NSP GB

National Simulator Program
FSTD Qualification Guidance Bulletin

U.S. Department
of Transportation

Federal Aviation Administration

NSP GB 16-03
DATE: 04/11/2016

Flight Standards Service
Washington, DC

National Simulator Program Guidance Bulletin
An NSP GB contains valuable information for FSTD sponsors that should help them meet certain administrative, regulatory, or operational requirements with relatively low urgency or impact on safety.

Subject: Objective Motion Cueing Test Implementation**.**

Purpose: To provide flight simulation training device (FSTD) sponsors and training device manufacturers (TDMs) guidance in implementing objective motion cueing tests (OMCT) for the purpose of meeting the FSTD initial evaluation requirements identified in Title 14 of the Code of Federal Regulations (14 CFR) Part 60. For harmonization of international FSTD evaluation standards, this guidance has been adopted from the guidance in International Civil Aviation Organization (ICAO) 9625, Edition 4, Part II, Appendices B and F.

Background: In recent years, motion cueing fidelity in flight simulation has been studied in an attempt to determine how the transfer of training from FSTD to aircraft may be affected. It is well known that the characteristics of the motion cueing system directly impact the perception and the reaction of the pilot training in the FSTD. Ideally, an FSTD would provide rotations and translations as they would occur in the real aircraft. Practically speaking, however, this is impossible to achieve due to physical excursion limits of any motion platform. To compensate, FSTD translations and rotations are used in a mixed manner to create the effect of rotations and translations experienced in the real aircraft. Until recently, no one has attempted to quantify the mixture needed to provide an optimum simulation.

A primary component of the motion cueing system is the Motion Drive Algorithm (MDA). The MDA transforms the calculated motion output from the flight model to FSTD motion platform commands. The MDA must do so while simultaneously maintaining the platform within its mechanical limits. In order for the FSTD to provide a feel that is representative of the aircraft being simulated, MDA variables are tuned by aid of an evaluation pilot in several flight regimes and conditions during FSTD acceptance. Historically, this process has relied heavily upon the subjective feel of the evaluation pilot. Experience has demonstrated that this methodology does not provide an outcome that is measurable or consistently reproduced on similar FSTDs. First, variations can and usually do exist between the preferences of any two pilots. Second, for any one given pilot, the perceived feel of an FSTD may vary over time due to a number of given factors.

Given the nature of subjective tuning, there has been legitimate concern that inconsistently tuned, or in the worst case, poorly tuned motion systems may adversely affect the transfer of training from FSTD to aircraft. FSTD users, TDMs, and regulators have long sought a more reliable and repeatable objective method of tuning the motion cueing system. In response, an industry and scientific working group developed the objective motion cueing test. Although still being refined in some areas, the Federal Aviation Administration (FAA) has determined that the application of this test represents a marked improvement over motion cueing tuning and evaluation conducted using purely subjective means. Part 60 now requires OMCT for applicable FSTDs initially evaluated after May 31, 2016.

Revision	Description of Change	Effective Date
0	Original Draft.	04/11/2016

14 CFR Part 60 Requirements

OMCT requirements are found in Appendix A, Table A2A (Objective Tests), line item 3.e.1. While the basis for these requirements is rooted in ICAO 9625, Edition 4, certain details have been modified to satisfy industry comment during the part 60 rulemaking process. In the revised part 60, OMCT results are required only for FSTD initial evaluation. Continuing qualification OMCT is not required. Testing may be accomplished by the TDM and results provided as a statement of compliance. The tests should be repeatable at the location of FSTD training, and the FAA may request to witness such testing during the initial qualification. Part 60 does not currently assign a specific tolerance to OMCT test results. Tolerances will be as specified by the TDM for initial qualification. Tests initially conducted by the TDM or at the sponsor's facility will be regarded as a footprint test for reference and documented in the Master Qualification Test Guide (MQTG). Although OMCT can be conducted in both the time and frequency domains, Part 60 requirements include testing in the frequency domain only. Separate tests must be conducted for in-air and on-ground motion cueing algorithm settings unless the settings are the same for both conditions.

