Automatic Flight Control System (AFCS)

- AFCS is an integrated system comprising primarily autopilot, autothrottle, caution and warning systems, automatically steers the aircraft using the autopilot and manager power output of an engine optimally to meet the needs of different phases of flight.
- AFCS takes major workload of the pilot without compromising safety of flight.

- Automatic Flight Control System (AFCS) directs the flight of the aircraft according to a predetermined flight path making use of the following subsystems:

1. Primary and secondary flight control surfaces
2. Corresponding actuators - servomotors, electrohydraulic systems, or all-electric actuators
3. Interconnection linkages (mechanical, electrical or optical)
4. Engine thrust control - to control the speed of the aircraft
5. AFCS Computer to compute the required actuator commands as well as to coordinate the functions of all the above systems

- It can take control of difficult pilot tasks, such as, flying through poor visibility in fog, low-altitude flight at high speed.
- AFCS has the following desirable features:

(i) Reduces the workload of pilots

(ii) Makes the navigation easier

(iii) Improves fuel economy

(iv) Enhances safely of flight

(v) Takes over control of difficult pilot tasks

(vi) Maintains selected speed regardless of changes in flight conditions such as rough weather, turbulent flight, climb up or descent, etc.

Autopilot (AP)

- An autopilot is an avionics equipment, used in larger aircraft (>20 seats), which automatically flies the aircraft in pilot-selected course.
- The term "autopilot" is not only used in aircraft, but also in spacecraft, ICBMs, ships and boats.
- The autopilot can have mechanical, electrical or hydraulic power boosts to move the larger flight surfaces, which in turn guides the aircraft on a pre-selected course.

Aircraft Autopilot

- In very old and lighter aircraft, pilot used to manually exert forces on the control surfaces and flying required his continuous attention. The range was rather limited to few hundred kilometres.
- However, as the range extended to several thousands of kilometers, (as in transoceanic flights) flying becomes tedious and fatigues the pilot, compromising flight safety. An autopilot removes this drudgery of flying long distances by taking over some of the tasks of the pilots.

- Basic flight control system used cables, pulleys and bell cranks.
- It has undergone substantial changes, as the size of the aircraft was greatly increased. Such purely mechanical systems were in use for few decades since 1900s, and they are still used in smaller aircraft (1-10 passenger capacity).

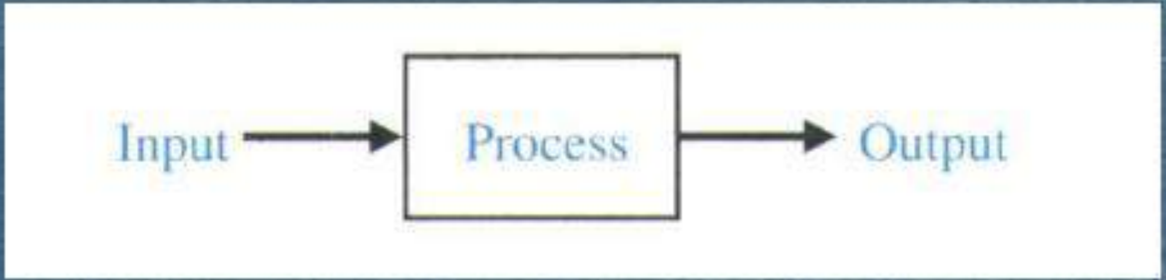
- The first autopilot was designed and developed by Sperry Corporation, USA.
- The two-axis autopilot used pitch and yaw data from gyros, to operate the elevator and rudder respectively to fly the aircraft in a straight and level flight path.
- Feedback servomechanism was used to maintain the straight and level flight


Autopilot?
@airplanetechtalk

Introduction

System – An interconnection of elements and devices for a desired purpose.

