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Evaluation of Handling Qualities for Level 5 Flight Training Device to Conventional Aircraft Simulator

[1]Ashok Kuppusamy and [2]Sug Joon Yoon

[1)] Modeling & Simulation Research Centre, Sejong University, Seoul-143737, South Korea.

[1]ORCID: 0000-0001-9562-4075

Abstract

Flight simulator is a device that artificially re-creates the aircraft flight and the environment it flies for pilot training, design, or other purposes. It includes replicating the equations that govern how aircraft fly, how they react to applications of flight controls, the effect of other aircraft systems, how the aircraft reacts to external factors such as air density, turbulence, wind shear, cloud, precipitation, etc. Flight simulation is used for a variety of reasons, including pilot training, design and development of aircraft, and research into aircraft characteristics and control handling qualities. For an aircraft simulator to be quite efficient, the handling qualities and pilot ratings must be satisfied which includes the test items like static control checks, longitudinal and lateral directions tests. The evaluation committee evaluates the simulator based on the performance obtained from the handling qualities results and if the results meets the tolerance value stated in the aviation administration regulations the simulator will be approved for use. In this paper, the test items for a level 5 Flight Training Device (FTD) and the classification of aircraft simulators will be explained in a brief way.

Keywords: Aircraft Simulators, Federal Aviation Regulations (FAR), Full Flight Simulator, Handling Qualities, Qualification Test Guide (QTG)

INTRODUCTION

Simulation is often still considered an art instead of a science reflects the fact that this complex mechanism of creating a virtual environment is not fully understood yet. The flight simulator or more specifically piloted simulation is, however, widely used nowadays, especially in the area of aerospace and astronautics. Because training the pilots directly in a real aircraft is really dangerous one which can risk human lives. By using simulators there are many advantages like cost effectiveness, safety requirements, environmental considerations, etc. To understand the discipline of handling qualities, the concept of stability should be understood. Stability can be defined only when the vehicle is in trim; that is, there are no unbalanced forces or moments acting on the vehicle to cause it to deviate from steady flight [1]. If this condition exists, and if the vehicle is disturbed, stability refers to the tendency of the vehicle to return to the trimmed condition. If the vehicle initially tends to return to a trimmed condition, it is said to be statically stable. If it continues to approach the trimmed condition without overshooting, the motion is called a subsidence. If the motion causes the vehicle to overshoot the trimmed condition, it may oscillate back and forth. If this oscillation damps out, the motion is called a damped oscillation and the vehicle is said to be dynamically stable. On the other hand, if the motion increases in amplitude, the vehicle is said to be dynamically unstable.

The theory of stability of airplanes was worked out by G. H. Bryan in England in 1904. This theory is essentially equivalent to the theory taught to aeronautical students today and was a remarkable intellectual achievement considering that at the time Bryan developed the theory, he had not even heard of the Wright brothers' first flight. Because of the complication of the theory and the tedious computations required in its use, it was rarely applied by airplane designers. Obviously, to fly successfully, pilotless airplanes had to be dynamically stable [2]. The airplane flown by the Wright brothers, and most airplanes flown thereafter, were not stable, but by trial and error, designers developed a few planes that had satisfactory flying qualities[3]. Many other airplanes, however, had poor flying qualities, which sometimes resulted in crashes. Today, India is proud to make its first indigenous Light Combat Aircraft called LCA Tejas which is inducted by Indian Airforce to replace the current Mig-21 fighters [4-5].

Bryan showed that the stability characteristics of airplanes could be separated into longitudinal and lateral groups with the corresponding motions called modes of motion. These modes of motion were either aperiodic, which means that the airplane steadily approaches or diverges from a trimmed condition, or oscillatory, which means that the airplane oscillates about the trim condition. The longitudinal modes of a statically stable airplane following a disturbance were shown to consist of a long-period oscillation called the phugoid oscillation, usually with a period in seconds about one-quarter of the airspeed in miles per hour and a short-period oscillation with a period of only a few seconds [6]. The lateral motion had three modes of motion: an aperiodic mode called the spiral mode that could be a divergence or subsidence, a heavily damped aperiodic mode called the roll subsidence, and a short-period oscillation, usually poorly damped, called the Dutch roll mode. The simulator evaluation used in the paper can be used even for the handling qualities of LCA by adding some extra tests which includes weapons and electronic warfare suite [7].

