FSTD Guidance Bulletin 14-02

Helicopter FSTD Vibration and Buffet QTG Evaluation

Purpose:

This bulletin provides guidance for both sponsors and NSP evaluators in understanding how to demonstrate and evaluate that the objective tests in Part 60 are satisfied.

Scope:

This bulletin only applies to Level D Helicopter Flight Simulation Training Devices (FSTDs) that have objective testing requirements for motion vibrations and buffets.

This Guidance Bulletin provides an acceptable means, but not the only means of compliance with Title 14 Code of Federal Regulations (CFR) Part 60 pertaining to the Evaluation and Qualification of Flight Simulation Training Devices (FSTD) for use in FAA Approved Flight Training Programs. If an applicant chooses to use the approach described within this Guidance Bulletin, that applicant must adhere to all methods, procedures, and standards herein. Should an applicant desire to use another means, a proposal must be submitted to the National Simulator Program Manager (NSPM) for review and approval prior to implementation. This Guidance Bulletin does not change regulatory requirements or create additional ones, and does not authorize changes in, or deviations from, regulatory requirements.

Approval: Harlan G. Sparrow III
National Simulator Program Manager

REVISION HISTORY		
Rev	**Description of Change**	**Effective Date**
0	Original	04/25/2014

1. Background

1.1. Reason for This Guidance Bulletin

There has been an increase lately in the number of Level D Helicopter Full Flight Simulators (FFSs) seeking qualification under CFR 14 Part 60. During these evaluations, the NSP concluded that the objective test requirements dealing with Vibration and Buffets lack clarity. This Bulletin attempts to better define the intent of the objective tests, and provide examples to satisfy the objective test requirements.

1.2. Vibrations versus Buffets

1.2.1. **<u>Vibrations</u>** are more of a steady state motion resulting from the interaction of the airframe with the rotating components, specifically: main rotor, tail rotor, engines, and transmission. I.e. these are generally periodic dynamics, occurring at defined frequencies.

1.2.2. **<u>Buffets</u>** are more transient or special effects motion resulting from either pilot action or aerodynamic / environmental effects on the airframe. Examples might include passing through translational lift, extension or retraction of landing gear, retreating blade stall, turbulence, etc. I.e. these are random in frequency (aperiodic), caused by unsteady aerodynamics.

1.3. Vibration caused by Rotors

While vibrations can be caused by the engine(s) and transmission, the most noticeable vibrations are usually caused by the rotation of the rotor blades. This is the reason why the objective vibration tests in the QTG make mention of "1/Rev and N/Rev" frequencies, where 'N' represents the number of main rotor blades. The analysis may show noticeable vibration amplitude at each blade multiple for k = 1 … N (e.g. for a 4-blade rotor, you may notice vibration amplitudes at 1/Rev, 2/Rev, 3/Rev, and 4/Rev). While the "in between" frequency vibrations are not strictly required to meet tolerances, it is desired that some attempt be made to include the correct vibration effects at these frequencies, particularly if they are of a magnitude approaching or perhaps even greater than that of the 1/Rev or N/Rev (engineering judgment and subject matter expert pilot opinion may be considered here). Additionally, there may be other significant vibratory modes. It should be noted that the Part 60, Table C2A entry "3f—Characteristic Motion (Vibration) Cues" which introduces the tests for Vibration (3.f.1) and Buffet (3.f.2) does indicate that "…the test results must exhibit the overall appearance and trends of the helicopter data, with at least three (3) of the predominant frequency 'spikes' being present within +/-2 Hz". It would be expected that the predominant frequency spikes required to be within tolerance would include these significant blade frequency spikes, unless there is some other significant spike which is more characteristic of the particular helicopter being simulated.

