CUE-SYNCHRONIZATION MEASUREMENT USING THE PILOTED FREQUENCY SWEEP TECHNIQUE

R. Thomas Galloway and R. Brad Smith
Naval Air Warfare Center Training Systems Division
Orlando, Florida

Abstract

Flight training simulator users and vendors understand well the importance of proper presentation of major sensory cues to a trainee within a simulated flight training system. Motion, visual, crew compartment displays and instrumentation form the primary cues delivered to a trainee in modern day flight simulators. Crucial to proper presentation of cues is having a quantitative means to measure the character of the cue. Subjective pilot evaluations of these cue sources typically reveal only the existence of problems but not the true problem source. Attempts to correct perceived cue deficiencies on this basis are usually ineffective and certainly not efficient. Objective measures of simulator cue behavior have been limited to some extent by sensor technology but more significantly by a lack of sophisticated data analysis tools. Current simulator testing of dynamic response of visual, motion, and cockpit display cues has been limited to time domain measures of initial response and simplified frequency domain measures. These current methods need to be expanded to provide a more complete presentation of the dynamic character and synchronization of these cues plus offer the potential for direct comparison with equivalent aircraft data when that data is available. This paper describes recent efforts to improve methods for testing and analyzing flight training system simulator cue synchronization (cue sync) and cue dynamic characteristics.

This paper documents the application of the piloted frequency sweep technique, and subsequent frequency response analysis, to quantitatively identify the cue-sync character of a USMC rotary wing training system -- the MV-22A Operational Flight Trainer. Frequency response comparisons were generated by analysis of data generated using the piloted frequency sweep technique. The frequency response comparisons were used to evaluate the simulator motion and visual systems versus the simulator model thereby providing a means for identification of cue-sync character without the need for special purpose software modifications. Measurement of bandwidth and phase delay from the frequency responses is also included, and was produced in a manner consistent with evolving aircraft measurement standards. A suggested evaluation criteria, representing the extent to which cue-sync behavior can be compared to aircraft response is also characterized. Finally, a quantitative evaluation criteria for motion system cueing quality is provided in order to assist in the determination of motion system character.

About The Authors

R. Thomas Galloway is the aeronautical engineering group leader at the Naval Air Warfare Center Training Systems Division in Orlando, Florida. His responsibilities include the investigation of flight simulation requirements for rotary wing and fixed wing pilot training. He has participated in the development and evaluation of many Navy flight simulators for training and research applications and has continuously fostered the application of aircraft flight test technology to optimize simulator flight fidelity. Mr. Galloway holds a BSAE from Georgia Institute of Technology, an MSAE from Princeton University, and is a graduate of the U.S. Naval Test Pilot School engineering curriculum.

R. Brad Smith is a systems engineer employed by the Naval Air Warfare Center Training Systems Division In-Service Engineering Office at Marine Corps Air Station New River, North Carolina. He is responsible for providing varying levels of training system support for existing training systems and is also heavily involved in the upgrade and procurement of new rotary wing training systems for the United States Marine Corps. Mr. Smith holds a Bachelor of Science degree in Electrical Engineering from North Carolina State University.

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INTRODUCTION

Background

Simulated flight training system users and vendors in the simulation industry understand well the importance of proper presentation of major sensory cues to a trainee within a simulated flight training system. Motion, visual, crew compartment displays and instrumentation form the primary cues delivered to a trainee in modern day flight training systems. Crucial to proper presentation of cues is having a quantitative means to measure the character of the cue. Key to proper characterization of the cues is making the measurement in such a way that the relationship, or synchronization with the other primary cues can be quantitatively determined. Measurement of cue-synchronization (cue-sync) character is the topic of this paper.