QUALIFICATION TEST GUIDE

A Qualification Test Guide (QTG) is a guide for certifying new flight simulation technology to one of the regulatory levels of the appropriate national or regional regulatory body. A QTG provides a list of tests that are necessary to qualify a flight simulator for use. Regulatory bodies that utilize QTGs include the Federal Aviation Administration (FAA) in the USA, the National Civil Aviation Agency (ANAC) in Brazil, the European Aviation Safety Agency (EASA) in the European Union and equivalent bodies in other countries.

Flight Simulator Operators are encouraged to submit an advance copy of the QTG to FAA, at the earliest opportunity, to ensure that the proposed tests and validation data are suitable. The substantially complete QTG should be submitted to FAA not less than 15 working days prior to the proposed date of commencement of the on-site evaluation [8-9]. All Validation, and Functions and Subjective Test results contained in the QTG should have been conducted on-site within the last 90 days. A letter of application should be submitted before commencement of the on-site evaluation confirming that Operator Testing is complete, listing all outstanding discrepancies and providing QTG updates (as necessary). For a FTD to get approved, the following tests items mentioned in table 1 should be satisfied by the comparing the results with the alternative data source listed in the FAA Part 60. A brief summary of the handling qualities will be discussed in the next section.

Table 1. QPS (Qualification Performance Standard) Test List

No.	***Description***	***Test Result***
PERFORMANCE		
CLIMB		
1.c.1	Normal Climb All Engines Operating	♦
ENGINES		
1.f.1	Engine Acceleration	♦
1.f.2	Engine Deceleration	♦
HANDLING QUALITIES		
STATIC CONTROL CHECKS		
2.a.1.b	Pitch Control Position vs. Force	♦
2.a.2.b	Roll Control Position vs. Force	♦
2.a.3.b	Rudder Control Position vs. Force	♦
LONGITUDINAL		
2.c.1	Power Change Force	♦
2.c.2	Flap/Slat Change Force	♦
2.c.4	Gear Change Force	♦
2.c.5	Longitudinal Trim	♦
2.c.7	Longitudinal Static Stability	♦
2.c.8	Stall Warning	♦
2.c.9	Phugoid Dynamics	♦
LATERAL - DIRECTIONAL		
2.d.2	Roll Response	♦
2.d.4.b	Spiral Stability	♦
2.d.6.b	Rudder Response	♦
2.d.8	Steady State Sideslip	♦
FTD System Response Time		
6.a.1	Latency	♦
6.a.2	Transport Delay	♦

♦ FAR Test items that meet the criteria of level 5 FTD

Figure 1. BOEING 737-800 Simulator Flight Deck

Flight Simulator Classification and Matlab® Interfacing

The sophisticated way of performing all the tests as per the QPS list is by choosing a good simulation engine. The commercial off-the-shelf (COTS) software and services are built and delivered usually from a third party vendor. COTS can be purchased, leased or even licensed to the general public. The various available commercial software are X-Plane® produced by Laminar Research, Microsoft Flight Simulator X® (FSX) originally developed and published by Microsoft Game Studios for Microsoft Windows and Prepar3D® (P3D) by Lockheed Martin. For illustrative purpose a full set-up of Boeing 737-800 simulator showing its flight deck is shown in figure 1.

The full simulator set up not only consists of just simulation engine alone but it also comprises of interfacing the Matlab®/Simulink interfacing to carry out the QTG test and handling qualities.

The interfacing between the commercial software and Simulink usually is made by means of UDP (User Datagram Protocol) or by means of TCP/IP [10]. The communication is very reliable through UDP or TCP/IP protocol with low latency rate by using a personal computer. The scenario of how to perform the test and the interfacing method [11] is shown above in the figure 2.

