Artificial Feel Unit in an Aircraft

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Abstract - Traditionally pilot's efforts were directly applied on control surfaces like aileron, elevator and rudder by system of cables, cranks, pulleys, etc. However the power required for surface control in high speed, military aircraft far exceeds the pilot's capabilities. Hydraulically powered control surfaces help to overcome limitations of mechanical system like complexity and weight of mechanical systems . In hydraulic flight control systems the aircraft's size and performance are limited by economics rather than a pilot's muscular strength. Modern high speed and performance piloted aircrafts uses electrical flight control systems (Fly-by-wire) to control the forces on control surfaces of flight. Since fly by wire system gives no feel to the pilot on control stick , an artificial feel unit is to be designed to give feel force to the pilot. Feel unit is an important part of control stick which provides force field to pilot proportional to the loads of the control surfaces.

Keywords: Artificial Feel Unit, Spring feel unit, Q Bellow feel unit.

1. Introduction

Modern high speed and high performance piloted aircraft uses Electrical Flight Control Systems (fly-by-wire) to control the forces on control surfaces of flight and the aircraft's direction and altitude. Traditionally pilot's efforts were directly applied on control surfaces like aileron, elevator and rudder by system of cables, cranks, pulleys, etc. However, the power required for surface control in high speed, military aircraft far exceeds the pilot's capabilities. Flight control systems installed in these aircraft are fully powered that is, none of the force required to overcome the aerodynamic moment on the control surface comes from the pilot's control stick.

Since fly-by-wire system gives no feel to the pilot on control stick, an artificial feel unit is to be design to give feel force to the pilot. They regard stick-feel as a particularly valuable because it is always available without distracting the pilot's attention from his target. A pilot upon whom is placed the tasks of navigation, communication and aerology, in addition to flight and combat, approaches the limit of his abilities. For such a man, a stick with feel is equivalent to a host of flight instruments.

Movement of any of the three primary flight control surfaces (ailerons, elevator, or rudder), changes the airflow and pressure distribution over and around the airfoil. These changes affect the lift and drag produced by the airfoil or control surface combination and allows a pilot to control the aircraft about its three axes of rotation. Hence even small mistakes in moving control stick will be dangerous. Hence artificial feel unit of control stick plays important roll.

Depending on components used in artificial feel unit of control stick the control stick is of two types- active stick and passive stick.

Artificial feel produces an opposition to the pilot movement of controls that is proportional to the aerodynamic loads acting on the control surfaces. For larger aircrafts where PCUs (Power Control Unit) are used, the pilot has no direct feedback 'feel'. Therefore the designer has to use artificial feel to ensure that the pilot senses the magnitude of the effect of the control movements.

Conventional control linkages permit the pilot to perceive some of the airplane's flight characteristics through position and pressure effects on stick and elevator controls. Stick feel depends on the forces arising from the feed-back of some fraction of the aerodynamic forces developed with displacement of the control surfaces. Artificial feel force can be generated by using various combination of components like spring, damper, Q bellow, electric motor, advance fluids like MR fluid, ER fluid.

In this paper, we will be concentrating mainly on two feel systems i.e. 1)Spring-Damper feel system and

2)Q feel system.

2. Fly By Wire System

A fly-by-wire (FBW) system replaces manual flight control of an aircraft with an electronic interface. The movements of flight controls are converted to electronic signals transmitted by wires (hence the fly-by-wire term), and flight control computers determine how to move the actuators at each control surface to provide the expected response. Commands

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from the computers are also input without the pilot's knowledge to stabilize the aircraft and perform other tasks. Electronics for aircraft flight control systems are part of the field known as avionics. Fly-by-optics, also known as fly-by-light, is a further development using fiber optic cables.

Improved fully fly-by-wire systems recognize pilot's input as the required aircraft action, acting in different situations with different rudder elevations or even combining several rudders, flaps and engine controls at once using a closed loop (feedback). Even without the pilot's input, automatic signals can be sent by the aircraft's computers to stabilize aircraft or partially unstable aircraft, or prevent unsafe operation of the aircraft outside its performance envelope.

