into a file that is then stored on the Target hard disk. Each time the “Begin Data Collection” button is depressed, the data collection process is restarted and the saved data file on the Target is overwritten. To prevent this file from being overwritten, the “Save Data to Host” button provides a functionality that copies the data file to the Host hard disk, renaming it with a unique filename corresponding to the current date and time. The “Clear Checkmarks” button will remove all checks from the GUI check boxes. The purpose for this functionality is to provide the operator with a means of putting the CCE GUI into a safe mode, by which no checks are applied to the GUI thereby, preventing the possibility of accidental movement of testbed actuators. The “Number of samples” box is used for entering the number of samples for a test, when required. The indicator to the right of this box displays the requested number of samples in seconds. At the bottom of this area, the length of the test is displayed in seconds.

Target Model

The Target model process is programmed to perform the following functions:

- Receive control logic information from the Host model process.
- Apply voltage signals to target D/A ports for setup and running experiments.
- Provide a signal for triggering the S-dSPACE process when the target computer malfunctions.
- Sense and log all signal data applied to the Target A/D ports and all signals transmitted on the Target D/A channels at a sampling rate of 2.5 kHz.
- Upload experiment data from the Target to the Host upon request.

Figure 6 depicts the top layer of the Phase-2 SysID rack Target model architecture. This layer includes blocks for interfacing with the Target A/D and D/A boards and data recorder blocks. These recorders are File Scope Simulink blocks used for data storage. Other blocks included at this level are eight Constant blocks, an Analog Output Sources block, a Rate Transition block, and a Signal Limiters block, which are described below.

The Analog Input blocks are linked to the SysID rack Target A/D boards. As illustrated in Figure 6 (far left), the two analog input blocks are configured to receive 39 signals: nine actuator feedback signals, twenty pressure sensor feedback signals, nine actuator set point signals (feedback signals from the S-dSPACE system), and one timing signal. Signal values are copied to the five File Scope blocks. Four of these scope blocks are connected to the analog input blocks. Block “File Scope Id: 1” is for recording the nine testbed actuator feedback signals. “File Scope Id: 2” and “File Scope Id: 3” record the twenty pressure sensor feedback signals, and “File Scope Id: 5” records copies of the signal values sensed from the S-dSPACE output channels. “File Scope Id: 4” is for recording the nine control signals that are applied to the nine actuator D/A ports. The purpose for the green timing signal block is to synchronize the SysID rack data recording timestamp with other DAQ system timestamps used during experiments. For post processing and data analyses purposes, this recording process is used to align recorded signal data date, and time of day. The other DAQ systems that are used for the facility systems are beyond the scope of this document.

The “Analog Output Sources” block shown in Figure 6 interprets the values from each of its seven “Constant Block” inputs depending on the constant block values. The “Analog Output Sources” block will stream signals to the analog output blocks, by way of a “Rate Transition” and a “Signal Limiters” blocks, to create the following four types of signal patterns shown in Figure 7: single pulse, step, staircase, and sine wave-sinusoidal frequency sweep. The “Rate Transition” block allows data transfer between Simulink blocks that operate at different rates. The “Signal Limiters” block imposes upper and lower limit values prior to the signals being applied to the “Analog Output” blocks. The upper limit values of these blocks are set to +10.0 volts while the lower limits are set to –10.0 volts.

The “Analog Output” blocks shown in Figure 6 are configured to transmit control signals to the SysID rack Target D/A ports. Nine of the ten signals are read by the S-dSPACE system and are used to calculate controller set point signals for each of the nine actuator HMCs. The “Constant” block input shown is intended to maintain an applied +5.0 volt signal on port 2 of the second Target D/A card. If a Target fault condition occurs, Target A/D and D/A port values will incur a step change to 0.0 volts—the Target system goes offline disconnecting itself from the SysID rack system real-time operations.

