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A Literature Review on Control Loading System for Aircraft Simulator

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Abstract

Present review paper is based on "Qualification test guide for flight simulation" which includes the study of flight simulation and control loading system for flight simulation. Tremendously increasing developments and research in aerospace industry requires virtual environment to perform high risk tasks. In such case, flight simulator plays vital role. Flight simulator is a key tool which creates virtual environment to do pilot trainings, design and to perform flight simulation tasks. It is one of the key training and engineering tools in the modern aerospace industry. The main goal of this review paper is to understand and learn the various concepts regarding flight simulator.

Keywords: Qualification Test Guide (QTG), Control Loading System (CLS), Flight Control System, quantitative feedback theory (QFT), National Aviation Authorities (NAA)

INTRODUCTION

The process of re-creating the aircraft flight and the environment it flies in for training purposes and design is called simulation and the device through which it is made possible is called Flight simulator. It helps in pilot training by trying to replicate the experience of the real time flight. Apart from pilot training, it is also used in design, development and research purposes and helps the operator learn controlling handling qualities. For the efficiency to be higher, the qualities of handling the aircraft and the pilot ratings are to be satisfied which includes longitudinal, lateral direction and static control check tests. Pilot training, designing and development of an aircraft are the different purposes served by the flight simulators. Due to hardware constraints, full scale flight simulators are usually found very expensive and often found dependent on type of aircraft. Therefore, a need for the design of flight simulators using virtual reality is observed and worked on [1-2]. A safest and a cost-effective way of training a pilot is through a flight simulator. A simulator helps the pilot to experience a broad range of situations that involve in a real flight without being in the situations and avoid the risk. Important part of a flight simulator is the so-called control loading system. The number of instances of flight gear is used to manage the motion of aircraft, control of flight and instrumentation of cockpit. The system comprises both hardware and software parts. Simulation through programmers on digital computer come under software and the structural study comes under hardware. Two other software modules support the simulation, between which one controls the cockpit motion in 6 degrees of freedom and the other implements a load reproducing system on cockpit controls [3]. Flight simulator is a real-time simulation system of man in the loop where the control loading system is used to simulate the pilot’s force sensing as manipulate real aircraft. Full digital control electric control loading system has technical and cost advantage than hydraulic system, became an ideal choice for large simulator [4]. The use of flight simulators for pilot training has played a major role in improving flight safety over the last few decades. Current standards for regulatory qualification of flight simulators involve matching a prescribed set of flight test data within set tolerances on various aircraft parameters. Despite comprehensive Qualification Test Guide (QTG) validation tests that demonstrate that the simulation matches flight test data, pilots sometimes complain that certain maneuvers in the simulator to not feel like the aircraft [5].

Fig 1: Flight Simulator

HISTORY AND DIFFERENT TECHNIQUES USED IN CONVENTIONAL SYSTEMS

The history of flight simulation dates to 1929 when Edwin Link built his first Link Trainer. The device had a basic set of instruments, a primitive motion platform, and no visual display (Lee, 2009). When World War II began, the Link Trainer was integrated into flight training and used extensively. At the time, training accident rates were quite high and using simulators to reduce the aircraft accident rate was believed to be a logical outcome (Valverde, 1973). The Link Trainer, an early flight simulator developed by Ed Link between 1927 and 1930, was an engineless plane that sat on a series of organ bellows. An instructor would inflate and deflate the bellows to various heights to make the trainer plane bank, climb, and dive, and the trainee would respond accordingly inside the plane (Roberson Museum and Science Center, 2000). The training value of simulators substituting for aircraft was intuitive and based on common sense (Lee, 2009). After the war, rapid simulator progress was achieved due to much technological advancement during the war. Crucial to this evolution was the development of analog computers. However, the academic study of flight simulators did not start until around 1949 (Valverde, 1973). These studies continue in earnest today.

Advantages:

Flight simulators play a prominent role in modern aviation training programs.

They provide advantages such as:

1. Safe environment for practicing potentially dangerous procedures that should not be performed on a real aircraft, for example, engine failure or rejected takeoff.,
2. Low training costs,
3. Shows positive impact on the environment by conserving the resources,
4. Research and laboratory,
5. Repetition of events.