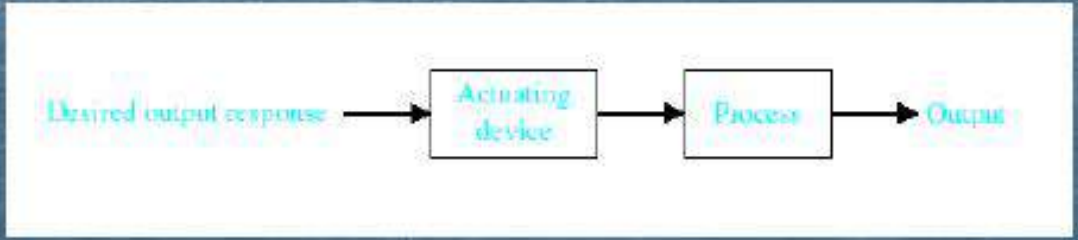
Control System – An interconnection of components forming a system configuration that will provide a desired response.



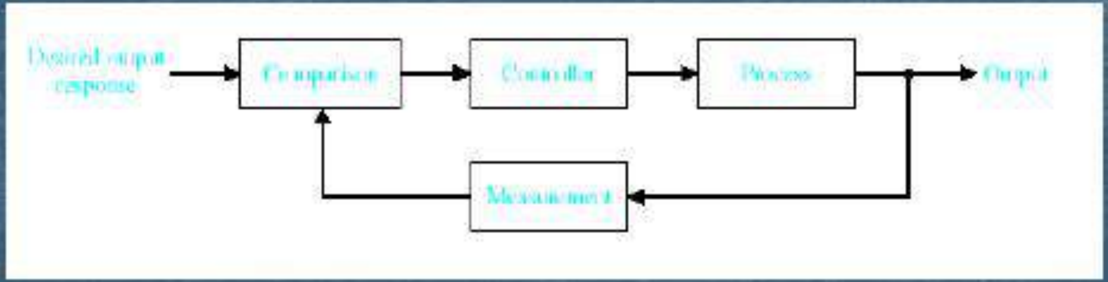
Process – The device, plant, or system under control. The input and output relationship represents the cause-and-effect relationship of the process.

Types of Control System

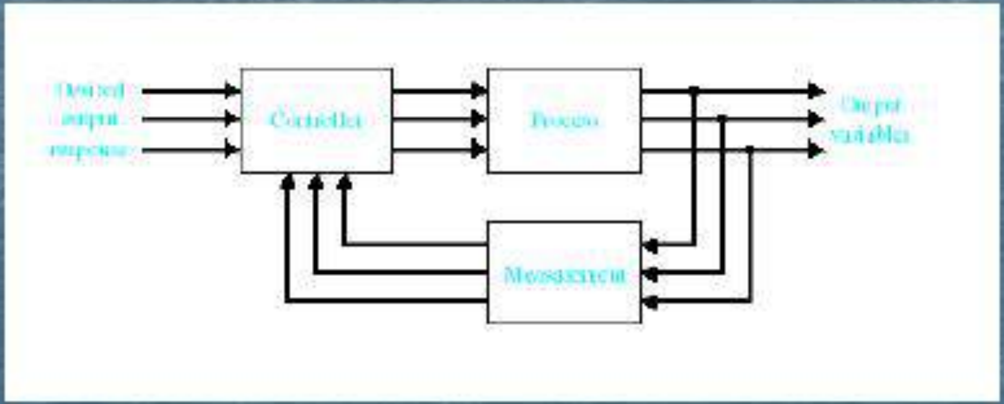
Open-Loop Control Systems utilize a controller or control actuator to obtain the desired response.



Closed-Loop Control Systems utilizes feedback to compare the actual output to the desired output response.



Multivariable Control System: Systems with more than one control loop are known as Multi Input Multi Output (MIMO) or Multivariable control Systems.



Intelligent Control Systems: Intelligent control is a class of control techniques that use various artificial intelligence computing approaches like neural networks, Bayesian probability, fuzzy logic, machine learning, evolutionary computation and genetic algorithms.