Operation of fly by wire system:

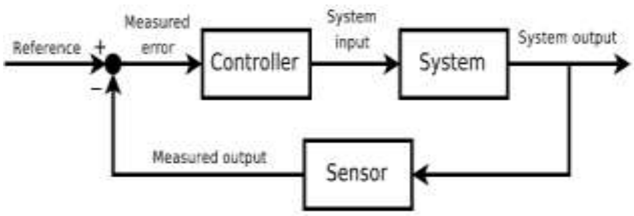

Figure 1 : Closed loop control unit of fly-by-wire

An above fig shows the closed loop system of an aircraft. A pilot commands the flight control computer to make the aircraft perform a certain action, such as pitch the aircraft up, or roll to one side, by moving the control column or side-stick. The flight control computer then calculates what control surface movements will cause the plane to perform that action and issues those commands to the electronic controllers for each surface. The controllers at each surface receive these commands and then move actuators attached to the control surface until it has moved to where the flight control computer commanded it to. The controllers measure the position of the flight control surface with sensors such as LVDTs.

3. Spring Feel System

The most elementary force producer which can be used in artificial feel system is the simple mechanical spring. Its purpose is to create a stick force proportional to control surface deflection. An artificial feel system using a spring only system would probably exhibit very poor longitudinal and lateral control feel characteristics for a typical fighter plane however directional control feel for such an airplane is acceptable. Preloaded spring is used to improve the stick centering characteristics of simple spring artificial feel system.

The purpose of damper is to provide stick force proportional to stick deflection mechanically this device consist of a small piston moving within a cylinder of oil the motion of piston being restricted by oil which must be forced through tiny orifices in piston when pilot deflects the stick he experiences a force proportional to velocity on elevator. The damper is used in longitudinal control feel systems to improve the transient feel if an airplane exhibit unsatisfactory transient feel characteristics.

Spring damper system used in feel unit of control stick is nothing but a system of mechanical forced vibration model. In feel unit of control stick spring-mass damper are used. Hence the mathematical model of spring damper system of aircraft feel unit can be written as follows:

$$m\ddot{x} + c\dot{x} + kx = F$$

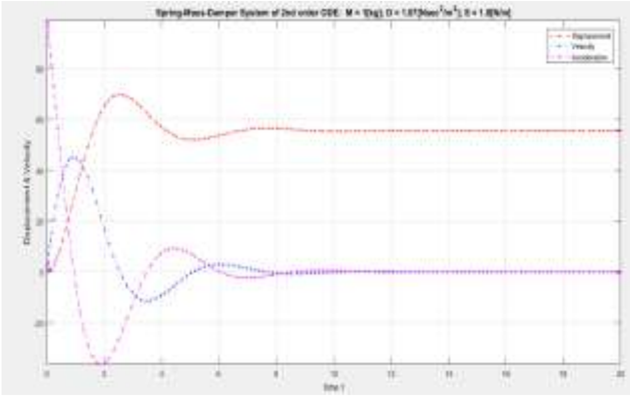

Figure 2: Curve for under damped condition Vs time

The energy dissipated out of the dynamic system is modeled through a one-dimensional damper in the MSD system. The viscous damper, for instance, is able to dissipate energy as heat outside the dynamic system. These three components, mass, spring and the damper can model any dynamic response situation in a general sense.