The necessity to measure cue-sync arises as a result of the knowledge that all cues may not arrive at the trainee station simultaneously. Delays within the various subsystems of the training system architecture are the culprit. Some delays are necessary and/or desirable, others are not. Delays result from a number of sources: data transfer time amongst the various subsystems of the architecture, processing time, sampling delays, model response, and hardware response. Data transfer time is the time required to move information from one subsystem to another. Typically, while information is being transferred, it cannot be utilized. Processing time is the time required for the computational system to produce an update to the solution of aircraft state. Sampling delays result because in a digital simulation, processing time occurs in discrete time intervals or frames. Inputs to the simulation are delivered in one frame, processing occurs in subsequent frames, and outputs are delivered to the cueing systems in succeeding frames. Sampling delays can be affected by data transfer delays if the transfers are asynchronous in nature. Utilization of synchronous transfer methods reduce this effect. Transfer delays can be grouped with processing time if the transfer can take place synchronously and can be accomplished in less than the time of one frame. Figure 1 provides a simple illustration of the above concepts. The proportions indicated are not to scale.

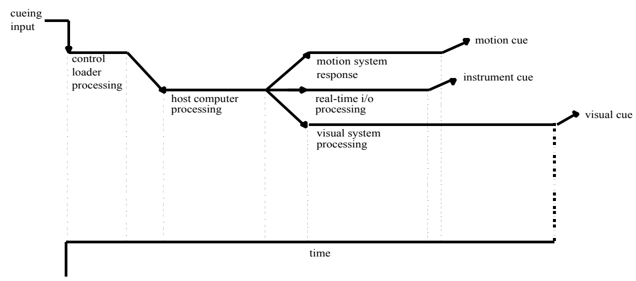

Figure 1 - Cue-Sync Relationships

Some methods [1] to determine the cue-sync character of simulator primary cueing systems involve the use of special purpose test software which bypass the aerodynamic model delays in the simulation and other cue compensation effects. The special purpose test software is placed downstream of the flight and cue dynamic models and acts to overwrite the normal results that determine and update the aircraft state so that their contribution to processing time will remain a component of the throughput measurement without the delays due to the dynamic properties of the models and any cue compensators present. The various control axes are driven (at a position downstream of the actual control in some implementations which neglects a portion of the system response) with a step input while measuring the time to first response of the primary output cues. The system is considered adequate if the response time measured falls below a certain delta time with respect to each other. A variation on the technique also provides for the application of *fixed* frequency input sinusoids to the various control axes while making the same or similar output measurements in an attempt to identify any gain and/or phase distortion as a function of frequency. Subsequent comparison of the output measurements determine whether the system is considered adequate.

One negative aspect of the above technique is the necessity to have special purpose software in place in order to make the desired cue-sync measurement. This can be especially disappointing if the design of the software architecture of the training system did not envision a requirement to perform special purpose testing of this nature. Another negative aspect of the above technique is that with the aerodynamics model "short-circuited" in this manner, a significant portion of the training simulation is missing. In other words, it is tested in a configuration that is different from that which is normal for training purposes.

A method to measure the cue-sync character in a manner that does not disturb the training system in its training configuration is desired. The method should allow for complete characterization of the training system total end-to-end response in any or all of the cueing axes. Additionally, the cue-sync measurement method should be compatible with normal aircraft flight test techniques.

This desire resulted in a plan to test the MV-22A OFT using the piloted frequency sweep technique. This technique can been applied to identify many aspects of simulation character [5,9] in addition to having been applied in many areas for identification of aircraft character [3,4,6,8]. This technique allows the measurement of the cue-sync character of the training system without the need to perform any special modifications to the training system software. The training system can be measured in the same configuration in which it is used for training. Subsequent frequency response analysis of data collected utilizing the piloted frequency sweep technique can produce quantitative information about the character of the cues produced in the simulated training system in order that compliance with requirements can be easily determined. The data can also be use to assess and improve the fidelity of the simulation model where equivalent aircraft data is available.

It is the assertion of the authors that determination of cue-sync character of a simulated flight training system can be obtained *exclusively* through use of the piloted frequency sweep technique. The frequency response, produced from analysis of the measured data obtained by the application of the piloted frequency sweep technique, characterizes the training system *total* end-to-end response, which includes the character of all elements that comprise that system. The frequency response results from visual, motion, displays, etc. can be compared directly against frequency response results produced from the equations of motion (EOM) model to determine cue-sync behavior. EOM frequency response results can then be compared directly against data produced from measurement and analysis of the aircraft in the same manner. The latter are *not* necessary for cue-sync determination.

Training System Architectural Description

Figure 2 provides a block diagram of the major components comprising the MV-22A OFT.