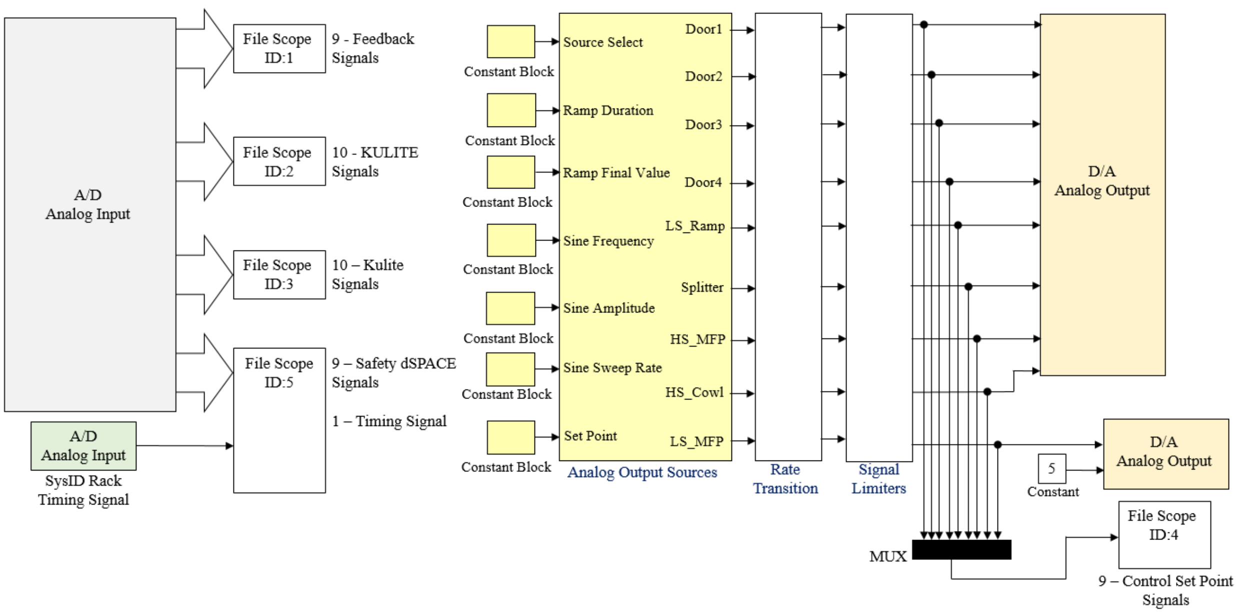

Figure 6.—The Target Model for Phase-2 system identification experiments.

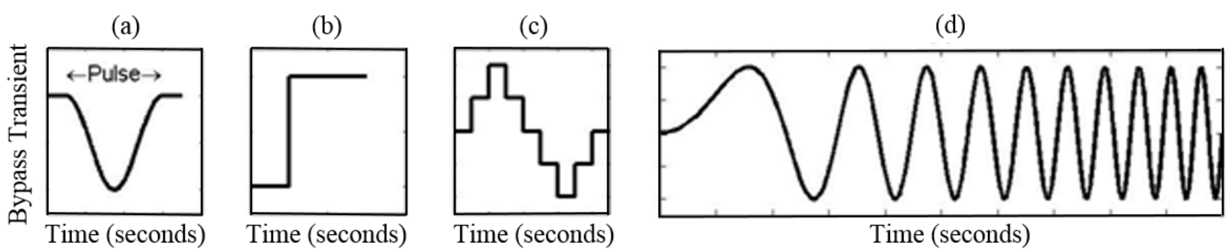

Figure 7.—Examples of perturbation signals (pulse (a), step (b), staircase (c), and frequency sweep (d)) generated by the SysID Rack for Phase-2 experiments.

dSPACE Model

The S-dSPACE software code was designed to transmit 0.0 to +5 volt setpoint signals to the HMC setpoint ports based on signals received from the Target. The S-dSPACE system receives Target signals on its A/D ports that range between ±10 volts, it then scales these signals to meet the required signal level of the HMCs, and then it outputs the scaled values through its D/A ports. If an instantaneous voltage signal step occurs on a dedicated (+5.0 volt) S-dSPACE input port, the S-dSPACE logic is designed to latch and hold the previous control signals that were applied to the D/A ports. These signals are latched such that subsequent signals from the Target will not affect the values applied to the S-dSPACE output ports. To resume normal operation after this type of error, the S-dSPACE system is reset with a release signal from a mechanical momentary push button, which is physically located on the SysID Rack.