3D model of spring damper system:

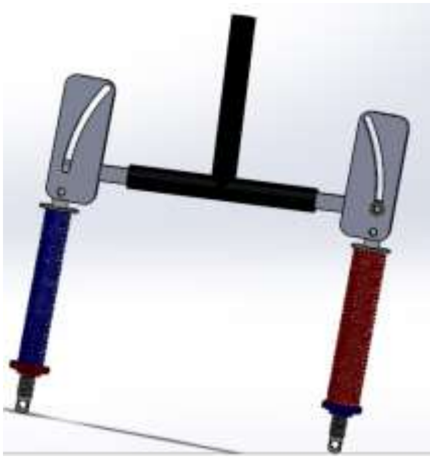

Figure 3: 3D model of spring damper system

4. Q Bellow Feel System

One method of improving the control feel characteristics with a rather simple mechanical feel system is to use a Q-bellows. Instead of spring gradient that is constant throughout the flight region of the airplane, the Q-bellows provide a variable spring gradient that is a function of mach number and altitude. Thus the Q-bellows can be thought of a mechanical gain changer or a gain compensator. A typical Q-bellow system produces a stick force proportional to the product of pressure differential across the diaphragm of the bellows, pt-p, and then control surface deflection.

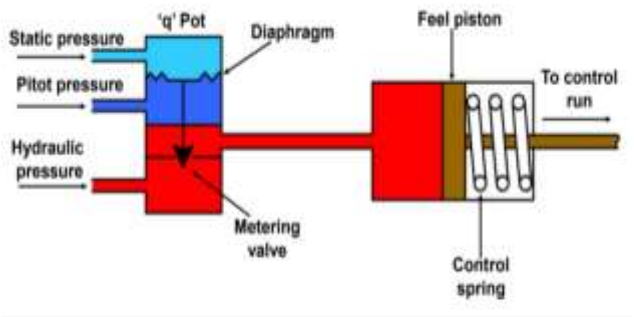

Figure 4: Basic Model of Q-fee [8]

Q is referred to as dynamic pressure found by subtracting static pressure from pitot pressure. Pitot pressure directed at one inlet and static pressure in other resulting in differential dynamic pressure, which acts to bias the system. Linear movement of piston leads to feel resistance to pilot i.e. greater the movement greater the feel. Increase in speed increases the value of Q which acts against the pilot although requiring only small deflections.

A requirement for flight control systems is that the faster you fly, the heavier it should appear to operate that control, be it elevator, aileron or rudder, the three primary flight controls. This is called "feel". So, the Q bellows intake is just another type of pitot tube, a device that measures or uses pressure created by increasing airspeed.

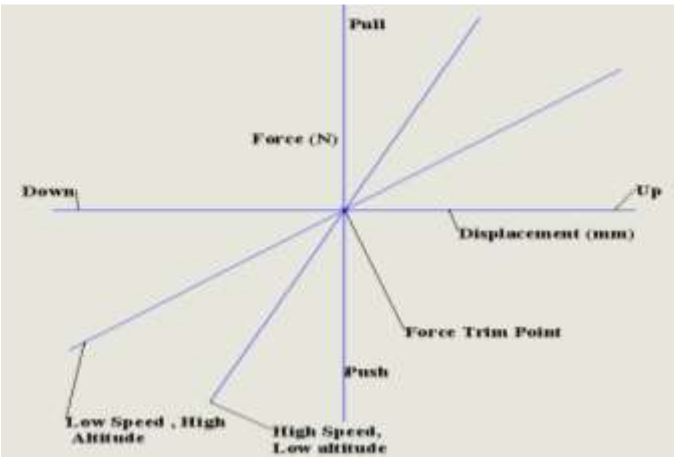

Figure 5: Characteristics of Q bellow feel system

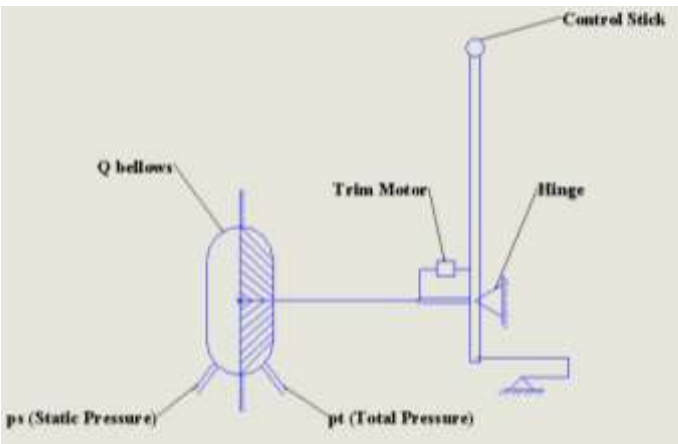

Figure 6: Schematic of Q bellow feel system

Equations in q bellow feel unit:-

$P_d = P_t - P_s$

Where,

P_d = Dynamic Pressure.