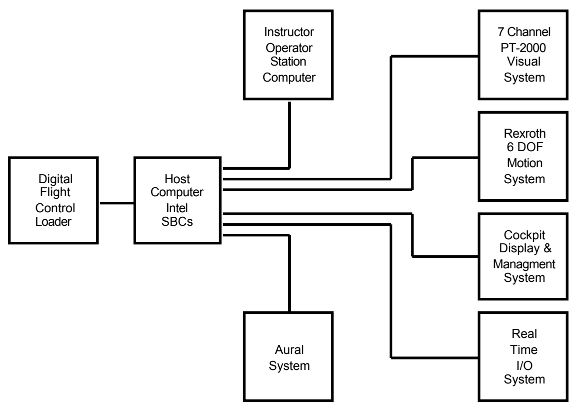

Figure 2 - MV-22 OFT Block Diagram

PURPOSE

The purpose of this paper is to document the application of piloted frequency sweep technique, and subsequent frequency response analysis, to quantitatively identify the cue-sync character of a USMC rotary wing training system -- the MV-22 Operational Flight Trainer (Device 2F151). An additional purpose is to propose further work to refine and quantify the techniques presented within.

Frequency response comparisons were generated by analysis of data generated using the piloted frequency sweep technique, which is described more fully below. The frequency response comparisons are used to evaluate the simulator motion and visual systems versus the simulator model thereby providing a means for identification of cue-sync character without the need for special purpose software modifications. Measurement of bandwidth and phase delay from the frequency responses is also included, and was produced in a manner consistent with evolving aircraft measurement standards. A suggested evaluation criteria, representing the extent to which cue-sync behavior can be compared to aircraft response is also characterized. Finally, a quantitative evaluation criteria for motion system cueing quality is provided in order to assist in the determination of motion system character.

This paper was composed primarily with the hope that it might provide a useful reference for future efforts of this type and also to provide a possible foundation from which to build. Many thanks go to the personnel at Hughes Training Inc. of Herndon, Virginia whose assistance and genuine interest in this new technique made this effort possible.

TEST TECHNIQUE

Piloted Frequency Sweep Description

A piloted frequency sweep was generated for each control axis by moving the control in a sinusoidal fashion starting at very-low frequency (20 second period -- 0.05 Hz) and continuously sweeping while increasing the sweep frequency at a linear rate up to a predetermined maximum of about 5 Hz. The pilot was coached by a data observer to ensure good frequency content. The resultant data recording is 90-100 seconds long when the sweep is completed.

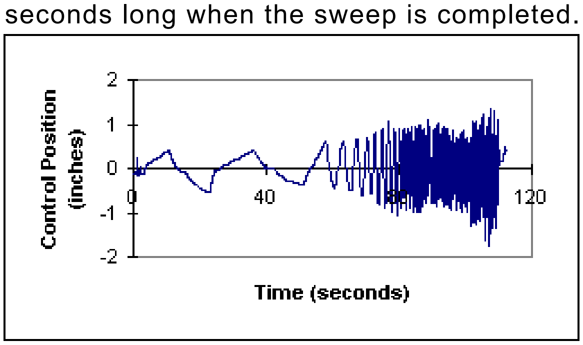

Figure 3 - Longitudinal Control Sweep (200 Kts)

Figure 3 shows a sample sweep for the longitudinal axis at 200 kts. A series of three sweeps were done and subsequently concatenated (placed end-to-end) for each control axis to ensure good frequency coverage and good data recording. Measured input and output parameters for the test effort are provided in Table 1. Although the cockpit displays and instruments (Multi Function Displays, including FLIR video, and the Standby Attitude Indicator) are also important to pilot perception of the simulated aircraft, no attempt was made during this test effort to acquire data to check the character of these devices. A subsequent effort will include these devices.

The piloted frequency sweeps were performed for two flight conditions: hover and at 200 knots. The most difficult axes to sweep in the hover condition are the lateral and longitudinal cyclic control axes because the aircraft (real or simulated) tends to gain speed and is displaced from the hover condition during the long-cycle (low-frequency) sweep. The pilot is allowed to correct for this drift as long as the correction remains relatively uncorrelated with the input signal. The Throttle Control Lever (TCL) sweep was omitted in the 200 Kts flight condition. The training system software was not modified in *any* way for this test effort. Software build #164 was active in the computational system.