Requirements of a Good Control System

- Accuracy: defines the limits of the errors made when the instrument is used in normal operating conditions. To increase accuracy of any control system error detector should be present in control system.
- Sensitivity: A control system should be sensitive to the input only.
- Noise: A good control system should be able to reduce the noise effect.
- Bandwidth: Bandwidth should be large as possible for frequency response of good control system.
- Speed: A good control system possesses high speed. The transient period for such system is very small.
- Oscillations: A small numbers of oscillation or constant oscillation of output tend to system to be stable.

Controllers :

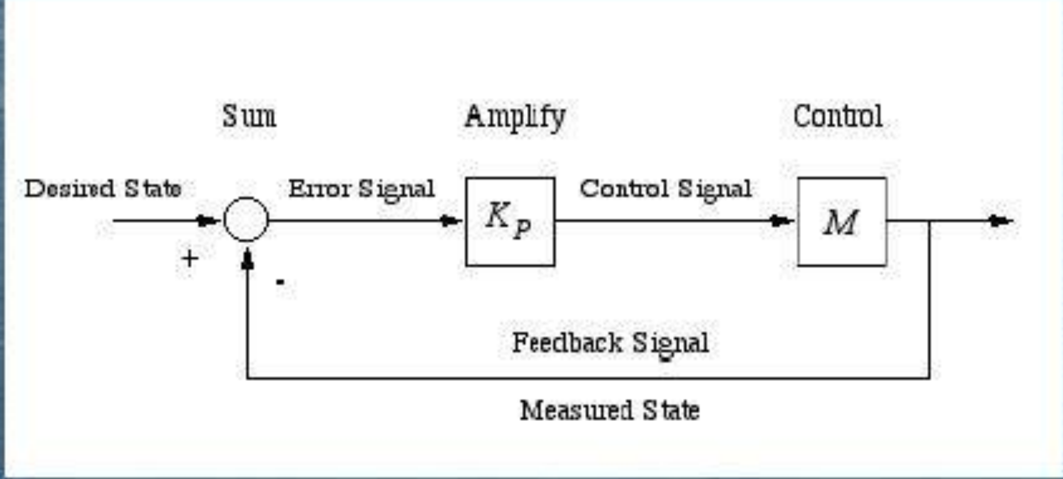
A controller is one which compares controlled values with the desired values and has a function to correct the deviation produced.

Type of Controllers :

1. Proportional Controller (P)
2. Proportional Derivative Controller (PD)
3. Proportional Integral Controller (PI)
4. Proportional Integral Derivative Controller (PID)

Proportional Controller

In a proportional controller the output (also called the actuating/contro signal) is directly proportional to the error signal.



Control signal = Kp X Error Signal

If the error signal is a voltage, and the control signal is also a voltage, then a proportional controller is just an amplifier.

Properties:

In a proportional controller, steady state error tends to depend inversely upon the proportional gain, so if the gain is made larger the error goes down.

$$SSE = 1/(1 + K_pG(0))$$

Proportional controller helps in reducing the steady state error, thus makes the system more stable.

Slow response of the over damped system can be made faster with the help of these controllers.

Shortcomings:

P controller has the advantage of reducing down the steady state error of the system , but along with that it also has some serious disadvantages.

Disadvantages of P Controller

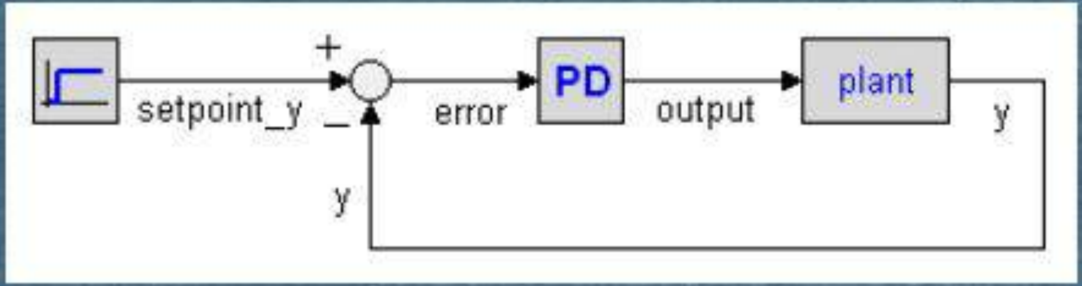
1. Due to presence of these controllers we some offsets in the system.
2. Proportional controllers also increase the maximum overshoot of the system.
3. It directly amplifies process noise.