Disadvantages:

Extensive simulator uses for training purposes also have few drawbacks.

The disadvantages include,

1. Simulator sickness in both fixed and motion-based simulators,
2. Inducing compensatory and adaptation skills,
3. Motion cueing is poor compared to real flight,
4. System architecture is complex,
5. High cost associated with the most advanced simulators (Lee, 2009).

The above advantages resulted in the usage of advanced simulators in the FAA's Advanced Qualification Program (Longride, 1997) [6-7]. Many new problems in flight control are arising due to the evolution of high-performance aircrafts. The problems are mainly associated with the control stick which is also said as control feel are among the prominent. The simulator was developed to afford proper investigation of control feel and everything that is related to this closely [8]. Flight simulator is a real-time simulation system of man in the loop where the control loading system is used to simulate the pilot's force sensing as manipulate real aircraft. Full digital control electric control loading system has technical and cost advantage than hydraulic system, became an ideal choice for large simulator. The electric control loading system of a company in Holland is currently the most widely used and most high-end products, torque motor, reducer and feedback sensors of the system are custom-made, the system performance is excellent, but high price, inconvenient repair, complex operation. So, we decide to develop high performance to price ratio control loading system[9]. In this paper, the torque sever motor is used as power actuator, coupled with the conventional speed reducer and force sensor constructed electric control loading system. This paper describes how to establish mathematical model of control loading system, the controller based on linear matrix inequality restrain the surplus force disturbance generated by the position disturbance, effective compensation within the inner-loop bandwidth. The control loading system achieves good simulation effect [10]. Simulators now a days play an important role and are widely used in the military training and civil aviation due to threats in real-environment flight trainings. A high-level fidelity is required for pilot training in simulators and depends on the available technologies. One of those technologies is applied in Pilot Control Loader (PCL) subsystems. PCL subsystems are necessary element of simulators that help the trainee, control the loads to be released on the control column and provide the trainee a real environment feel [11]. The theoretical development of the so-called active stick is focused on solving three technical issues. Among which, one is that the force-feel characteristics to be defined accurately. The solution for which is, by using a 3- degrees of freedom (DOF) mathematical model of the given aircraft dynamics developed by the MATLAB SIMULINK software. The second one of which includes the grip force pick up on the control stick. The problem has been considered in [12]. The final one concerns the degradation of performance of the active stick caused by torque due to friction existing between the several mechanical parts i.e, from the reduction gear mainly. To overcome this issue, a pre-defined look-up table can be used. This table was formed using the results obtained from the experiments performed on the active stick in open loop conditions. It tells us how to obtain frictional torque with respect to stick rotational speeds inspired by the research [13].

CONTROL LOADING SYSTEM FOR FLIGHT SIMULATOR

One of the major engineering challenges in a flight simulator is an accurate replication of the control forces that the pilot experiences at the control column, wheel or pedals. This is the task of a control loading system (CLS), which can provide the necessary forces in various ways. Simulators play a vital role in aircraft industry especially when they come to train the pilots. They are ground based machines. So, simulating the effects of pressure distribution over the control surface becomes one of the greatest challenges. This is where the Control Loading System (CLS) comes in handy. CLS can be classified into two categories namely hydraulically driven CLS and electrically driven CLS. The CLS used for the presented experiment is an electrically driven CLS, hence the discussion would be limited to it. A CLS is a computer which controls the spring action present inside the hardware. By applying a suitable force, it is possible to obtain the mechanical vibrations and the spring action, which are controlled simultaneously [14].

