EASA European Union Aviation Safety Agency Information Paper	**FSTD Special Conditions for the use of Head Mounted Displays (HMD) combined with a motion platform with reduced envelope**
16 March 2023	

Type of FSTD:	FNPT II, FTD 3 - with type specific cockpits - with a motion platform with reduced envelope
Primary Reference Document applied as Qualification Basis:	CS-FSTD(H) Initial Issue and Special Conditions
New technology:	HMD to use Virtual Reality (VR)
Represented Aircraft:	Robinson R22 Beta II (FNPT II) Airbus Helicopters H125 (FTD 3)

List of Abbreviations

AMC	Applicable means of compliance
CIE	International Commission on Illumination
CS-FSTD(H)	Certification Specifications for Helicopter Flight Simulation Training Devices
DoF	Degrees of Freedom
EASA	European Union Aviation Safety Agency
FFS	Full flight simulator
FNPT	Flight and navigation procedures trainer
FOR	Field of regard
FOV	Field of view
FSTD	Flight simulation training device
FTD	Flight training device
HMD	Head mounted display
IOS	Instructor operator station
IPD	Interpupillary distance
ISO	International Organization for Standardization
N/A	Not Applicable
OLED	Organic light-emitting diode
QTG	Qualification test guide
UCS	Uniform color space
VR	Virtual reality

References

Title	Reference	Issue	Date
Certification Specifications for Helicopter Flight Simulation Training Devices	CS-FSTD(H)	Initial Issue	26.6.2012

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1 Cockpit Replica using Virtual Reality

1.1 Background

FSTDs typically consist of a physical cockpit and a projector or monitor based visual system. With a Head Mounted Display (HMD) and Virtual Reality (VR) technology pilots are immersed into a virtual environment where they can interact with the physical cockpit through visualisation of the tracked pilot body pose.

Using Virtual and Mixed Reality systems there is a visual interface between the pilot and the physical setup if present. The visual system is therefore used as a complementary element in accordance with the physical setup.

These special conditions describe the additional requirements (compared to CS-FSTD(H) Initial Issue) for a VR technology-based cockpit to comply with

- Appendix 1 to CS FSTD(H).300 Flight Simulation Training Device Standards
  - **1.1.a.1** A cockpit that is a full-scale replica of the helicopter simulated. Additional required crew member duty stations and those required bulkheads aft of the pilot seats are also considered part of the cockpit and shall replicate the helicopter.
  - **1.1.b.1** Full size panels with functional controls, switches, instruments and primary and secondary flight controls, which shall be operating in the correct direction and with the correct range of movement.
  - **1.1.d.1** Relevant cockpit circuit breakers shall be located as per the helicopter and shall function accurately when involved in operating procedures or malfunctions requiring or involving flight crew response.
  - **1.1.c.1** Lighting for panels and instruments shall be as per the helicopter.
- Appendix 9 to AMC1 FSTD(H).300 General technical requirements for FSTD qualification levels
- AMC3 FSTD(H).300 Guidance on design and qualification of helicopter flight training devices (FTDs)
- AMC5 FSTD(H).300 Guidance on design and qualification of helicopter flight and navigation procedures trainers (FNPTs)

1.2 Applicability

(1) The process applies to FTDs and FNPTs designed using VR technology to comply with full scale cockpit replica requirements (1.1.a.1, 1.1.b.1) independent of the type of rotorcraft.

(2) Alternate integration of circuit breakers (1.1.d.1) if adequate for the intended use.
(3) The process does not describe detailed requirements for the display system which has separate special conditions. These have been described in subpart 2 Display System.

1.3 Statements of Compliance

Statements of compliance should address each of the following items:

(1) The relevant components of the cockpit representation should be described. The statement of compliance should contain a schematic representation (e.g. block diagram) and illustrate how the systems are interconnected. All components requiring calibration and alignment should be described.
(2) Alternate means to operate cockpit elements (such as gesture control) should be described. The statement of compliance should confirm the applicability of the methods to the training task and state how negative training is avoided.
(3) If a motion system is fitted, the statement of compliance is required to demonstrate and confirm that the motion system is not interfering the HMD environment (tracking systems etc.).
(4) The statement of compliance should confirm that there is no negative training impact with the proposed cockpit integration. A set of signature manoeuvres (representative manoeuvres covering all kinds of operation) should be presented.
(5) If the transport delay of graphical cockpit instruments is not measured the statement of compliance should confirm that the transport delay of the cockpit instruments is equal to the transport delay of the visual system itself.
(6) The statement of compliance should confirm the accurate representation of the cockpit in terms of dimensions, colours and haptic feedback of cockpit elements as well as the readability of instruments/indicators and the acceptance of reference colours if parts of the cockpit are digitally replicated should be confirmed.