Table 1 - Signals Collected for Test Effort

Description	Symbol	Units
Inputs		
Directional Pedal Position	δ_{dir}	inches
Lateral Control Position	δ_{lat}	inches
Longitudinal Control Position	δ_{lon}	inches
TCL Control Position	δ_{tcl}	inches
Outputs		
Equations of Motion Roll Rate	p	rad/sec
Equations of Motion Pitch Rate	q	rad/sec
Equations of Motion Yaw Rate	r	rad/sec
Equations of Motion Load Factor	O	G
PT-2000 IG Filtered Video	n/a	volts
PT-2000 IG Unfiltered Video	n/a	volts
MotionPak X Acceleration	a_x	G
MotionPak Y Acceleration	a_y	G
MotionPak Z Acceleration	a_z	G
MotionPak Roll Rate	p	deg/sec
MotionPak Pitch Rate	q	deg/sec
MotionPak Yaw Rate	r	deg/sec

TEST CONFIGURATION

Test Equipment

Figure 4 contains a block diagram representing the equipment setup designed by the authors for data collection. A

MotionPak sensor was used to measure motion platform angular rates (p, q, r) and translational accelerations (a_x, a_y, a_z). The motion sensor was mounted at a position immediately behind the pilot's seat on a rigid section of the cockpit baseframe. The mounting position is accurately known with respect to the modeled aircraft CG. Attachment was made to the Digital Flight Control Loader force actuator boards in order to obtain information on the control positions as close to the control point as could be achieved. Attachment was also made to the strip chart analog recording outputs of the real-time I/O subsystem in order to obtain the equations of motion (EOM) outputs indicated in Table 1. Finally, RGB video was obtained from the Compuscene PT-2000 Image Generator and sampled in both filtered and unfiltered format at the PC Computer.

The data collected were digitally sampled at 60 Hz using a commercially available data acquisition board inserted into an expansion slot of the PC Computer and custom sampling software written by the author. The data collection system currently supports 16 channels (single-ended) and also supports sampling rates up to 6 kHz per channel using all 16 channels. Higher rates are possible when the channel count is reduced. The sampled data collected was saved in ASCII columnar format for ease of delivery to other analysis software and plotting utilities.

ANALYSIS TECHNIQUE

Frequency Responses

Due to the short time limitations associated with this test effort, a MATLAB™ "m-file" (sisofra.m) previously developed by the author to perform Single-Input Single-Output (SISO) frequency response analysis was used. The m-file provides for concatenation (end-to-end placement) of both input and output time histories, scaling, linear trend and bias removal, digital filtering, tapered windowing for reduction of spectral leakage and sidelobe reduction, 50% overlapped windowing for maximum averaging, s-domain conversions (integration and/or differentiation), and SISO spectral content extraction. Multiple runs of sisofra.m can be performed in an unattended fashion. Table-2 indicates the input/output pairs used to produce the frequency responses.

Table 2 - Frequency Response Input/Output Pairs

Description	EOM	Video	MotionPak
Directional Sweep Hover & 200 kts	r_{eom}/δ_{dir}	$video/\delta_{dir}$	r_{mpak}/δ_{dir}
Lateral Sweep Hover & 200 kts	p_{eom}/δ_{lat}	$video/\delta_{lat}$	p_{mpak}/δ_{lat}
Longitudinal Sweep Hover & 200 kts	q_{eom}/δ_{lon}	$video/\delta_{lon}$	q_{mpak}/δ_{lon}
Vertical Sweep Hover Only	a_z/δ_{tcl}	$video/\delta_{tcl}$	a_{zmpak}/δ_{tcl}

Subsequent analysis efforts will make use of the more sophisticated NASA Ames Comprehensive Identification from FrEquency Responses (CIFER) product [2]. While CIFER incorporates more sophisticated analysis methodologies, CIFER setup and analysis time as compared to the MATLAB™ method used here was deemed to be too prohibitive given the very limited time available for this effort.