Vibration plots (particularly Power Spectral Density plots) may be shown in frequency units of Hertz (Hz) along the horizontal axis. It can easily be shown that given the Rotor RPM of an n-bladed rotor, one would expect to find the rotor-caused vibration peaks at:

(1, 2, …, N)/rev x Rotor_RPM x (1 min/60 secs)   (Hz)

Example:

Given: Rotor Speed == 300 rpm

Number of Blades, N == 4

Then we expect to see vibration amplitude peaks at,

(1, 2, 3, 4)/rev x 300 rev/min x (1 min/60 sec) or

5, 10, 15, and 20 Hz

Each presented QTG test should identify the characteristic blade-multiple frequencies at the observed rotor speed for that test.

2. Tolerances

In the past, there has been some confusion on what the vibration and buffet tolerances specified in Part 60 mean and how to evaluate them.

2.1. Tolerance Questions

The tolerances specified for both Vibrations and Buffets are: "+3 dB to -6 dB[1] or +/- 10% of nominal vibration level in flight cruise and correct trend". These look straightforward enough, but looking further raises questions such as:

[1] For power quantities, such as PSD, dB is defined as $10*\log_{10}(a_1/a_0)$

- What exactly is meant by "nominal vibration level"?
- Why mention "nominal vibration level" in the test requirement dealing with buffets?
- How does a logarithmic tolerance (+3 / -6 dB) compare to a linear tolerance (+/-10%)?
- What are we to make of the qualifier, "in flight cruise"? (Note: ICAO 9625 Ed 3 Vol II Draft does NOT limit tolerance to "in flight cruise" cases.)
- Does the "correct trend" requirement apply to all tests or some of the tests?

While there may be some repetition or overlap, let us look at these tolerances for the Vibration and Buffet cases separately.

2.2. Vibrations

As mentioned earlier, vibration is intended to address those motions caused by rotating machinery, particularly the main rotor, and their interactions with the airframe. These are more steady state or long term.

2.3. Buffets

As mentioned earlier, buffet is intended to address those motions caused by pilot action (e.g., lowering/raising landing gear) or aerodynamic/environmental effects on the airframe. These are usually more temporary or transient.

2.4. Tolerances: dB or %?

This will be explained further down in this Bulletin, but the expectation is that tolerance in decibels (dB) will be applied to Power Spectral Density analyses, and percent (%) tolerances will apply to the overall (nominal) vibration levels measured in Gs.

In trying to research where the tolerance values, in dB and %, came from the best explanation is that it may have come from MIL-STD-810G, METHOD 514.6 – VIBRATION, which mentions +/-10 % and also +/-3 dB.

2.5. In Flight Cruise

The phrase "in flight cruise", with respect to the application of tolerances to vibrations and buffets, appears common to JAR STD-1H, Part 60, and CS-FSTD(H), but that phrase is NOT included in ICAO Doc. 9625 Vol II. As 10% is a relative tolerance, perhaps what is intended is to compute what +/-10% of the nominal cruise vibration is, and apply that to the other flight regimes. The fact that 9625 has specifically listed the same tolerances for each test, would indicate that the intention was NOT to limit the tolerance to only a level cruise condition.

2.6. Correct Trend

The requirement for correct trend is discussed in more detail in **Section 3.4 -The Overall G_RMS Value**. This has to do with the need to present the simulator pilot with a representative change in vibration level for each phase of flight, similar to what can be expected in the actual helicopter. In other words, if the actual helicopter experiences an increase in vibration level transitioning from one mode to another, the simulator should provide the same (or close to it) change in vibration level.

3. Process

3.1. Raw Data

Raw acceleration data is gathered at a high sampling rate. The acceleration can be in units of feet/sec^2, meters/sec^2, etc., but is commonly non-dimensionalized into units of G. It is plotted in the time domain. Sample size will vary, but should be sufficient to ensure enough frequency content is included. See Figure 1 for an example of this data.

It is possible to compute an overall level of vibration acceleration in units of G_rms. G_rms is the “square root of the area under the PSD vs. frequency curve”. Or, if starting from a time domain of an accelerometer trace (see Figure 1) instead of a frequency domain, you could square each acceleration value and find the resulting mean, take its square root, and arrive at the same value.