Implementation Guidance for OMCT

This test quantifiably compares the calculated motion response of a flight model (motion system input) to the actual movement of the FSTD motion platform (output) as modified by the MDA. It should be obvious that the point of reference for this response in either the aircraft or the FSTD must be defined at the pilot position, F_{PA} or F_{PS}[1], as opposed to the aircraft center of gravity. Test result output provides a traditional frequency response (Bode plot) for F_{PS}/F_{PA} indicating both gain and phase of the motion system over a range of frequencies for specific and repeatable inputs. Given the end-to-end nature of the test with respect to the motion system, measurements inherently include the combined influence of the motion cueing algorithm, the motion platform dynamics, and the transport delay associated with the motion cueing and control system.

Test Inputs.

A number of sinusoidal inputs in varying axes and frequencies are needed to demonstrate the ability of the FSTD to reproduce direct relationships (aircraft translations and rotations) as well as those relations that are cross-coupled (non-aircraft movements). The relevance of these inputs is explained in the following example. The simulation of forward aircraft acceleration requires a momentary acceleration of the FSTD in the forward direction (surge) to provide the onset cueing. This is considered the direct transfer relationship. The FSTD, however, is simultaneously pitched nose-up due to the MDA low-pass filter in order to generate a sustained specific force. The pitch-up associated with the generation of the sustained specific force, and the angular rates and angular accelerations to initiate the sustained specific force, are considered cross-coupling relations. Although the specific force is required for the perception of the aircraft sustained

[1] See Attachment 1, Frames of Reference.

specific force, these angular rates and accelerations do not occur in the aircraft and should be minimized.

A total of ten required test conditions in varying axes are shown in Table 1. The matrix format of aircraft input versus motion platform output perfectly demonstrates the direct transfer and cross-coupling relationships. Tests 1, 3, 5, 6, 8 and 10 show the direct transfer relations, while tests 2, 4, 7 and 9 show the cross-coupling relationships. Test descriptions follow the table. Keep in mind that each test requires a sinusoidal input varied over a range of frequencies.

Table 1.
Test Matrix with Test Numbers

Aircraft Input Signal	FSTD Response Output Pitch	FSTD Response Output Roll	FSTD Response Output Yaw	FSTD Response Output Surge	FSTD Response Output Sway	FSTD Response Output Heave
Pitch	**1**			**2**		
Roll		**3**			**4**	
Yaw			**5**			
Surge	**7**			**6**		
Sway		**9**			**8**	
Heave						**10**

Test Number	Relation	Test Description	Dimension Frequency Response
1	Direct	FSTD pitch response to airplane pitch input.	No dimension
2	Cross	FSTD surge acceleration response due to airplane pitch input.	[m/°]
3	Direct	FSTD roll response to airplane roll input.	No dimension
4	Cross	FSTD sway specific force response due to airplane roll input.	[m/°]
5	Direct	FSTD yaw response to airplane yaw input.	No dimension
6	Direct	FSTD surge response to airplane surge input.	No dimension
7	Cross	FSTD pitch response to airplane surge input.	[° s^2/m]
8	Direct	FSTD sway response to airplane sway input	No dimension
9	Cross	FSTD roll response to airplane sway input.	[° s^2/m]
10	Direct	FSTD heave response to airplane heave input.	No dimension

Input amplitudes are selected to mimic those experienced during normal, manual aircraft maneuvering. They must be large enough to produce an adequate Signal to Noise Ratio (SNR) at the measurement point, but not aggressive enough to overly excite non-linear elements of the motion cueing system. To meet these objectives, sinusoidal input signals of known amplitudes and frequencies are provided in the tables that follow. These test signals stimulate the motion cueing system much like the aircraft model output would during manually controlled flight. The test signal represents the aircraft state variables: $\left(\varphi_{a/c}, \theta_{a/c}, \text{ and } \psi_{a/c}, f^{x}{}_{a/c}, f^{y}{}_{a/c}, \text{ and } f^{z}{}_{a/c} \right)$.