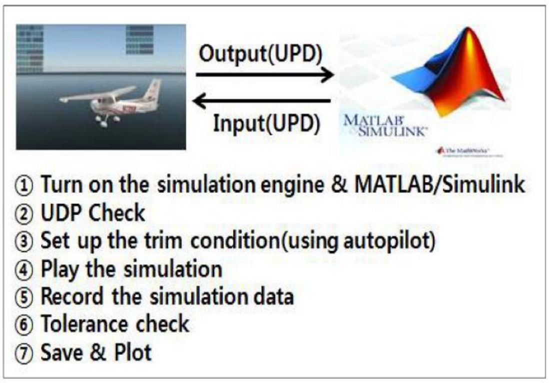

Figure 2. Matlab/Simulink interfacing with Simulation Engine

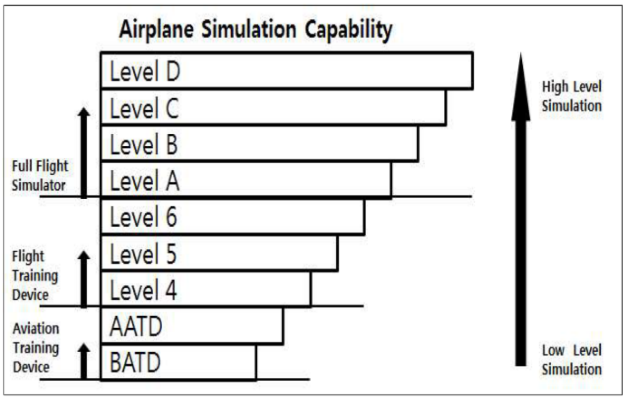

Figure 3. FAA Flight Simulator Classification

The FAA level of flight simulators and its classification are listed down [12] and its low level to high level in diagram view is shown in figure 3.

1. Flight Training Devices (FTD)
   - FTD Level 4
   - FTD Level 5
   - FTD Level 6
   - FTD Level 7
2. Full Flight Simulators (FFS)
   - FFS Level A
   - FFS Level B
   - FFS Level C
   - FFS Level D
3. Advanced Aviation Training Device (AATD)
4. Basic Aviation Training Device (BATD)

Handling Qualities

The tests can be performed in 2 ways. The first way is to set up the initial conditions trimming the aircraft and make the test fully automatic which will perform the test by itself and print the results at the end once the test is finished [13]. Another way is manual test procedure where we set the initial conditions again and the pilot itself will manually perform the test and at the end the results will be printed [14]. In this paper we are discussing only the manual test procedures. Before performing the test the aircraft should be placed in a proper runway and it has to be trimmed.

I. Static Control Checks

a. Pitch Control Position vs. Force

Complete a full sweep on the pilot side control as follows [15-16].

- Slowly push full forward on the column.
- Slowly pull aft on the column.
- Return columns to neutral.
- Results will be printed once the test is finished.

b. Roll Control Position vs. Force

Complete a full sweep on the pilot side control as follows [17].

- Slowly push full forward on the column.
- Slowly pull aft on the column.
- Return columns to neutral.
- Results will be printed once the test is finished.

c. Rudder Control Position vs. Force

Complete a full rudder pedal sweep on the pilot side control as follows.

- Slowly push right pedal full forward.
- Slowly pull left pedal full forward.
- Return rudder pedals to neutral.
- Results will be printed once the test is finished.

II. Longitudinal

a. Power change Force

The objective is to demonstrate that the FTD column force required to maintain altitude after a power change conforms to the airplane [18].

- Maintain pitch and roll attitude at start of test.
- At 6 seconds after test starts, push throttle position to maximum.
- Push on the column to maintain the initial altitude throughout the test.
- Results will be printed once the test is finished.

b. Flap Change Force

The objective is to demonstrate that the FTD column force required to maintain altitude after settling of initial transience due to change in flap position conforms to the airplane.

- Maintain pitch and roll attitude at start of test.
- During the start of test select the flaps to 30
- At 6 seconds after test starts, select flaps to 0.
- Apply the required column input to maintain the initial altitude throughout the test.

c. Gear Change Force

The objective is to demonstrate that the FTD column force required to maintain altitude after settling of initial transience due to change in landing gear position conforms to the airplane.