- Time History (VibesZ_G)

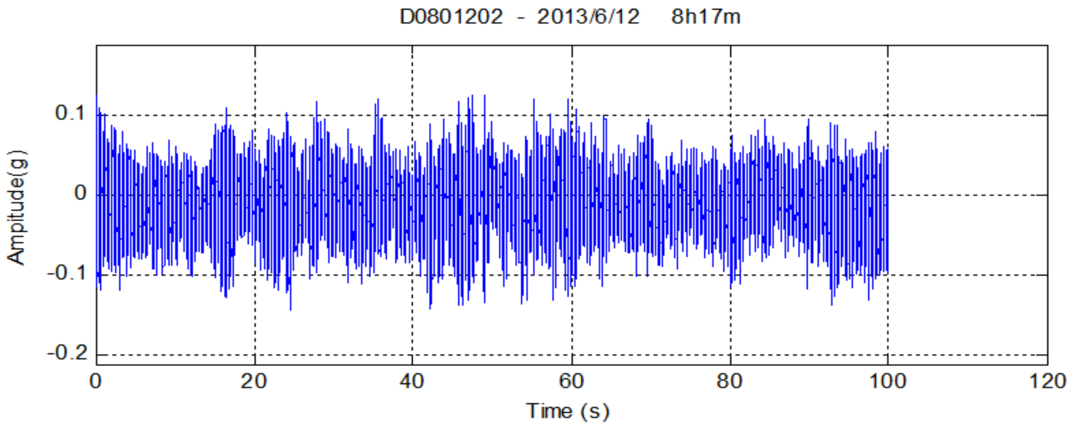

Figure 1

3.2. Frequency Analysis

The next step will be to analyze the time domain acceleration data for frequency content, using the method of Fast Fourier Transform (FFT). The FFT identifies the component frequency of the acceleration time history. (see Figure 2)

--FFT plot

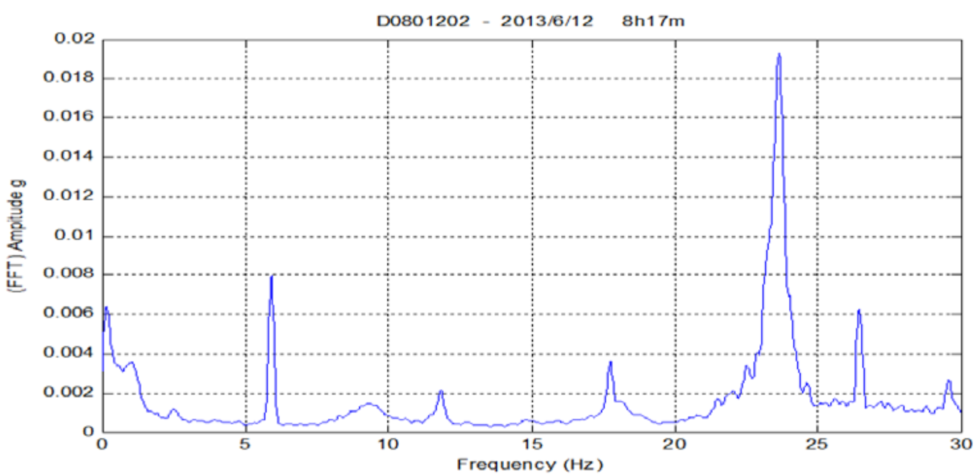

Figure 2

3.3. Power Spectral Density (PSD)

Power Spectral Density will be shown usually in units of G_rms^2/Hz along the vertical axis and Hz along the horizontal axis. (see Figure 3). PSD can also be displayed in units of decibels (see Figure 4 – note: this is not from the same data as used in the earlier figures).