To avoid these errors and to make the controller more accurate and practical, we use the advanced and modified version of it known as the Proportional Integral Controllers (PI) and Proportional Derivative Controllers (PD).

Proportional Derivative (PD) Controller:

This kind of action gives an output which is proportional to the derivative or the rate of change of the error.

Derivative action could not be used alone in practice. This is because its output is only related to the rate of change of the error. The error could be huge, but if it were unchanging, the controller would not give any output. Thus although it is theoretically possible, it is practically impossible.



Derivative control is usually found in combination with proportional control, to form so-called P+D.

Properties/Advantages of PD Controller:

$O_D = - k_D \, dEr / dt$

where

O_D = output derivative controller

k_D = derivative gain or action factor of the controller

dEr = deviation change over time sample dt

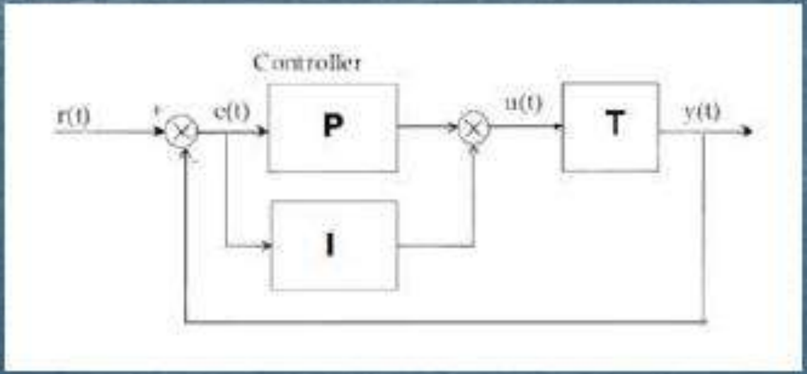
dt = time sample

- Derivative part in the PD controller reduces the overshoot and improves the transient stability of the control system.
- It reduces the time constant of the system and thus making system faster.
- It has no effect on the steady state error (derivative part) and on the offset caused by the P controller.

Proportional Integral (PI) Controller:

As the name suggests in integral controllers the output (also called the actuating signal) is directly proportional to the integral of the error signal.

Integral Controllers used alongside with proportional controllers are called PI controllers.



PI controller equation:

$$CO = K_C\left(E + \frac{1}{T_I}\int E\,dt\right)$$

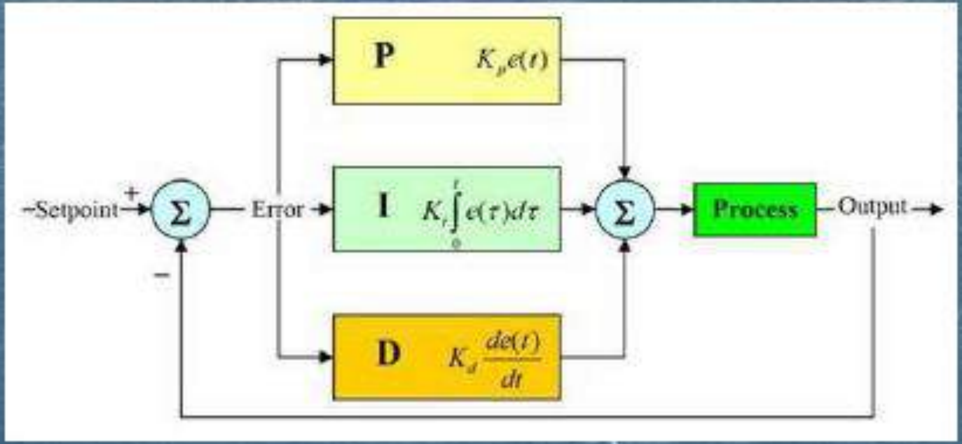
Just like PD controller it also has a parallel connection of P and I controllers.