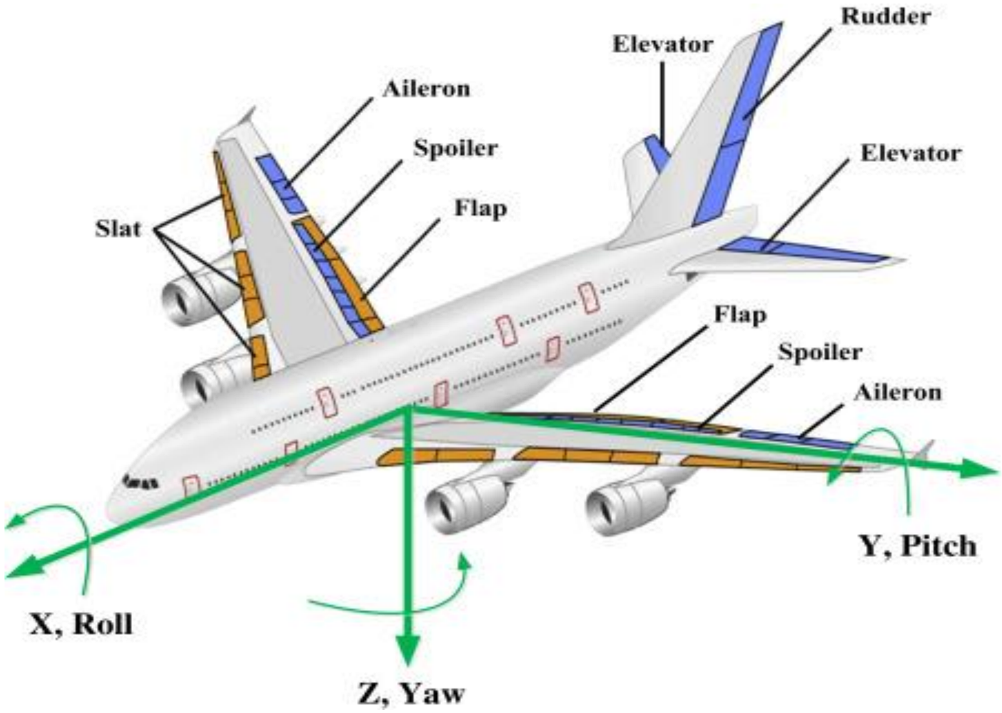

Fig 2: Aircraft control surfaces

Simulation of linear and non-linear dynamic systems has in recent years been dominated using digital computers. This technology has allowed flight simulators to provide more diversified and truer to life simulations by creating a cost-effective means of simulating complex non-linear dynamic systems. One area which has not fully benefited from this technology has been the control loading area. The goal of obtaining a fully digital control loading system has been somewhat elusive. The simulator's control loading system provides two primary functions:

(1) It provides forces to a control lever (control stick, rudder pedal, etc.) replicating the forces that the pilot experiences during flight and

(2) It measures the pilot's inputs (displacement and rate of displacement) so that these can be included in the "real time" computation of the aircraft's attitude.

Realistic stick "feel" and reliable aircraft reaction to pilot stick input are two of the most noticeable (and therefore important) attributes of effective training in a flight simulator [15]. Electro-hydraulic control loading system dynamic model .The basic structure of the EHCLS includes a link mechanism, a servo valve, a hydraulic cylinder and its power supply, and force and displacement sensors; their relationship is demonstrated in Figure 3(a). The inner loop is a force close loop driven by a hydraulic actuator. If the mass and viscous damping coefficients of the control stick are converted to a position of the link mechanism, an equivalent simplified physical model is as shown in Figure 3(b), where the force sensor is treated as a flexible link while the others are treated as rigid links. The EHCLS can be modeled according to the simplified physical model in Figure 3(b) [16].