The actual variables used should correspond to those normally applied in the particular motion cueing system. In other words, if the TDM uses the angular rates instead of attitudes, the corresponding input signals should be generated:

a. <u>Specific force input amplitudes</u>. In the specific force channels, the input signal is defined by the following equation, using the amplitudes *A* are given in Table 2: $f_{a/c}^{x,y,z}(t) = A \sin(\omega t)$.
b. <u>Rotational input amplitudes</u>. For the rotational inputs, the relations between attitude, angular rate and angular acceleration are given in Table 3, and the corresponding amplitudes in Table 4. These equations are only valid for ω in rad/s. The tests may be carried out with attitude, angular rate or angular acceleration inputs, as long as the inputs are consistent with the MDA implemented in the FSTD.

Table 2.
Specific Force Input Amplitudes

Frequency Signal Number	Frequency [rad/s]	Frequency [Hz]	Amplitude A [m/s^2]
1	0.100	0.0159 Hz	1.00
2	0.158	0.0251 Hz	1.00
3	0.251	0.0399 Hz	1.00
4	0.398	0.0633 Hz	1.00
5	0.631	0.1004 Hz	1.00
6	1.000	0.1591 Hz	1.00
7	1.585	0.251 Hz	1.00
8	2.512	0. 399 Hz	1.00
9	3.981	0.633 Hz	1.00
10	6.310	1.004 Hz	1.00
11	10.000	1.591 Hz	1.00
12	15.849	2.515 Hz	1.00

Table 3.
Rotational Input Amplitudes

	Airplane pitch	Airplane roll	Airplane yaw
Attitude	$\theta_{a/c}(t) = A\sin(\omega t)$	$\varphi_{a/c}(t) = A\sin(\omega t)$	$\psi_{a/c}(t) = A\sin(\omega t)$
Angular rate	$q_{a/c}(t) = A\omega\cos(\omega t)$	$p_{a/c}(t) = A\omega\cos(\omega t)$	$r_{a/c}(t) = A\omega\cos(\omega t)$
Angular acceleration	$\dot{q}_{a/c}(t) = -A\omega^2\sin(\omega t)$	$\dot{p}_{a/c}(t) = -A\omega^2\sin(\omega t)$	$\dot{r}_{a/c}(t) = -A\omega^2\sin(\omega t)$

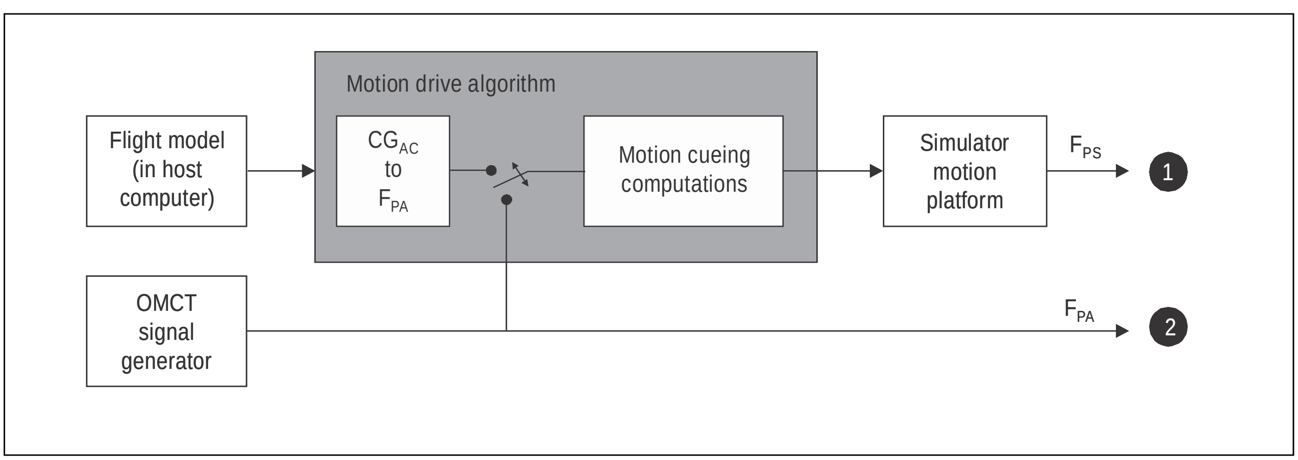
Table 4
Rotational Input Amplitudes Given by Attitude, Angular Rate or Acceleration