Properties/Advantages of PI controller:

- Output is proportional to the integral of the input signal.
- As the integrator is involved, it increases the type of the system.
- As the type of the system increases, it reduces SSE and hence improves accuracy.
- Integral action enables PI controllers to eliminate offset, a major weakness of a P-only controller. Thus, PI controllers provide a balance of complexity and capability that makes them by far the most widely used algorithm in process control applications.
- As the type of the system is increased, there is some negative impact over the stability of the system.

Proportional-Integral-Derivative (PID) Controller:

PID controller involves all the three controllers studied earlier i:e P, PD and PI connected in parallel.



PID controller involves the parallel combination of these 3 controllers and the output equation is proportional to the derivative as well as integral of the error signal.

$$u(t) = \overbrace{K_p e(t)}^{\text{Proportional}} + \overbrace{K_i \int_0^t e(\tau) d\tau}^{\text{Integral}} + \overbrace{K_d \frac{d}{dt} e(t)}^{\text{Derivative}}$$

The Characteristics of P, I, and D controllers

- A proportional controller (Kp) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error.

- An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse.

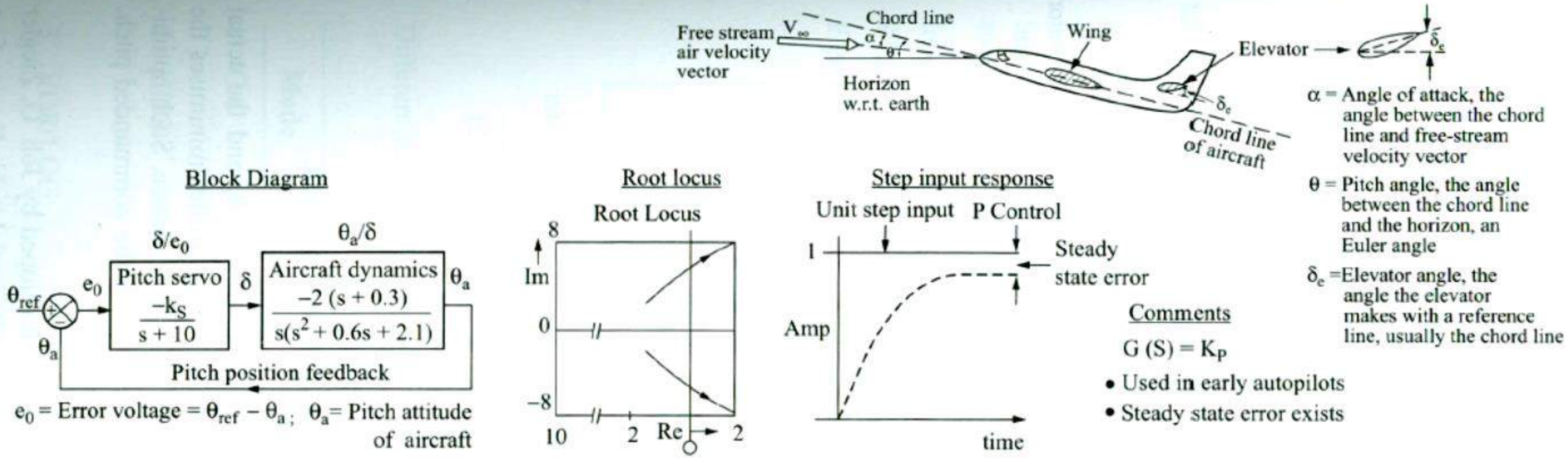
- A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response.

All design specifications can be reached with the PID controller and 100% desired conditions can be achieved .