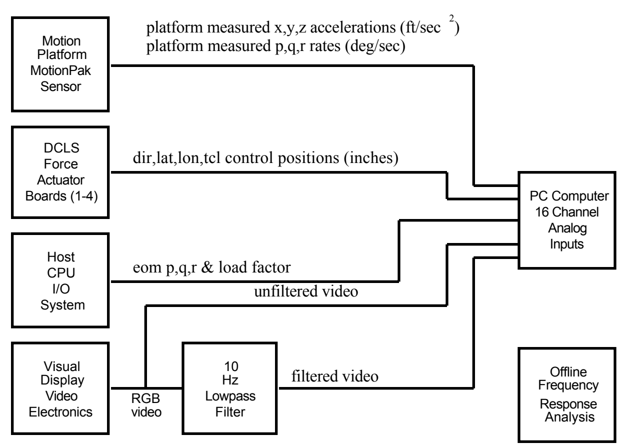

Figure 4 - Test Equipment Setup

After the data collection effort was complete, the data were organized in a manner convenient for analysis by the MATLAB™ m-file. The subsequent results were saved in ASCII columnar format for submission to a plotting utility. The following information was produced:

G_{xx} Input autospectrums (frequency spectra for the directional, lateral, longitudinal and throttle control lever control positions). Displayed in dB as a function of frequency.

G_{yy} Output autospectrums (frequency spectra for the roll, pitch and yaw angular rates and display video). Displayed in dB as a function of frequency.

G_{xy} Input-Output cross spectrums displayed in dB as a function of frequency.

$|H_{xy}|$ Transfer function magnitude displayed in dB as a function of frequency.

$<H_{xy}$ Transfer function phase displayed in degrees as a function of frequency.

G^2_{xy} Coherence (a dimensionless measure of the response quality). Values > 0.6 are generally acceptable. Coherence represents the fraction of the output that is linearly related to the input.

The above information was produced for EOM, motion, and visual responses for each control axis for each of the flight conditions and overlaid on the same plots. Additionally, spectrograms (frequency -vs- time) were produced for each input using a m-file (spectgram.m) included with the MATLAB™ Signal Processing Toolbox in order to provide quick feedback regarding the quality and frequency content of the input sweeps prior to further detailed analysis.

CUE-SYNC COMPLIANCE CHARACTERIZATION

Gain and Phase Envelopes

Research work in aircraft handling qualities has produced parameters and criteria that may be adaptable to flight simulator fidelity. The analysis of the handling qualities of aircraft with highly augmented flight control systems led to the use of equivalent systems methods. In the equivalent system method, a relatively simple transfer function is used in ground-based and in-flight simulators to characterize a very complex aircraft/high order flight control system combination which expedites the analysis process. Research data revealed that large mismatches in frequency response between the high order and equivalent low order systems were not noticed by the evaluating pilots, except when operating in the 1 to 5 rad/sec frequency range. Reference [12] describes gain and phase envelopes for maximum unnoticeable added dynamics derived from analysis of experimental data for conventional and V/STOL flight tasks. These envelopes were presented to focus the tuning process for equivalent systems applied in military standards for aircraft handling qualities. Figure 5 illustrates the envelope of maximum unnoticeable added dynamics presented in a current military standard [13]. For cue sync analysis of flight simulator fidelity, it appears that the same or similar envelopes would be appropriate. The simulator math model, motion system, and visual system can be considered equivalent systems and compared to the real world aircraft frequency response. For acceptable fidelity, the deviation of simulator gain and phase from aircraft values would be expected to fall within the gain and phase envelopes presented here. For cue-sync analysis, the motion and visual cue response difference from EOM response can be evaluated with this criteria. Of course, some experience with this criteria is necessary before definite gain and phase envelope boundaries can be declared for cue sync applications.