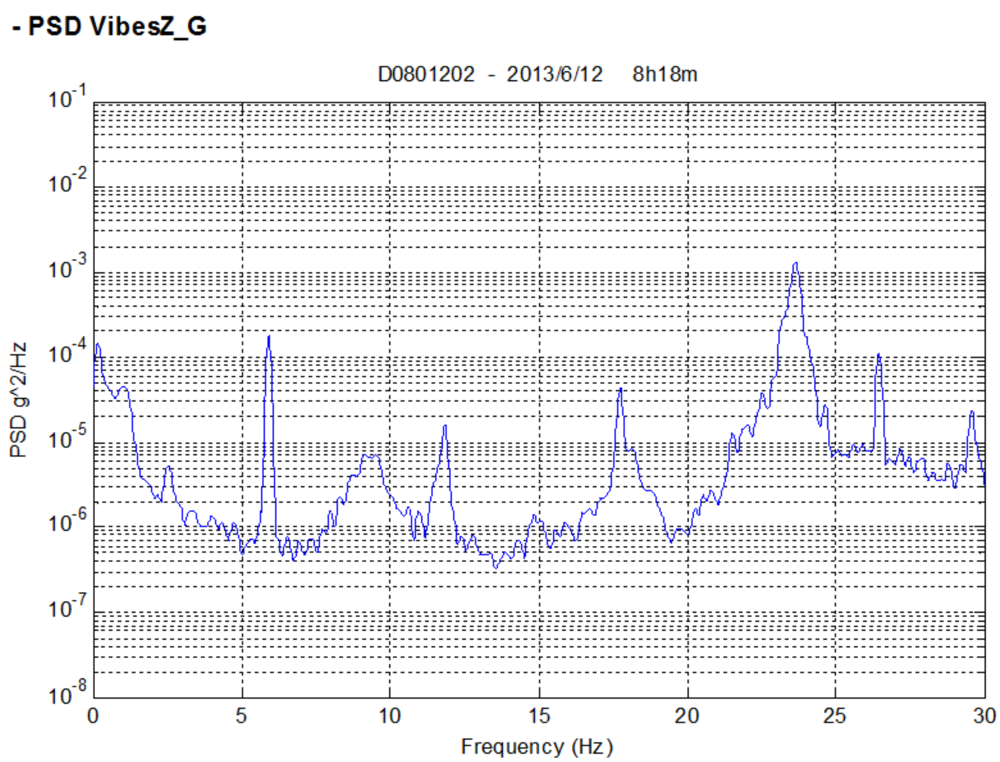

Figure 3

PSD in units of dB

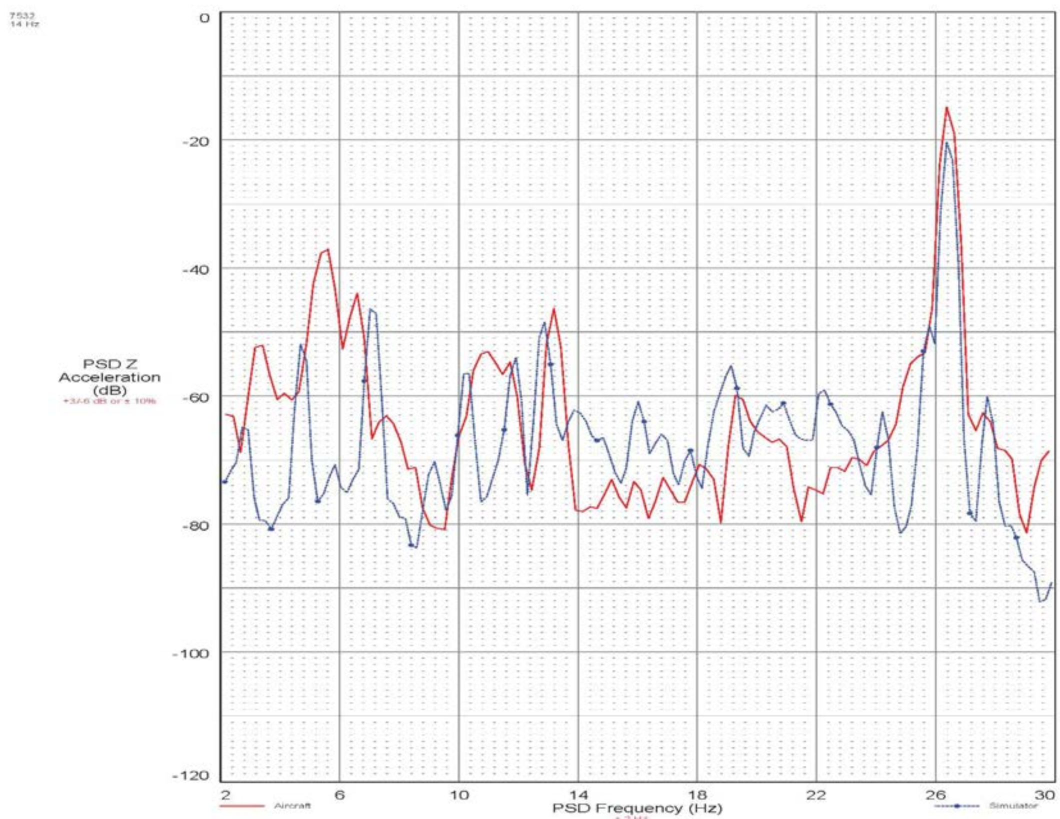

Figure 4

3.4. The Overall G_RMS Value

The overall G_rms value is obtained by integrating the area under the PSD curve and taking the square root of the area.

It should be noted that it is important to be aware of the frequency range being integrated, because the results will be different for different frequency ranges.

The G_rms values for a particular vibration component may be obtained by integrating just over the 1/Rev frequency band, or the N/Rev frequency band, individually (the width of these integrated frequency bands are subjective and left to the discretion of the analyst, but must be the same for both the flight test data and the flight simulator data).

The comparison overlays for 1/Rev and N/Rev should be presented for each flight condition, for longitudinal, lateral, and vertical axes. These should be presented in a way which demonstrates the required correct