All statements of compliance and the included confirmations as addressed in chapter 1.,2. and 3. referring to the device's suitability for training should be signed by a training expert on the helicopter simulated (valid type rating, flight instructor).

1.4 FTD and FNPT Standards

(1) General requirements for VR Cockpit
  (i) Acceptable means for using checklists and maps should be provided.
  (ii) Primary flight controls should be integrated, and they should be full scale replicas of the helicopter simulated.
  (iii) No noticeable misalignment is allowed between hardware and visual overlay.
  (iv) States of cockpit elements (such as switches, levers, guards) should be

correctly represented in the visual system.

(v) The IOS should provide means to observe states of cockpit elements.

(vi) The cockpit should represent the simulated aircraft. Dimensions, colours, lighting and behaviour of cockpit elements, controls and equipment should be accurate. Special attention should be paid to the correct representation of optical indicators (e.g., warning lights). A list of instrument/indicator colours with physical colour reference and representation target values on the FSTD should be provided.

(vii) The representation of the cockpit, colours, and simulated light effects should be consistent and not interfered by sources independent from the simulation. Lighting of the FSTD environment, dynamic white balance, exposure, focus, geometric distortion, eyepoint correction, head and pose tracking or other techniques that may apply for HMDs should not be affected.

(2) Haptic feedback is required. The minimum requirements are as follows:

(i) A physical full-scale cockpit for pilot interaction.

(ii) Type specific FSTDs require a full-scale physical cockpit replica of the rotorcraft represented with all the components needed to perform the training tasks. Haptic feedback should be representative of the helicopter simulated.

(iii) Primary flight controls (pedals, cyclic, collective) and frequently used cockpit elements should be physically represented.

(iv) Some cockpit elements may be controlled by alternate means such as gestures.

(v) Pilot's body pose needs to be represented in Virtual Reality as required by the training tasks.

(vi) All relevant systems for the cockpit perception (visual system, cockpit hardware, body pose tracking) have to be aligned and stable during operation.

(3) Virtual Reality cockpits require an HMD with accurate head tracking. The minimum requirements for the head tracking system are as follows:

(i) The tracking of the HMD should be fast and robust. Tracking noise, glitches and other disruptive effects should not be present during the operation.

(ii) If a motion system is fitted, effects of motion should not noticeably affect the head tracking or inaccurately impact the pilot's view.

(iii) The visual cockpit in the HMD should always be aligned with the cockpit hardware.

(iv) The head tracking should have 6 DoF and accurately change the viewpoint in the cockpit.

1.5 Objective Tests

(1) The alignment of relevant systems for cockpit perception should be tested objectively.
(2) The influence of the motion system to the head tracking should be tested objectively.
(3) The delay of the HMD tracking should be tested objectively.
(4) The transport delay of the cockpit instruments should be measured or covered by a statement of compliance.

Table 9 summarizes the added objective tests for the VR based cockpit replica.

	Test	**Tolerance**	**Flight Condition**	**Comments**
7	**Cockpit Replica**			
7.a	**Alignment Tests**			
(1)	Cockpit alignment	Alignment error ≤ 10 mm		A number of cockpit elements should be operated for this test. The visual correspondence can be confirmed subjectively. The alignment error of all operated cockpit elements has to be evaluated.
(2)	Motion compensation	Position error ≤ 10 mm Angle error ≤ 1°	Test envelope for the motion system.	The motion compensation of the HMD tracking should be tested with a static position of the HMD in the cockpit and a motion trajectory that covers 50% of the specified motion range in all the degrees of freedom. The motion envelope should be a dynamic manoeuvre with transient motion effects representative for the aircraft or an equivalent synthetic signal.
(3)	HMD tracking delay	$t \leq 20$ ms		The delay of the HMD tracking system should be measured.
(4)	Colour representation	$\sqrt{(\Delta u)^2 + (\Delta v)^2} \leq 0.02$		Test is performed for all cockpit elements with target colour references. Colour is represented in CIE 1976 UCS colour space according to ISO/CIE 11664-5:2016. Test introduced for the FTD 3 and not implemented for the FNPT II (previous version of these SCs).

Table 9: Objective tests

2 Display System

2.1 Background

These special conditions describe the additional requirements for the HMD based display system to comply with

- Appendix 1 to CS FSTD(H).300 Flight Simulation Training Device Standards
  - **1.3.b.1** "Continuous", cross-cockpit, minimum visual field of view providing each pilot with 150 degrees horizontal and 40 degrees vertical.
  - **1.3.b.2** "Continuous", cross-cockpit, minimum visual field of view providing each pilot with 150 degrees horizontal and 60 degrees vertical.
  - **1.3.g.1** Surface (Vernier) resolution shall be demonstrated by a test pattern of objects shown to occupy a visual angle of not greater than 3 arcmin in the visual display used on a scene from the pilot's eye point.
- AMC1 FSTD(H).300 Qualification basis

2.2 Applicability

(1) This process applies to FTDs and FNPTs using a HMD based display system and is independent of the type of rotorcraft.