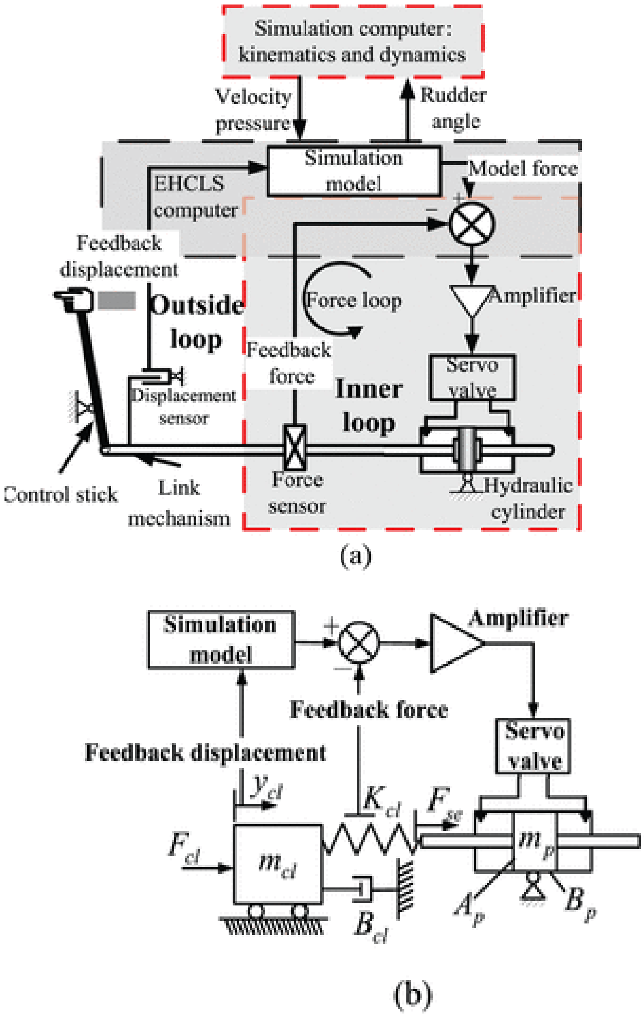

Fig 3: Electro-Hydraulic control loading system, a) EHCLS Model b) simplified model

Hydro-mechanical flight control system, as aircraft increased in size and the achievable velocity grew, the aerodynamic forces on control surfaces became too large to be handled by the pilot's muscle strength alone. A hydraulically powered mechanical flight control system incorporates hydraulic power control units (PCU), with servo-valves connected to the control column again via mechanical linkages. The PCUs assist with or completely take over the actuation of the control surfaces, while still keeping them kinematically linked with the control column. [17]

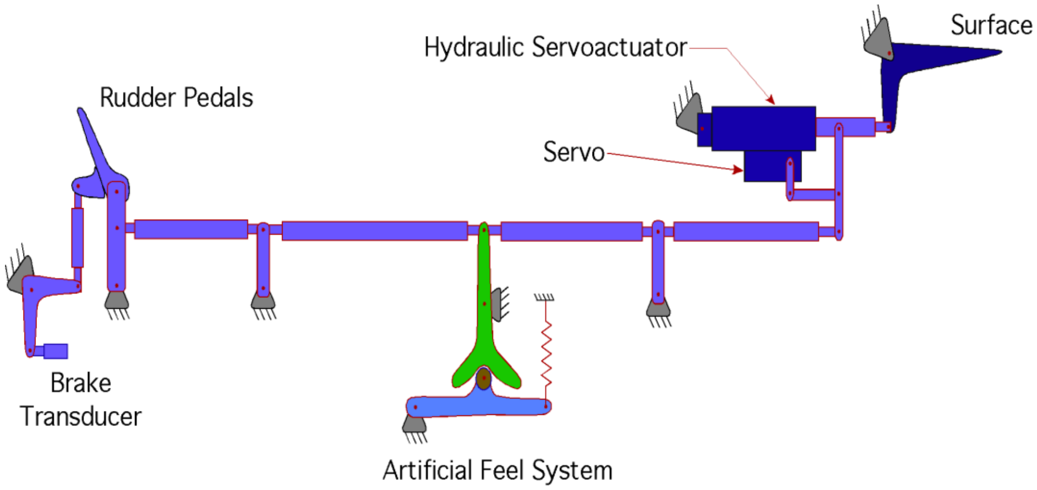

Fig 4: Hydro-mechanical flight control system

For the performance and stability test of an aircraft actuation system a dynamic load simulator is needed, which helps to reproduce on ground aerodynamic hinge moment. The hinge moment varies widely over the flight envelope depending on the specific flight condition and maneuvering status. To replicate the wide spectrum of this hinge moment variation within some accuracy bounds, a force controller is designed based on the quantitative feedback theory (QFT) [18]. So-called control loading system which consists of a control stick of the simulator and the hardware, software components to emulate the behavior of the flight which enables the pilot to experience through the stick, is the important part of the flight simulator. The plant part set-up is as shown below:

1. The stick has only one degree of rotation and the angular position is measured by potentiometer.
2. The transmission between motor and the stick is formed by the ball-screw-spindle.
3. A tachometer that has to be mounted on the motor (a PMDC electric motor) to measure its angular velocity.
4. As the transmission is considered stiff, the angular position of the stick varies linearly with the angular velocity of the motor.