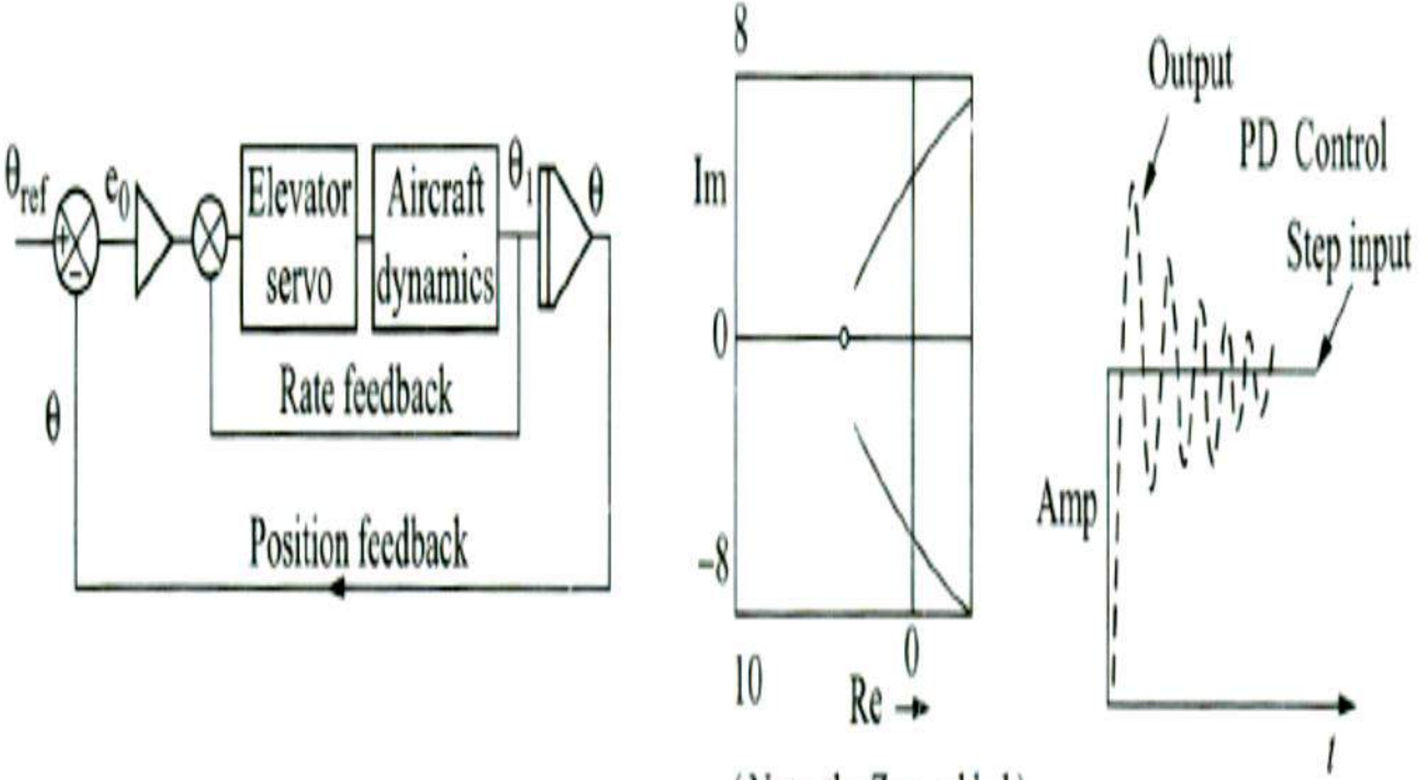
Effect of increasing the individual gains:

The Characteristics of P, I and D controllers

CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	Small Change



(a) Proportional control / pitch servo

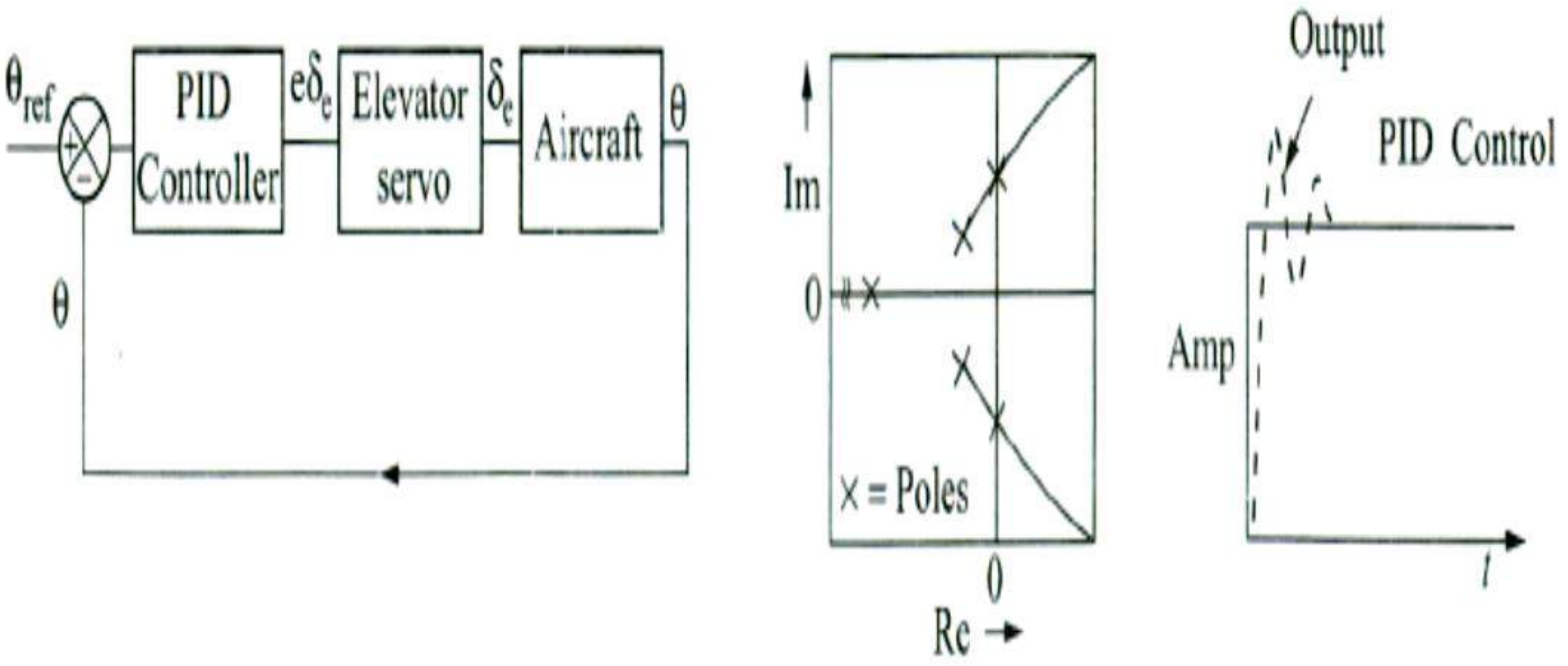


(Note the Zero added)

(b) Proportional + Derivative control / pitch servo

$G(S) = K_P + K_D S$

- Derivative control controls damping
  For ex: Tacho feedback
- Used to control overshoot. Overshoot decreases as K_D is increased



(c) PID control / pitch servo

(PID = Proportional Integral Derivative)