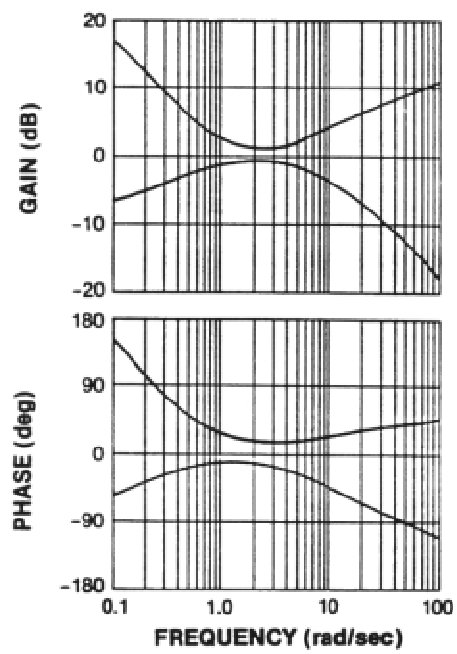

Figure 5 - Gain & Phase Envelope Plots

Bandwidth and Phase Delay

Aircraft handling qualities specifications for fixed and rotary wing aircraft now utilize frequency domain parameters such as bandwidth and phase delay to characterize aircraft behavior. These same parameters can be applied to simulator fidelity and cue-sync assessment. The following method is utilized to extract bandwidth and phase delay information from the frequency responses:

Magnitude and Phase

$$magnitude = \left|\frac{X}{X_i}\right| db$$

$$(X = \Theta, \Phi, \Psi)$$

$$(X_i = F_s \, or \, \delta_s)$$

phase = f (degrees)

both versus ω(rad/sec)

Phase Delay

$$t_p = \frac{\Delta\Phi(2\omega_{180})}{57.3(2\omega_{180})}$$

Note: If phase is nonlinear between ω_{180} and $2\omega_{180}$, τ_p is determined from a linear least squares fit to the phase curve between ω_{180} and $2\omega_{180}$.

Bandwidth

For Rate Response types:

ω_{BW} is the lesser of ω_{BWgain} and $\omega_{BWphase}$

For Attitude Command/Attitude Hold Response (ACAH) types:

$\omega_{BW} \equiv \omega_{BWphase}$

Application of the above technique for the extraction of bandwidth and phase delay from frequency responses is used to produce the table shown in the assessment section below. Since only angular rates were measured during the data collection effort, an s-domain conversion (1/s integration) was applied to obtain the angular *positions* necessary for the measurement.

MOTION CUEING FIDELITY

Range Determination

An uninvited consequence of motion cueing algorithms (due to the need to ensure that the motion system does not exceed its physical displacement limits) is that the lower frequencies are attenuated and phase shifted ahead in time. Reference [5] provides a detailed assessment of motion phase shift impact on pilot opinion for several helicopter tasks flown in the Vertical Motion Simulator at NASA Ames. This assessment applied a tolerance criteria of ±20 degree phase difference when comparing motion response to the equivalent EOM parameter. The results were summarized in terms of the frequency range where motion phase met this criteria and the cross-over frequency where the phase of each parameter was identical. Analysis of pilot handling quality ratings and other comments supported the concept that the motion cues were more satisfactory during tasks performed in frequency ranges where the ±20 degree phase tolerance was met.

FAA Alternative Method

The FAA has issued Advisory Circular (AC) 120-63 [14] to establish a way to certify helicopter simulators for use in training programs. This AC makes a general recommendation that frequency response data be utilized when available for comparing helicopter and simulator dynamic response characteristics. Appendix 2 of the AC describes two methods for motion system testing: one that documents time history response for later repeatability comparison, and another method that documents frequency response of the end-to-end motion system. The frequency response method is conducted as follows: At the point at which the accelerations from the equation normally excite the motion system, including the washout algorithms, a sinusoidal input would be used to excite the motion system. Acceleration at the pilot station would be measured to determine frequency response. The resulting frequency response measured in each axis must comply with the following specification: Gain tolerance: ±2 dB from 0.5 Hz to 5.0 Hz; Phase tolerance 0 - ±20 degrees from 1.0 Hz to 2.0 Hz. These tolerances were derived by consensus of simulator experts during the AC development process; notice that the frequency range is limited to the area where pilots typically conduct aggressive flight tasks and that the frequency ranges are different for gain and phase.