A force sensor that measures the force applied by the pilot on the stick.

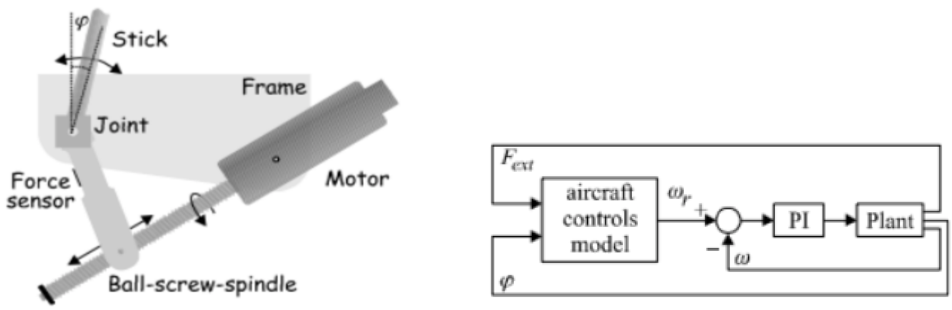

Fig 5: Control stick and its mechanism

The mechanical impedance experienced by the pilot at the stick can be controlled by controlling the plant properly.

This can be done as shown in the below figure.

1. The inner loop has the motor in a velocity loop with the PI controller.
2. The aircraft controls model calculates the angular velocity of the commanded stick for the inner loop.

The outer loop consists of the inputs to the system (the external force exerted by the pilot on the stick and the angular position of the simulator stick) [19]. Classification of control loading devices passive or active controls. When the variation in forces which need to be simulated according to flight condition not required in that case passive devices are used. It does not produce energy in the system. When the variation in forces which need to be simulated according to flight condition is required their active devices used. These devices are usually implemented on primary controls and some secondary controls. A typical control loading system comprise of the following basic components: Cockpit control and linkage, Loader, Electric motor (DC or AC), Control force (or loading) is provided by the motor. With mechanical linkages each and every control axis or channels are attached to a motor. For avoiding the backlash friction and stretch transducers are used. The control loading system is controlled by a computer. The control loading computer interfaces with a power amplifier (or servo driver) of each channel. And at last, with the help of Ethernet the control loading computer communicates with the main simulation computer (host) [20].

QUALIFICATION TEST GUIDE (QTG)

FAA and EASA Certification

National Aviation Authorities (NAA) for civil aircraft such as the U.S. Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA), certify each category of simulators and test individual simulators within the approved categories. U.S. commercial pilots can only log required training time in simulators that are certified by the FAA and European pilots in simulators approved by EASA. For a simulator to be officially certified, it must be able to demonstrate that its performance matches that of the airplane that is being simulated to the fidelity required by the category of Flight Training Device (FTD) or Full Flight Simulator (FFS) to which it is designed and approved by the regulatory body. The testing requirements are detailed in test guides referred to as 10.

An Approval Test Guide (ATG) or Qualification Test Guide (QTG). Simulators are classified as Level 1-7 Flight Training Devices (FTD) or Level A-D full-flight simulators. A detailed requirements and training standards can be accessed from JAR-FSTD A and JAR-STD 1A and 2A. However, it is stressed at this point that all these standards are defined with respect to pilot training instead of research and teaching and must only be used as a reference purpose.

CONCLUSION

Our goals with this paper were to collect references to significant results obtained by the simulator research community. We have collected these results and provided our review paper in the hopes that as virtual environments research progresses and in academics study of flight simulator students will be able to learn from these results, rather than re-establish them unnecessarily. This document compiles all the relevant research done on the subject. This literature divided into different groups, i.e. history and different techniques used in conventional system, control loading system for flight simulator, and qualification test guide.

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