Frequency Signal Number	Frequency [rad/s]	Frequency [Hz]	Attitude Amplitude A [°]	Angular Rate Amplitude A ω [°/s]	Angular Acceleration Amplitude A ω^2 [°/s^2]
1	0.100	0.0159	6.000	0.600	0.060
2	0.158	0.0251	6.000	0.948	0.150
3	0.251	0.0399	3.984	1.000	0.251
4	0.398	0.0633	2.513	1.000	0.398
5	0.631	0.1004	1.585	1.000	0.631
6	1.000	0.1591	1.000	1.000	1.000
7	1.585	0.251	0.631	1.000	1.585
8	2.512	0.399	0.398	1.000	2.512
9	3.981	0.633	0.251	1.000	3.981
10	6.310	1.004	0.158	1.000	6.310
11	10.000	1.591	0.100	1.000	10.000
12	15.849	2.515	0.040	0.631	10.000

Test Signal Input

The test signals should be injected at a point after the flight model output is transformed to the pilot reference position just before the motion cueing computations, and measured at the response of the FSTD platform (see Figure 1). Measurements at the twelve specified frequencies should be taken for each test input.

Figure 1



Frequency Range

In theory, the tested range of frequencies should be representative of the manual control range for the aircraft being simulated and the FSTD as set up during qualification. For practicality and standardization, twelve pre-defined frequencies from 0.100 rad/s to 15.849 rad/s have been suggested for testing as shown in Tables 2, 4, and 5. It is possible, however, that the exact number of frequencies needed for a specific application may differ.

Table 5.
Input Test Signal Frequencies and Required Modulus and Phase Measurements

Input Signal Number	Frequency [rad/s]	Frequency [Hz]	Gain (F_{PS})/(F_{PA}) [non-dimensional]	Phase ϕ [°]
1	0.100	0.0159 Hz		
2	0.158	0.0251 Hz		
3	0.251	0.0399 Hz		
4	0.398	0.0633 Hz		
5	0.631	0.1004 Hz		
6	1.000	0.1591 Hz		
7	1.585	0.251 Hz		
8	2.512	0.399 Hz		
9	3.981	0.633 Hz		
10	6.310	1.004 Hz		
11	10.000	1.591 Hz		
12	15.849	2.515 Hz		

Sum of Sines

In lieu of repeating each of the required test conditions twelve times for each of the above frequencies, the possibility exists to utilize a sum of sines methodology. Proper implementation must be exercised, however. Using this method, a total test time of 200-300 seconds has been estimated for each of the required cases in Table 1.