2.3 Statements of Compliance

Statements of compliance should describe the following:

(1) Display system characteristics. This should include general characteristics (resolution, field of view, refresh rate), display type, lens type, tracking system and other technologies if applicable such as eye-tracking, foveated rendering or tuneable lenses for vergence accommodation.
(2) Methods customising the HMD to pilot's eyesight (interpupillary distance, IPD).
(3) Methods for HMD calibration and testing. It should also include methods to ensure accurate vision of the pilot. Visual acuity, colour perception and stereo 3D vision tests should be covered as a minimum.

2.4 FTD and FNPT Standards

(4) FTDs and FNPTs with an HMD based display system should meet the following requirements:

(i) The visible scene should be measured as a field of view (FOV) and field of regard (FOR).
(ii) The system geometry requirements should be met for the entire FOV.
(iii) The frame rate of the visual system should be tested and monitored during operation.
(iv) If night vision training is intended with the FSTD, the visual system should provide sufficient contrast and black level. The usage of e.g. OLED based display technologies is recommended.
(v) The colour degradation should be tested.
(vi) Chromatic aberration should be tested.
(vii) The IPD setting and 3D projection should be tested.

(2) FTDs and FNPTs with Virtual Reality require the following additional IOS functionality:
(i) The view of the pilot should be presented on the IOS.
(ii) The body pose of the pilot should be visualised on all visualisation channels of the IOS and other crew members if applicable.
(iii) If a direct view to the pilot is not possible, a camera-based view for an observer should be streamed to the IOS.

(3) For practical reasons the following requirements should also be met:
(i) The nature of a wearable visual display system is likely to encounter damage due to incorrect handling, e.g. cleaning and mechanical shocks. Therefore, the visual system should be periodically tested in detail. This should be part of the preventive maintenance process.
(ii) Optical measurement devices for QTGs are sensitive to environmental changes such as temperature. Devices should be factory calibrated and be subject to inspection in preventive maintenance. Simple means to verify its functionality should be provided.
(iii) For motion sickness prevention and avoidance of negative training, it has been decided for these specific training devices to use a 6 DoF motion platform according to Appendix 1 to CS FSTD(H).300. A motion platform with reduced envelope is considered to be acceptable.
(iv) For motion sickness prevention and training comfort, the room climate should be controlled. Sufficient fresh air, appropriate room temperature and appropriate CO2 content should be ensured.

2.5 Objective Tests

(1) *AMC1 FSTD(H).300 Qualification basis* defines mandatory QTG tests.
(2) Test 5.b.1.(b) is modified to be used for HMD based display systems.
(3) Table 10 summarizes the additional or modified objective tests (compared to CS-FSTD(H) Initial Issue) for the HMD based display system.

	Test	Tolerance	Flight Condition	Comments
5.	**VISUAL SYSTEM**			
b.	**Display system tests**			
1.(b)	Continuous cross-cockpit visual field of view for HMD display systems.	Static FOV: Horizontal: ± 40° Vertical: 30° up, 35° down Field of regard (FOR): Horizontal ± 180° Vertical ± 180°		Field of view should be measured using a visual test pattern filling the entire visual scene. If a measurement system is used to measure the static FOV of the display system, a manual method should also be provided.
3.	System geometry	Maximum absolute geometric error from optical centre for FOV ± 30°: 0.5° and FOV ± 60°: 1.0° Maximum relative geometric error for FOV ± 30°: 0.05 °/° and FOV ± 60°: 0.10 °/°		The system geometry should be measured with a spatial resolution of minimum 1°. Tolerances are defined as scalar of the distortion vector independent of the direction. Absolute and relative geometric error should be smooth in transition. The relevant FOV is measured from optical centre.
6.	Vernier resolution	Minimum requirements for 1 arcmin: FOV ≥ ± 20° 3 arcmin: FOV ≥ ± 30°		Vernier resolution should be demonstrated by a test of objects shown to occupy the required visual angle in each visual display used on a scene from the pilot's eye-point.