trend. An example is shown in Figure 5 (shown only as an example of the rank ordering – data is not meant to be representative). Note that the values have been rank ordered so that the correct trend can be more readily observed. The 10% tolerance on vibration should be applied to these values.

There may be flight conditions which the simulator's vibration platform is unable to produce a high enough value of peak G vibration. The maximum capability of the vibration platform (in each axis) should be identified. Regardless of whether the simulator can produce the same level of vibration (magnitude), the correct trend should still be evident.

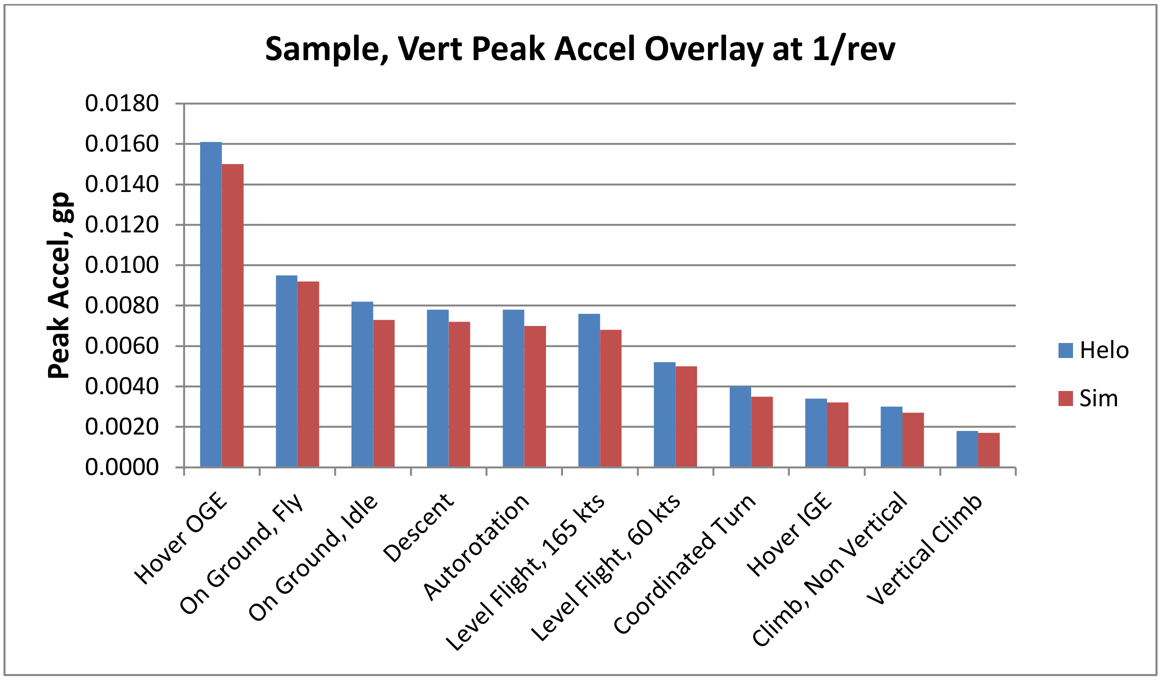
Sample, Vert Peak Accel Overlay at 1/rev
Peak Accel, gp
0.0180
0.0160
0.0140
0.0120
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
Hover OGE
On Ground, Fly
On Ground, Idle
Descent
Autorotation
Level Flight, 165 kts
Level Flight, 60 kts
Coordinated Turn
Hover IGE
Climb, Non Vertical
Vertical Climb
Helo
Sim