SysID Rack Testing and Performance

SysID experiments were conducted on the CCE-LIMX at various operating conditions that included all the types of perturbation tests described previously. All experiments were conducted in the NASA GRC 10x10 SWT. At Mach 3, 156 experiments were conducted and 495 experiments were conducted at simulated Mach 4 conditions (Refs. 3 and 4). Experiment data was analyzed and includes steady state measurements of all flow path pressure sensors and actuator positions before and after each experiment, and response measurements during perturbation testing. The SysID rack hardware and software performed very well during the testing, which allowed for efficient collection of high-fidelity data. Additionally, the SysID rack was useful for performing tests designed to simulate an inlet MT. The data collected is being used to create plant TFs for separate closed-loop control system designs for the shock position in the LSFP (Ref. 5) and HSFP (Ref. 6).

An example experiment is covered here, which should help to clarify the function of the SysID rack to facilitate the process of conducting system identification experiments. The example experiment discussed in this section is representative of a sine pulse test—also known as a pulse test. This pulse test involves modulating the position of a bypass door. As illustrated in Figure 8, hydraulic fluid is regulated by an HMC to extend or retract a piston rod that will move the bypass door between two slotted horizontal rails mounted on a stationary plate. The movement of the door creates an opening to regulate bleed air passage when needed. The door opening is designed to operate continuously from fully open to fully closed. The door has range of travel from 0.0 in. (full closed) to 0.75 in. (full open).

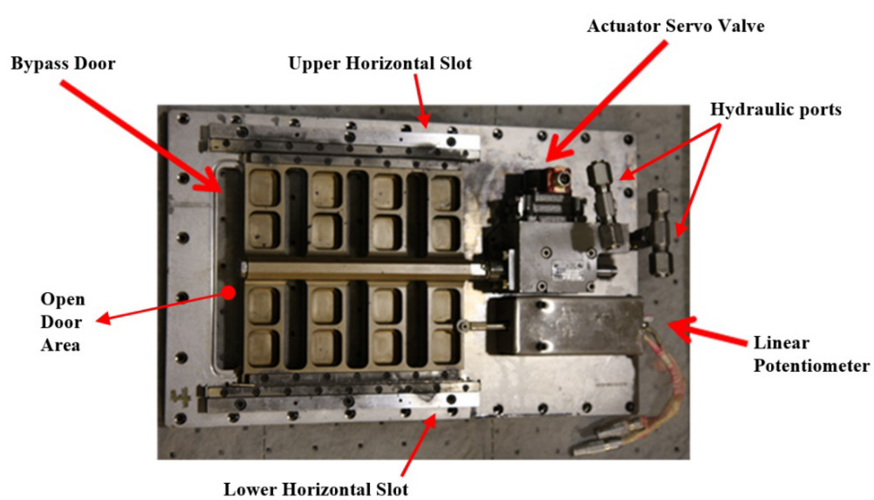

Figure 8.—One of four CCE-LIMX overboard bypass doors that are mounted at the aft end of the LSFP diffuser.

For the experiment example shown in Figure 9, the door started partially open, moved towards fully closed, and then back to the starting position. For a pulse test, the trace representing the door position with respect to time (Figure 9(a)) resembles a biased sine wave. For the SysID rack to perform a pulse test, or to perform any of the system identification experiments, the SysID system processes apply a stream of time-synchronized control signal values to the HMC. This is to modulate the bypass door position as desired with respect to time. The mathematical description of calculating the control signal values is described in Equation (1).

$$y(t) = y_0 + \frac{\Delta y}{2}\left(\cos(2\pi f t) - 1\right) \tag{1}$$

The desired door position, with respect to time, is y (inches), the initial door position is y_0 (inches), the magnitude of maximum door displacement is Δy (inches), f is the pulse frequency (Hertz), and t is time (seconds). The illustrations in Figure 9 are traces representing the signals read from the SysID Rack A/D ports while performing this test.

While all four doors operate the same way, they differ in their volts-EU conversions. Illustrated in Figure 9(a), is the control signal for this test; it is an EU signal trace representative of the desired movement, inches verses time, for bypass door number four. For this pattern, the initial door position is at 0.35 inches, the pulse amplitude is minus 0.30 in., and the time scale is normalized. The top right illustration in Figure 9(b) is a trace representative of the control signal from the SysID Rack Target that was applied to the Target D/A port (volts vs. time), voltage span of ±10.0 volts, delivered to the S-dSPACE system. Since the computational hardware communicates by transmitting voltage values on D/A channels and receiving voltage signals on A/D channels, the EUs (inches) describing the desired test pattern were converted to voltage values within a ±10.0 volt range. The electrical hydro pneumatic configuration for operating the bypass doors requires a voltage signal decrease to move the door towards fully closed and a voltage signal increase to further open the door area. Under normal operation, which