P_t = Total Pressure.

P_s= Static Pressure.

In the design and operation of aircraft, *static pressure* is the air pressure in the aircraft's static pressure system. An aircraft's altimeter is operated by static pressure system.. An aircraft's airspeed indicator is operated by the static pressure system.

The basic pitot tube consists of a tube pointing directly into the fluid flow. As this tube contains fluid, a pressure can be measured; the moving fluid is brought to rest (stagnates) as there is no outlet to allow flow to continue. This pressure is the stagnation pressure of the fluid, also known as the total pressure or (particularly in aviation) the pitot pressure.

The dynamic pressure, then, is the difference between the stagnation pressure and the static pressure. The dynamic pressure is then determined using a diaphragm inside an enclosed container. If the air on one side of the diaphragm is at the static pressure, and the other at the stagnation pressure, then the deflection of the diaphragm is proportional to the dynamic pressure.

$\delta = (F/ (k (P_t - P_s)))$

Where,

δ = Control surface deflection

F = Stick Force

K= spring stiffness

Pt= Total pressure

Ps= Static pressure

In Q bellow feel system, stick force is directly proportional to pressure differential across the bellows.

5. **Pitot Static Tube**

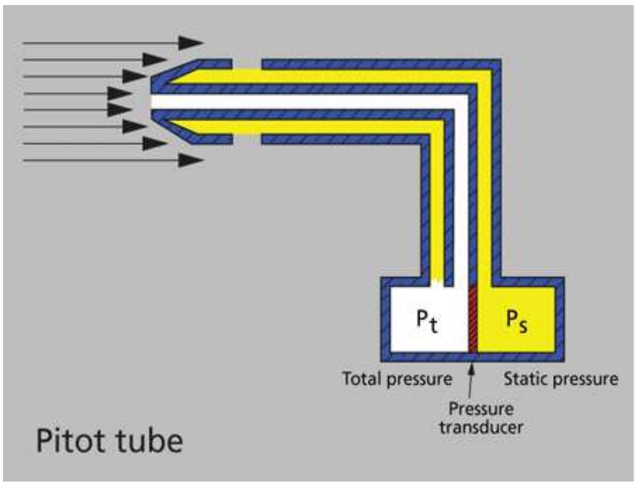

Figure 7: Pitot-static tube[4]

Pitot tubes are used on aircraft as speedometers. The actual tube on the aircraft is around 10 inches (25 centimeters) long with a 1/2 inch (1 centimeter) diameter. Several small holes are drilled around the outside of the tube and a center hole is drilled down the axis of the tube. The outside holes are connected to one side of a device called a pressure transducer. The center hole in the tube is kept separate from the outside holes and is connected to the other side of the transducer.

The transducer measures the difference in pressure in the two groups of tubes by measuring the strain in a thin element using an electronic strain gauge.

The pitot tube is mounted on the aircraft so that the center tube is always pointed in the direction of travel and the outside holes are perpendicular to the center tube. (On some airplanes the pitot tube is put on a longer boom sticking out of the nose of the plane or the wing.)

Difference in Static and Total Pressure:-

Since the outside holes are perpendicular to the direction of travel, these tubes are pressurized by the local random component of the air velocity. The pressure in these tubes is the static pressure (ps) discussed in Bernoulli's equation. The center tube, however, is pointed in the direction of travel and is pressurized by both the random and the ordered air velocity. The pressure in this tube is the total pressure (pt) discussed in Bernoulli's equation. The pressure transducer measures the difference in total and static pressure measurement = pt - ps

Figure 8: Pitot tube on aircraft[2]

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