Figure 5

Attachments:

JAR STD 1-H

Part 60 Change 1 Appendix C

EASA CD-FSTD(H)

ICAO Document 9625 Manual of Criteria for the Qualification of Flight Simulation Training Devices. Volume II - Helicopters (Type III, IV, V)

References

MIL-STD-810G, METHOD 514.6 – VIBRATION

JAR-STD 1H:

TESTS	TOLERANCE	FLIGHT CONDITIONS	COMMENTS
e. Characteristic vibrations/buffets (1) Vibrations Tests to include 1/Rev and n/Rev vibrations where n is the number of main rotor blades.	+3/-6db or ±10% of nominal vibration level in flight cruise and correct trend (see comment).	On ground (idle, flight Nr); Low and high speed transition to and from hover; Level flight; Climb/Descent (including vertical climb); Autorotation; Steady turns;	Correct trend refers to a comparison of vibration amplitudes between different maneouvers. Example: If the 1/Rev vibration amplitude in the helicopter is higher during steady state turns than in level flight, this increasing trend shall be demonstrated in the simulator.
(2) Buffet A test with recorded results is required for characteristic buffet motion which can be sensed in the cockpit.	+3/-6db or ±10% of nominal vibration level in flight cruise and correct trend (see comment).	On ground and in flight.	The recorded test results for characteristic buffets should allow the checking of relative amplitude for different frequencies. For atmospheric disturbance general purpose models are acceptable which approximate demonstrable flight test data.

PART 60 Appendix C Table C2A:

3.f Characteristic Motion (Vibration) Cues --- For all of the following tests, the simulator test results must exhibit the overall appearance and trends of the helicopter data, with at least three (3) of the predominant frequency "spikes" being present within ±2 Hz.				Characteristic motion cues may be separate from the "main" motion system.
Test	**Tolerance(s)**	**Flight Condition**	**Test Details**	**Notes**
3.f.1 Vibrations—to include 1/Rev and n/Rev vibrations (where "n" is the number of main rotor blades).	+3db to -6db or ±10% of nominal vibration level in flight cruise and correct trend (see comment).	(a) On ground (idle); (b) In flight	Characteristic vibrations include those that result from operation of the helicopter (for example, high airspeed, retreating blade stall, extended landing gear, vortex rig or settling with power) in so far as vibration marks an event or helicopter state, which can be sensed in the flight deck. [See Table C1A, table entries 5.e and 5.f]	Correct trend refers to a comparison of vibration amplitudes between different maneuvers; e.g., if the 1/rev vibration amplitude in the helicopter is higher during steady state turns than in level flight, this increasing trend should be demonstrated in the simulator. Additional examples of vibrations may include: (a) Low & High speed transition to and from hover; (b) Level flight; (c) Climb and descent (including vertical climb); (d) Auto-rotation (e) Steady Turns.
3.f.2 Buffet—Test against	+3db to -6db or ±10% of nominal	On ground and in flight.	Characteristic buffets include	The recorded test results for