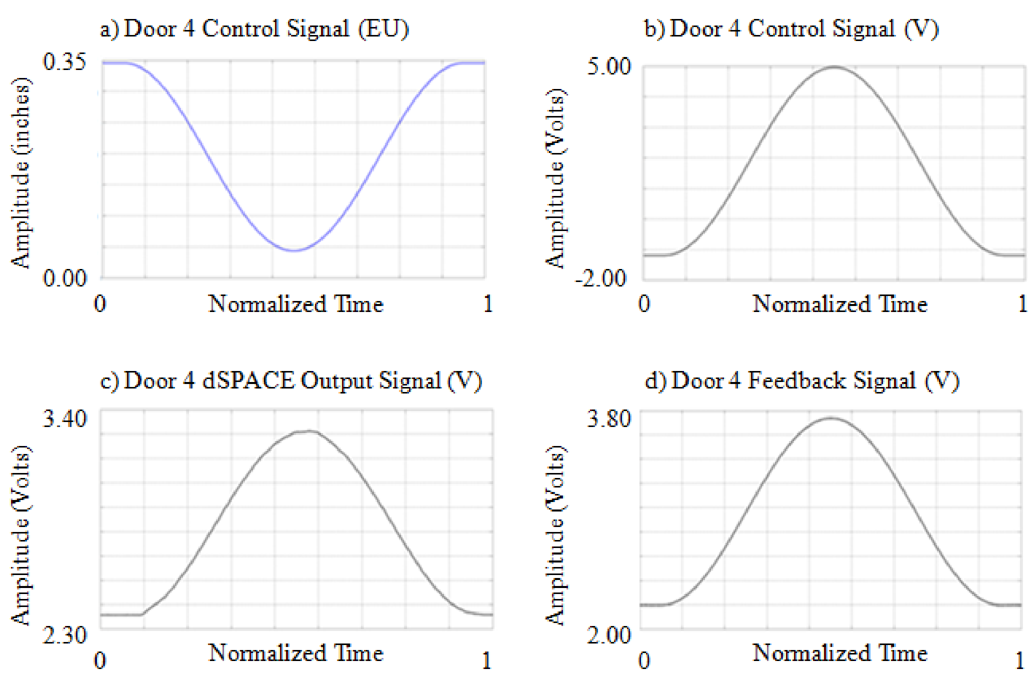

Figure 9.—Time normalized plots for a negative going pulse on door four.

was the case while recording the data illustrated in Figure 9, the S-dSPACE system scales the input voltage signals from the Target to an equivalent output signal within 0.0 to +5.0 volts. The illustration in Figure 9(c) is a trace reconstructed from the data file that represents the voltage signals from the output of the S-dSPACE system. Finally, the illustration in Figure 9(d) is a trace that represents the data recorded from the CCE-LIMX actuator feedback potentiometer for the fourth bypass door during this experiment. Again, the units are volts with a range from 0.0 to +5.0 volts. The voltage values represented by the trace in Figure 9(d) can be converted to inches by applying a voltage to inches calibration polynomial to the data. The plots in Figure 9 are representative of the SysID rack's ability to perform all perturbation experiment tests.

Summary

This report described the System Identification rack developed and used to perform Combined Cycle Engine Large-Scale Inlet for Mode Transition Experiments (CCE-LIMX) Phase-2 testing for System Identification experiments. Prior, Phase-1 testing was conducted to generate mode transition schedules, where the Phase-2 experiments were designed to generate and acquire perturbation data at various operating points. The rack software and hardware were developed to enable the application of various types of actuator perturbations and measure the response of various pressure sensors for the CCE-LIMX experimental model. In this paper, the hardware and software code have been described in detail. During System Identification experiments, perturbation data were recorded at Mach 3 freestream conditions and simulated Mach 4 conditions. The system identification experimental data collected in Phase-2 were subsequently used to developed transfer functions for the system dynamics. These, in turn, were used to develop feedback control designs for shock position and various backpressures. These models and controls are needed to support hypersonic propulsion system mode transition experiments. An example was provided to demonstrate how the System Identification rack custom application code commanded a control signal to an actuator, and how it provided and recorded a feedback signal to the rack confirming the actuator's position.

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