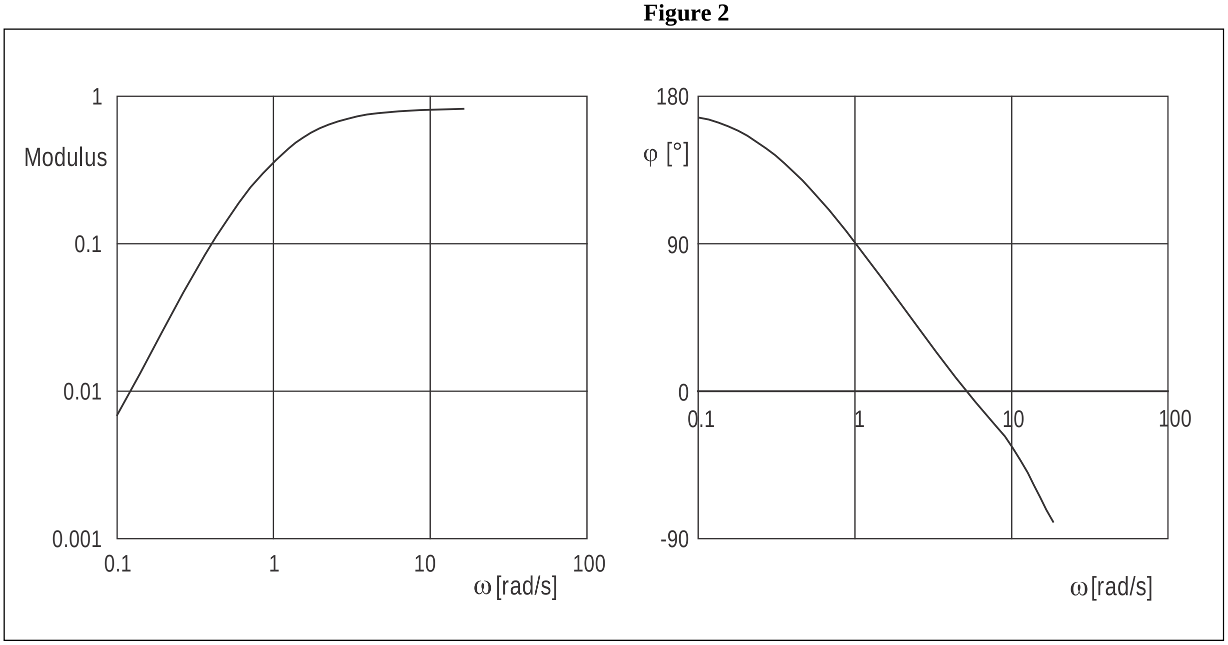
Data Recording and Test Presentation

The measured parameters should include the gain and phase as a function of frequency for each test condition shown in Table 1. The gain indicates the amplitude ratio of the output signal divided by the input signal, F_{PS}/F_{PA}. For the direct transfer relation cases (1, 3, 5, 6, 8, and 10), it is expressed in non-dimensional terms and in dimensional terms for the cross-coupling relation cases (2, 4, 7, and 9). The phase describes the delay between the output signal and the input signal, and is expressed in degrees.

Note that by measuring two output signals simultaneously for each of the aircraft input signals of Table 1, all of the required data for the ten test conditions can be collected in six independent tests.

A total of ten test results must be presented for the corresponding test conditions in Table 1 including gain and phase over the entire range of frequencies specified in Table 5. Bode plots are the required format with the gain and the phase along the vertical axis and the frequency in rad/s along the horizontal axis. The gain and phase should be presented as a function of frequency in rad/s. The gain should be presented in a log-log plot and the phase in a semi-log plot. An example of one test result is shown in Figure 2. In addition to the graphical output, tabular output may also be presented, but is not required by part 60 at this time. If provided, ten tables should be presented with a format similar to that of Table 5.

Figure 2



Test Result Interpretation

The revised part 60 does not currently assign a specific tolerance other than that chosen by the TDM for initial qualification. It is appropriate, however, to discuss how the test results are interpreted. As OMCT results show the additional gain and phase introduced by the FSTD motion cueing system, the criterion on which the OMCT is based stipulates that it is important to achieve a gain close to 1 and a relatively low phase for tests 1, 3, 5, 6, 7, 8, 9 and 10. Tests 2 and 4 demonstrate undesired motions and should have relatively low gain. Note that when the gain is low, phase errors are correspondingly less significant.