- Maintain pitch and roll attitude at start of test.
- During start of test the landing gear switch position should in UP POSITION.
- At 6 seconds after test starts, select gear to DOWN POSITION
- Apply the required column input to maintain the initial altitude throughout the test.

d. Longitudinal Trim

The objective is to demonstrate that the FTD inter-relationships of lift, drag, thrust and longitudinal trim conforms to the airplane.

- Record the relevant trim state parameters, including elevator trim indicated position, pitch angle and power setting.
- Fly straight and level for 10 seconds.

e. Longitudinal Static Stability

The objective is to demonstrate that the FTD static longitudinal stability characteristics conforms to the airplane.

- From the approach trim conditions apply a control column deflection to achieve a deviation from the trimmed airspeed while maintaining wings level.
- Record the control column force needed to hold the new target airspeed.
- Obtain data for a speed 10 knots below the trim speed.
- Repeat the steps while applying the necessary column input to maintain altitude at the new airspeed.

f. Stall characteristics

To demonstrate that the simulation of lift, angle of attack and stall related factors conforms to the airplane.

- Reduce the throttle to near idle and gradually pull on the column so as to achieve a deceleration rate of approximately 2.4 knots/sec.
- Upon activation of the stall warning, take note of the airspeed and bank angle.

g. Phugoid Dynamics

To demonstrate that the FTD phugoid dynamics conforms to the airplane.

- Maintain pitch and roll attitude at start of test.
- At 11 seconds after test starts, quickly return the column to neutral.
- At a 20 degrees nose down pitch attitude, quickly return the column to neutral.
- Let the aircraft respond freely in pitch.

III. <u>Lateral-Directional</u>

a. Roll Response

To demonstrate that the FTD roll response characteristics conforms to the airplane [19].

- Maintain pitch and roll attitude at start of test.
- At 5 seconds after test starts, quickly apply a right step input on the wheel of 20 degrees and hold till the end of the test.
- Let the aircraft respond freely (Do not touch any controls)