9.	Frame rate	Not less than 60 fps		Measure frame rate in complex scenery cruising through an airport during 120 s. Take moving average of frame to frame timing for 10 frames. Then calculate frame rate.
10.	Colour degradation	6 dB deviation of luminance on each colour channel, 3 dB deviation of luminance ratio between colours		The luminance is measured for each colour with at least two intensity levels (100%, 50%). The colour ratio is defined as ratio of the luminance green/red, green/blue and red/blue. Tolerances are applicable for recurrent testing only.
11.	Black level	Black intensity: < 0.1 cd/m^2		A black polygon should be displayed and measured for the black level.
12.	Chromatic aberration	Maximal aberration for FOV ± 30°: 6 arcmin and FOV ± 60°: 12 arcmin		Chromatic aberration has to be verified with adequate grid over the display range and be measured with at least 100 positions.
13.	IPD setting and 3D projection	10% of test object distance		This test should be performed using a test pattern of known size in the visual field and a measurement setup to validate the projection. The distance should be measured at 3 m, 10 m, and 20 m. Object distance should be measured from the pi-lot's eyepoint. This test should be performed with the entire rendering pipeline (visual system). A direct display test is not sufficient.

14.	Grating resolution	Minimum requirements for 2 arcmin: FOV ≥ ± 20° 3 arcmin: FOV ≥ ± 30° 8 arcmin: FOV ≥ 120° Minimum vertical upper FOV for 3 arcmin can be reduced 25° if applicable for the intended use.		A grating resolution test should be performed for the full FOV in 45° rotation angles of the pattern. The test should be designed with a set of parallel lines with equal width and spacing. The test should be designed as such that chromatic aberration does not affect the result. This test should be performed with the entire rendering pipeline (visual system). A direct display test is not sufficient.

Table 10: Objective tests

3 Motion System for an FSTD using VR

3.1 Background

The use of motion system in VR based FSTD's gives additional cues for the pilot to create a more realistic training environment and reduce VR based discomfort.

A motion platform with reduced motion envelope (see Appendix 9 to AMC1 FSTD(H).300 Table 1 and Appendix 1 to CS FSTD(H).300) has been fitted to address the following challenges:

- A pilot performing training in a FSTD perceives incongruent signals from the visual system (movement perceived by the eyes), the vestibular system (sense of balance and spatial orientation) and the proprioception system (sense of self-movement and body position). These perception errors often cause symptoms similar to motion sickness and lead to general discomfort, nausea and disorientation.
- Motion cues are a very important for the realistic training environment especially for the light helicopters where pilot constantly uses motion cues to perform his/her tasks (e.g flight path management).
- The accelerations in the pilot seat of the simulated aircraft should be sufficiently represented in the FSTD. Creating representative motion cues in the pilot seat is essential for preventing motion sickness.
- Motion cueing algorithms with noticeable higher order washout effects should be avoided to prevent motion sickness.

This chapter describes the special conditions for reduced stroke motion system based on

- AMC1 FSTD(H).300 Qualification basis
- AMC5 FSTD(H).300 Guidance on design and qualification of helicopter flight and navigation procedures trainers (FNPTs)
- AMC3 FSTD(H).300 Guidance on design and qualification of helicopter flight training devices (FTDs)

3.2 Applicability

(1) If a motion system is fitted to an FNPT or FTD the validation tests should follow the requirements for an FFS Level A. For an FFS level A, if more than the specified 3 DoF are used, then the corresponding Level B performance standards should be used, and a reduced motion performance envelope is acceptable.

3.3 Statements of Compliance

A statement of compliance is required for the following:

(1) The motion system and its characteristics should be described including the motion cueing logic.
(2) Confirmation that the motion cues are representative for the helicopter simulated.
(3) A set of signature manoeuvres (representative manoeuvres covering all kinds of operation) should be presented.

3.4 FTD and FNPT Standards

(1) The minimum requirements for a 6 DoF motion system installed in FNPTs and FTDs are:

(i) The objective requirements should be validated with the validation tests for level B FFS.

(ii) The motion system should have a transport delay of 100 ms or less after control movement.

3.5 Objective Tests

(1) Validation tests need to meet level A FFS requirements according to AMC1 FSTD(H).300(b)(1)(vii)(B) and furthermore level B FFS requirements if more than 3 DoF are used.
(2) Table 11 summarizes the modified objective tests (compared to CS-FSTD(H) Initial Issue) building the Special Conditions for the reduced motion envelope system used in this VR based FNPT and FTD.

	Test	Tolerance	Flight Condition	Comments
4.	**MOTION SYSTEM**			
a.	Motion Envelope			
(4)	**Vertical**			
(i)	Displacement ± 6 in			Reduced envelope (Reference value FFS- B ± 22 in)
(5)	**Lateral**			
(i)	Displacement ± 8 in			Reduced envelope (Reference value FFS- B ± 26 in)
(6)	**Longitudinal**			
(i)	Displacement ± 8 in			Reduced envelope (Reference value FFS- B ± 27 in)
d.	Turn Around	0.05 g		Reduced peak to peak displacement to ± 4 in (Reference value FFS-B ± 6 in)
6.	**FSTD SYSTEMS**			
a.	Visual, Motion and Cockpit Instrument Response			
(i)	**Transport Delay**	70 ms		

Table 11: Objective tests