ICAO 9625, Edition 4, has defined areas of acceptable fidelity and low fidelity across the frequency spectrum for each of the ten test conditions. To do so, the working group developing the tests chose an approach based on the results of OMCT measurements from eight Type VII (level D) FSTDs. Through statistical means, the boundaries for acceptable fidelity were defined for each test. The ICAO 9625 document provides the acceptable limits for gain and phase in tabular form for all ten test conditions throughout the required frequency range (see Attachment F of ICAO 9625, Edition 4). Figures 3-A and 3-B are graphical examples depicting the fidelity areas for one of the ten tests (Test 3). Note that presentation with the ICAO boundary lines is not required for FAA initial qualification under the revised part 60. Boundary lines, as determined by TDM specified tolerances, are encouraged for FAA initial FSTD qualification.

Figure 3-A

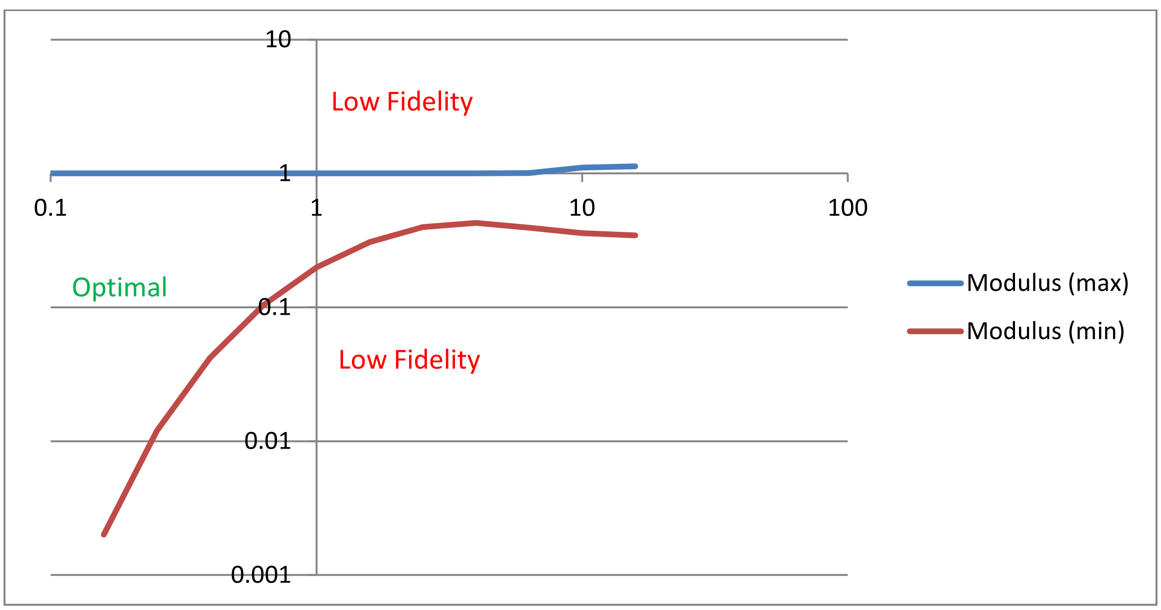
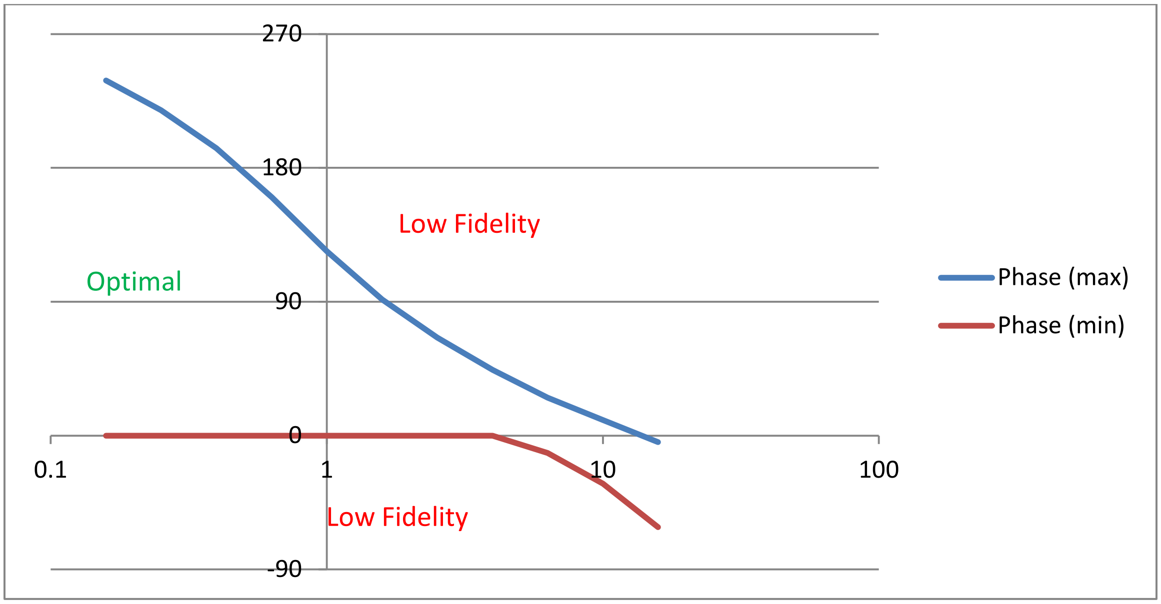