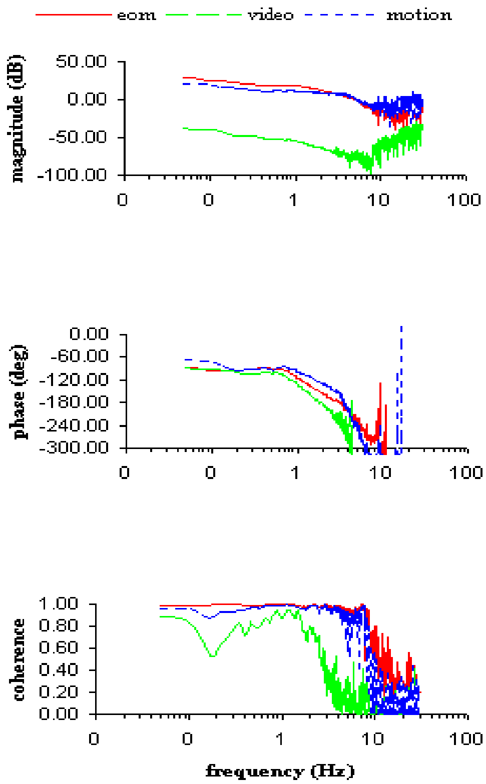

Figure 6 - Longitudinal Frequency Response (200 kts)

ASSESSMENT

Frequency Sweeps

The quality of the frequency sweeps produced for this effort were deemed to be adequate for the purposes of this paper and are based on the criteria established in the references [2,3,4]. Additionally, spectrograms (MATLAB™ - "specgram.m") were utilized as a rough indication that the range of frequencies desired were adequately represented in the time histories acquired before the frequency response analysis was performed. (The desired linear change in frequency for the frequency sweeps from lower to higher values in the desired range was present).

Frequency Responses

Figure 6 illustrates a sample of the measured frequency responses used for the calculation of bandwidth and phase delay presented in Table-3. The measurement technique used is the method described above. An s-domain 1/s conversion was applied to all measured *rate responses* in order to obtain the corresponding *position responses* required for the bandwidth and phase delay measurement.

Cue-Sync Compliance

A missing element fundamental for characterization of EOM behavior is the aircraft frequency domain response. Discussions with flight test engineering personnel from NAWCAD indicate that the EOM character of the training system, as determined through application of classical time domain techniques, is "adequate". While equivalent aircraft responses are highly desirable, they are *not* mandatory for measurement of cue-sync. Given these limitations, the EOM frequency domain responses are *assumed* to compare favorably against the aircraft. Table 3 contains the calculated bandwidths and phase delays for the various cueing sources for the longitudinal at 200 Kts only. This step establishes the baseline from which motion and visual system response character can later be compared.

Table 3 - Bandwidths & Phase Delays for Lon Axis at 200 kts

Axis	Bandwidth (rad/sec)	Phase Delay (sec)
Aircraft	Not Available	Not Available
EOM	8.5	0.082
Visual	6.5	0.940
Motion	1.7	0.770

Motion Cueing Fidelity

Table-4 presents the results of applying the ±20 degree phase tolerance to the frequency response results for motion cueing quality assessment. These results are a quantitative measure of how well the respective motion axes matched the corresponding EOM axes. Although not performed for this test effort, a rating mechanism such as this should be further substantiated with pilot evaluation.

Table 4 - Motion Cueing Fidelity Range

** - phase always within tolerance

SUMMARY OF PROPOSED METHODS

Simulator frequency response test techniques and data analysis methods have been described in this paper. Frequency domain test results can be interpreted in a variety of ways that are potentially useful to flight simulator cue-sync analysis. Simulator cue fidelity can be accurately determined if aircraft frequency response data is available as reference criteria. Even without aircraft data, the EOM response can be utilized as criteria for quantifiable analysis of cue-sync character of all cueing systems present. A summary diagram illustrating the process is shown in Figure 7.

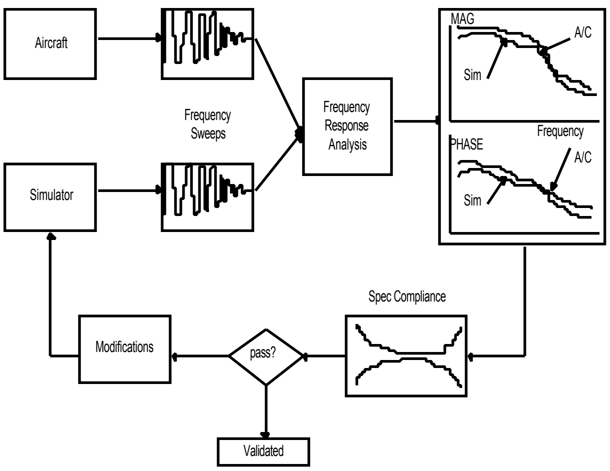

Figure 7 - Frequency Domain Validation Criteria

Cue-Sync Compliance Characterization

Two analysis approaches are described in this paper, both derived from aircraft handling qualities technology.