recorded results for characteristic buffet motion that can be sensed in the flight deck.	vibration level in flight cruise and correct trend (see comment)		those that result from operation of the helicopter (for example, high airspeed, retreating blade stall, extended landing gear, vortex ring or settling with power) in so far as a buffet marks an event or helicopter state, which can be sensed in the flight deck. [See Table C1A, table entries 5.e and 5.f.]	characteristic buffets should allow the checking of relative amplitude for different frequencies. For atmospheric disturbance, general purpose models are acceptable which approximate demonstrable flight test data.

Information:

e. Motion Vibrations.
(1) Presentation of results. The characteristic motion vibrations may be used to verify that the flight simulator can reproduce the frequency content of the helicopter when flown in specific conditions. The test results should be presented as a Power Spectral Density (PSD) plot with frequencies on the horizontal axis and amplitude on the vertical axis. The helicopter data and flight simulator data should be presented in the same format with the same scaling. The algorithms used for generating the flight simulator data should be the same as those used for the helicopter data. If they are not the same then the algorithms used for the flight simulator data should be proven to be sufficiently comparable. As a minimum the results along the dominant axes should be presented and a rationale for not presenting the other axes should be provided.

(2) Interpretation of results. The overall trend of the PSD plot should be considered while focusing on the dominant frequencies. Less emphasis should be placed on the differences at the high frequency and low amplitude portions of the PSD plot. During the analysis, certain structural components of the flight simulator have resonant frequencies that are filtered and may not appear in the PSD plot. If filtering is required, the notch filter bandwidth should be limited to 1 Hz to ensure that the buffet feel is not adversely affected. In addition, a rationale should be provided to explain that the characteristic motion vibration is not being adversely affected by the filtering. The amplitude should match helicopter data as described below. However, if the PSD plot was altered for subjective reasons, a rationale should be provided to justify the change. If the plot is on a logarithmic scale it may be difficult to interpret the amplitude of the buffet in terms of acceleration. For example, a 1×10^{-3} g-rms2/Hz would describe a heavy buffet and may be seen in the deep stall regime. Alternatively, a 1×10^{-6} g-rms2/Hz buffet is almost imperceptible, but may represent a flap buffet at low speed. The previous two examples differ in magnitude by 1000. On a PSD plot this represents three decades (one decade is a change in order of magnitude of 10, and two decades is a change in order of magnitude of 100).

NOTE: In the example, ‘‘g-rms2’’ is the mathematical expression for ‘‘g’s root mean squared.’’

EASA CS-FSTD(H) (for FFS, Level D):

TESTS	TOLERANCE	FLIGHT CONDITIONS	COMMENTS
e. Characteristic vibrations/buffet (1) Vibrations – tests to include 1/rev and n/rev vibrations where n is the number of rotor blades.	+ 3 / - 6 db or ± 10% of nominal vibration level in flight cruise & correct trend (see comment)	On ground (idle flt nr); Low & high speed; Level flight; Climb/descent (including vertical climb; Autorotation; Steady turns)	Refer to book 1, Appendix 1 to CS-FSTD(H).300 paragraph 1.2.e.1. Correct trend refers to a comparison of vibration amplitudes between different manoeuvres. E.g. If the 1/rev vibration amplitude in the helicopter is higher during steady state turns than in level flight this increasing trend should be demonstrated in the FFS.
(2) Buffet A test with recorded results is required for characteristic buffet motion which can be sensed in the cockpit.	+ 3 / - 6 db or ± 10% of nominal vibration level in flight cruise & correct trend (see comment)	On ground and in flight	Refer to section 1, Appendix 1 to CS-FSTD(H).300 paragraph 1.2.e.1. The recorded test results for characteristic buffets should allow the checking of relative amplitude for different frequencies. For atmospheric disturbance, general purpose models are acceptable which approximate demonstrable flight test data.