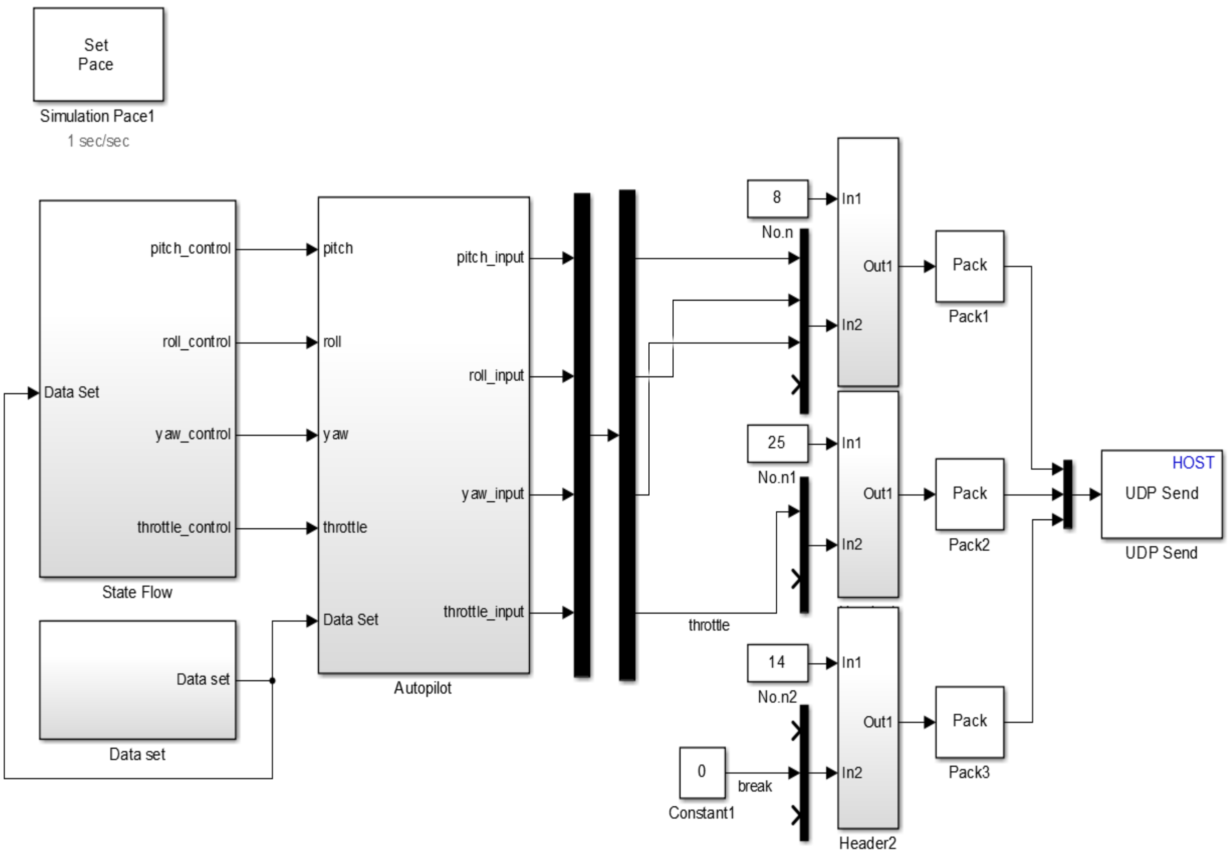

Figure 4. Simulink Model for Longitudinal Trim Test

b. Spiral Stability

To demonstrate that the simulation of the dynamic lateral/directional characteristics in the spiral mode conforms to the airplane.

- Maintain the pitch attitude at start of test.
- Establish a 20 degrees bank right wing down.
- When stabilized, release the control wheel to neutralize the ailerons.

c. Rudder Response

To demonstrate that the FTD directional control response from rudder control movements conforms to the airplane.

- Maintain pitch and roll attitude at start of test.
- Initiate a rapid rudder input and measure the resultant yaw rate and compare to validation rate. This test should be done in the approach configuration and the rapid input should be approximately 25% of the full range.
- At 5 seconds after test starts, quickly apply approximately 0.5 inches in right pedal input and hold till the end of the test.
- Let the aircraft respond freely (Do not touch any controls)

d. Steady State Sideslip

To demonstrate that the trainer exhibits the correct inter-relationship of steady state lateral/directional flight characteristics in conformance with the airplane.

- Displace the left rudder pedal 25% and 50% of full travel and hold while maintaining heading and altitude using wheel and elevator inputs. When steady-state is achieved, record the relevant parameters.