- Bandwidth and Phase Delay offers the potential for direct comparison of simulator cues with aircraft flight test data. Further evaluation of this approach must await the more widespread use of frequency domain techniques by the flight test community.

- Gain and Phase Envelopes offer a straight forward tolerance criteria for assessing the difference between cues and when available, the aircraft, over a broad frequency range. Further experience is needed to confirm the exact envelope values for simulator application.

Axis	Lower Freq f_1 (Hz)	Upper Freq f_2 (Hz)	Crossover Freq f_c (Hz)	"Hi-Fi" Range
Dir- Hover	0.180	2.600	1.000	2.420
Dir- 200kts	0.160	2.200	0.850	2.045
Lat- Hover	0.190	4.700	2.900	4.510
Lat- 200kts	0.100	3.500	1.800	3.400
Lon- Hover	0.120	5.000	3.000 *	4.880
Lon- 200kts	**	**	3.6 **	**

Motion Cueing Fidelity

Evaluation of motion cues has traditionally been a subjective process. Two methods are described in this paper to establish a more quantitative basis for assessing motion cue fidelity.

- Fidelity Range Determination is based on the simple criteria that motion phase remain within 20 degrees of the input signal. Further experience is needed to clarify the interpretation of the resulting identified "hi-fi" frequency range for typical simulator tasks.

- FAA Alternative Method imposes straight forward tolerance on motion gain and phase response over specific frequency ranges. Experience with this method is needed to see if these tolerance values are effective.

CONCLUSION

While a tolerance criteria for comparison against requirements has not been quantified, it has been characterized. New techniques are suggested that differ from previous methods. A means to quantitatively measure cue-sync character without the necessity for modification of training system software has been demonstrated.

RECOMMENDATIONS FOR FUTURE EFFORTS

- The piloted frequency sweep technique can be used for numerous purposes, all or many of which can have a positive impact on the quality and fidelity of simulated rotary wing flight training systems. Additional test and/or research efforts should be initiated to further substantiate use of the piloted frequency sweep technique as the primary means of determination of cue-sync character.

- Further efforts are necessary to establish a quantitative tolerance criteria for comparison of frequency response results for EOM performance against the aircraft. Similar efforts are also necessary for quantifying cueing tolerance relationships to EOM behavior with the realization of what is practical within the physical limitation of the cueing systems.

- While the MATLAB™ m-files developed for use during the limited time available for this test effort were deemed adequate (and potentially quite useful for *rapid* frequency response estimates), the frequency sweep data from this effort should be re-processed using the CIFER (Comprehensive Identification from FrEquency Responses) utility. This utility contains several programs for the analysis of frequency response data. The subprograms FRESPID (Frequency RESPonse IDentification), MISOSA (Multi-Input Single-Output Spectral Analysis), and COMPOSITE (Multi Window Averaging) all serve for production of wide band, high fidelity frequency responses. The additional subprograms DERIVID (Generalized Stability Derivative Identification from Frequency Responses), VERIFY (State Space Model Verification), and NAVFIT (General Purpose Frequency Response Fitting) work together for identification and evaluation/verification of state-space models of up to 40 states.

- Development of a method to incorporate real-time spectrograms for use in the cockpit while applying the frequency sweep technique. Real-time spectrograms can provide immediate feedback to the pilot on the quality of the sweep as it is being generated in order to ensure adequate data is obtained prior to detailed analysis.

- Development of a technique for measurement of cue-sync character of the cockpit displays and related devices. These devices are equally as important to pilot perception of the simulated aircraft as any of the other major subsystems measured for this effort. One interesting approach to measurement of video based instrument displays is described in reference [7].

- As has been suggested by numerous references, future efforts should incorporate *matched* lowpass filters on all measured values in order that filter characteristics need not be subtracted from measured responses. This was not possible during this effort due to lack of time and material.

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