ICAO Document 9625 – Manual of Criteria for the Qualification of Flight Simulation Training Devices. Volume II - Helicopters (Type III, IV, V):

TEST	TOLERANCE	FLIGHT CONDITION	COMMENTS
VIBRATIONS			
Characteristic motion vibrations. The following tests with recorded results and an SOC are required for characteristic motion vibrations, which can be sensed at the cockpit where applicable by helicopter type. Vibrations Tests Results to include1/Rev and n/Rev vibrations where n is the number of rotor blades	None.	Ground and flight.	The recorded test results for characteristic buffets should allow the comparison of relative amplitude versus frequency. Statement of Compliance required. Tests required with recorded results which allow the comparison of relative amplitudes versus frequency in the longitudinal, lateral and vertical axes with helicopter data. Steady state tests are acceptable. For type III devices, only footprint test results are required. Where initial evaluation employs approved subjective tuning to develop the approved reference standard, tolerances should be used during recurrent evaluations
(1) On Ground	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	On Ground	Test to demonstrate the normal vibration level with helicopter on ground, all engines operating at normal idle and Flight NR
(2) Hover (IGE)	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	Hover	Test to demonstrate the normal vibration level with helicopter in hover condition IGE
(3) Hover (OGE)	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	Hover	Test to demonstrate the normal vibration level with helicopter in hover condition OGE.
(4) Normal Climb	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	Climb	Test to demonstrate the normal calibration level with helicopter in normal climb at normal climb speed, all engine operative
(5) Vertical Climb	+3 / -6db or ± 10% of	Climb	Test to demonstrate the normal

	nominal vibration level and correct trend (see general comment for 3bis.a test section)		vibration level with helicopter in vertical climb from a hover condition
(6) Level Flight Low speed	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	Cruise	Test to demonstrate the normal vibration level with helicopter in forward translational level flight around Vy
(7) Level Flight Cruise speed	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	Cruise	Test to demonstrate the normal vibration level with helicopter in flight at normal cruise speed.
(8) Level Flight High speed	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	Cruise	Test to demonstrate the normal vibration level with helicopter in flight at high speed (near or at VNE)
(9) Descent	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	Descent	Test to demonstrate the normal vibration level with helicopter in normal powered descent at normal speed, all engine operative
(10) Autorotation	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	Autorotation	Test to demonstrate the normal vibration level with helicopter in autorotation descent, all engines inoperative (or at least at idle), nominal main rotor RPM and recommended autorotation speed
(11) Steady State Turns	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	Cruise	Test to demonstrate the normal vibration level with helicopter in stabilized turn at various bank angles, at least 2 conditions are to be demonstrated (for instance for a standard turn rate and a higher bank angle around 45 ° in order to demonstrate effect of rotor disk load on vibration level if any)
Special Conditions.	+3 / -6db or ± 10% of nominal vibration level and correct trend (see general comment for 3bis.a test section)	On ground and in flight	This applies to special steady-state cases identified as particularly significant to the pilot, important in training, or unique to a specific helicopter type or model. This may include effect of landing gear, icing effect, vortex ring state, atmospheric disturbance and all relevant vibration cues due to normal and abnormal operations of the rotor and transmission system.

			The recorded test results for characteristic buffets should allow the comparison of relative amplitude versus frequency. Statement of Compliance required. Tests required with recorded results which allow the comparison of relative amplitudes versus frequency in the longitudinal, lateral and vertical axes with helicopter data. Steady state tests are acceptable. Where initial evaluation employs approved subjective tuning to develop the approved reference standard, tolerances should be used during recurrent evaluations. For atmospheric disturbance, general purpose models are acceptable which approximate demonstrable flight test data