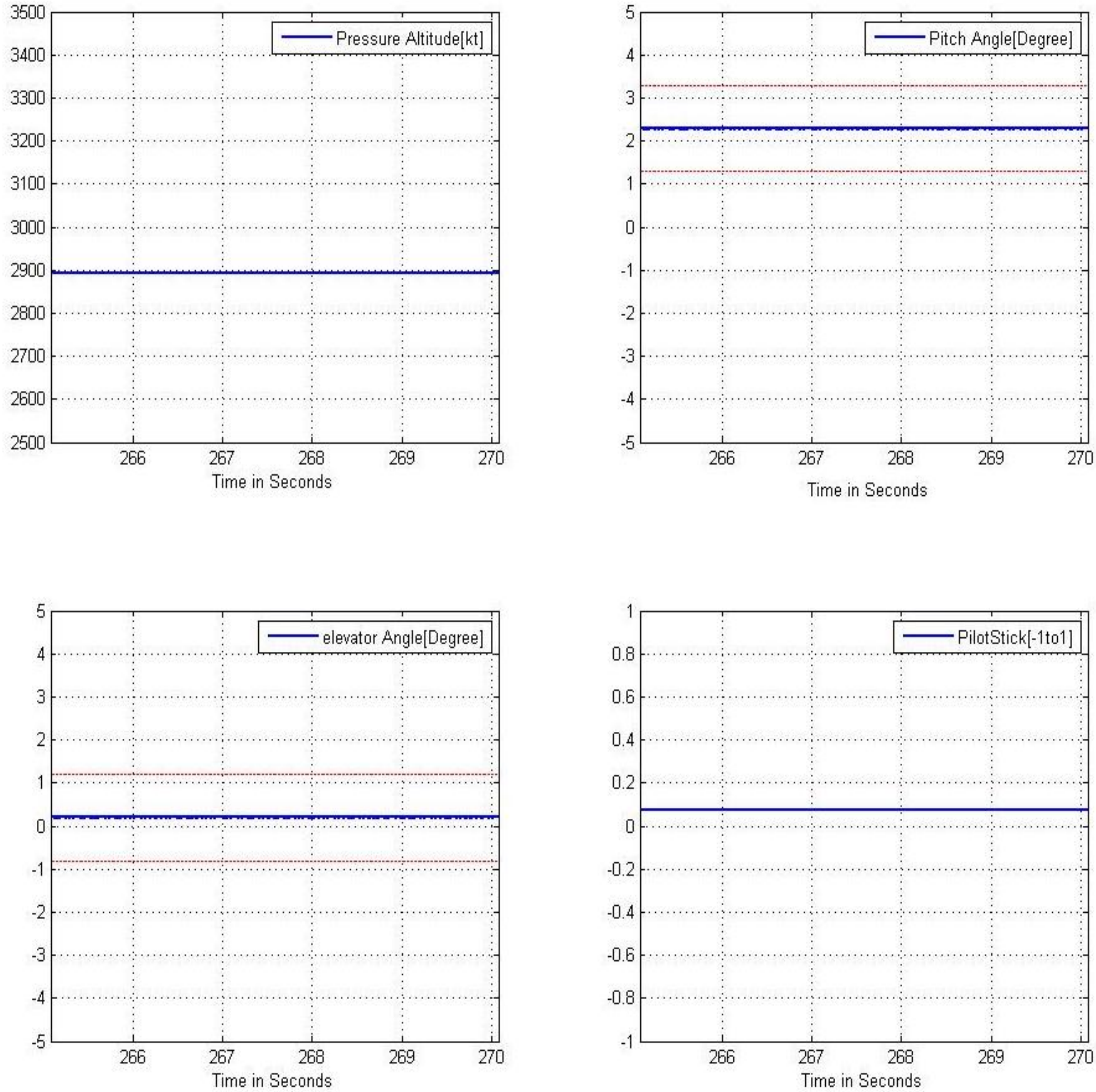

Figure 5. Simulink Output for Longitudinal Trim

- The test driver will reposition the aircraft at a steady sideslip of 6 degrees nose left.
- While holding the rudder pedals to maintain the new steady sideslip attitude by maintaining the pitch and bank angle.
- The test driver will reposition the aircraft at a steady state sideslip of 11 degrees nose left.
- While holding the rudder pedals to maintain the new steady sideslip attitude by maintaining the pitch and bank angle.

RESULTS AND CONCLUSION

Handling qualities evaluation is default criteria for every flight simulator when it comes to evaluation by any aviation regulation committee. So by following all the test items the evaluation of a level 5 FTD can be obtained for any aircraft simulator. The goal of this paper also teach us the same. Additionally, references providing additional details were provided. The Simulink block diagram of the Longitudinal Trim experimental set up is shown below in the figure 4 and simulated output is shown in figure 5. Initial conditions and simulated output results will be printed once the test is finished.

Initial Conditions:

'True Airspeed (kt)'	[98.7055]
'Pressure Altitude (ft)'	[2.8937e+03]
'Weight (lb)'	[500]
'Rate of Climb (fpm)'	[0.0063]
'Pitch Angle (deg)'	[2.2850]
'Roll Angle (deg)'	[0.0055]
'Heading (deg)'	[151.0853]
'Pitch rate (deg/s^2)'	[-8.3968e-06]
'Roll rate (deg/s^2)'	[-3.7304e-05]
'Yaw rate (deg/s^2)'	[8.1308e-04]
'Pilot Column Position -1 push 1 pull'	[0.0739]
'Elevator Angle (deg)'	[0.1926]
'Propeller Speed (RPM)'	[0.3330]
'Pitch Angular Moment (ft-lb)'	[-0.0016]
'Roll Angular Moment (ft-lb)'	[0.0408]
'Yaw Angular Moment (ft-lb)'	[0.0022]

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