Figure 3-B



Contact: Questions or comments regarding this GB can be directed to the National Simulator Program, AFS-205, at (404) 474-5620.

Attachment 1

Nomenclature and References

Notation	Description	Unit
θ	Pitch Angle	[°]
φ	Roll Angle	[°]
ψ	Yaw Angle	[°]
ω	Frequency	[rad/s]
Φ	Phase Angle	[°]
A	Amplitude	
M	Modulus (or Gain)	
a	Linear Acceleration	[m/s^2]
f	Specific Force	[m/s^2]
g	Gravity	[m/s^2]
i	Input Signal	
p	Roll Rate	[°/s]
q	Pitch Rate	[°/s]
r	Yaw Rate	[°/s]
u	Output Signal (or response)	
t	Time	[s]
Δt	Measured Phase Delay	[s]

Subscript Index	Description
A	Aircraft
a/c	Aircraft
S	Simulator or FSTD
PA	Aircraft Pilot
PS	FSTD Pilot

Superscript Index	Description
X	Along the X axis
Y	Along the Y axis
Z	Along the Z axis

Frames of Reference

In order to ensure that the results are consistent between FSTDs, the following frames of reference are defined.

Frame F_D
Reference frame F_D is located with its origin at the centre of the motion measurement system that may be used in these tests. The x-axis points forward, and the z-axis points downward. The x-y plane is parallel to the upper FSTD frame which will be assumed to be parallel to the floor of the cockpit. Note that F_D is not explicitly shown in Figure 4.

Frame F_I
The inertial reference frame F_I is fixed to the ground with the z-direction aligned with the gravity vector g. This frame is often used in the MDA.

Frame F_S
The FSTD reference frame F_S has its origin at a reference point selected to suit the manufacturer's MDA. It is attached to the FSTD cab and is parallel to frame F_D. Its origin may be coincident with F_D.

Frame F_A
The airplane reference frame F_A has its origin at the airplane centre of gravity. Frame F_A has the same orientation with respect to the flight deck as the FSTD frame F_S.

Frame F_{PS}
This is a reference frame attached to the FSTD in the plane of symmetry of the cab, at a height approximately 35 cm below eye height. The x-axis points forward, and the z-axis points downward. F_{PS} is parallel to F_D.

Frame F_{PA}
This is the same as F_{PS}, but for the airplane pilots.

Figure 4.

Aircraft and FSTD frames of reference relevant to MDAs.