- Best controller of choice.
- $G(s) = K_P + K_I / S + K_D S$

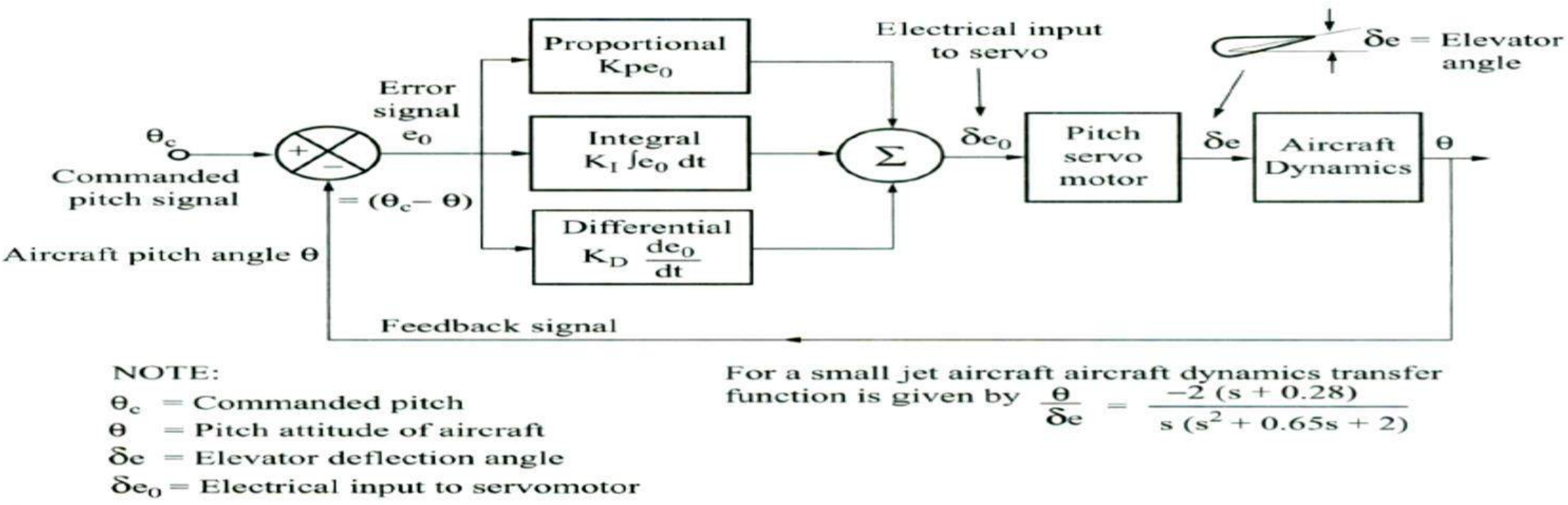
  K_P, K_I and K_D can be optimally adjusted to get correct damping and time constant
- Using Ziegler - Nicholos method

  (see a standard textbook on control systems)

- The earliest autopilot used just a proportional (P) control.
- Proportional control suffers from poor damping characteristics, large response time and has a steady state error, which is not desirable characteristics.
- Damping characteristics and speed of response were improved using the derivative (D) control.
- Next, integral(I) control was included to reduce the steady state error.
- All the three controls are adapted in the PID controller.

PID Controller

- PID control is widely used in industrial control systems.



- An error signal, obtained by taking the difference between commanded pitch and the actual pitch attitude of aircraft B is fed to the PID controller.
- The controller minimises the error by adjusting the gains Kp, Ki, and KD to optimise the controllers performance.
- Such optimization achieves the desired overshoot, damping and settling time, to reach the commanded pitch.

- The gains must be tuned according to the aircraft dynamics.
- One of the popular methods of tuning is the Ziegler-Nichols method, developed by Joh. G. Ziegler and Nathaniel B. Nichols.
- In this method, the integral gain Kr and differential gain, KD are first kept at zero. The proportional gain KD is increased until the gain reaches a critical value, Kc.

- The values Kc and the period of oscillation Tc are used to tune the gain as shown below:

Control Type	K_P	K_I	K_D
P	$0.5\ K_C$		
PI	$0.45\ K_C$	$1.2\ K_P/T_C$	
PID	$0.60\ K_C$	$2\ K_P/T_C$	$K_P T_C/8$

- Modem PID controllers, however do not use the above manual tuning method. Instead, they use PID tuning software to achieve consistent results, using impulse response of the system.
- Modem aircraft use Flight Management System

• Figure shows the Autopilot Mode Select Panel.

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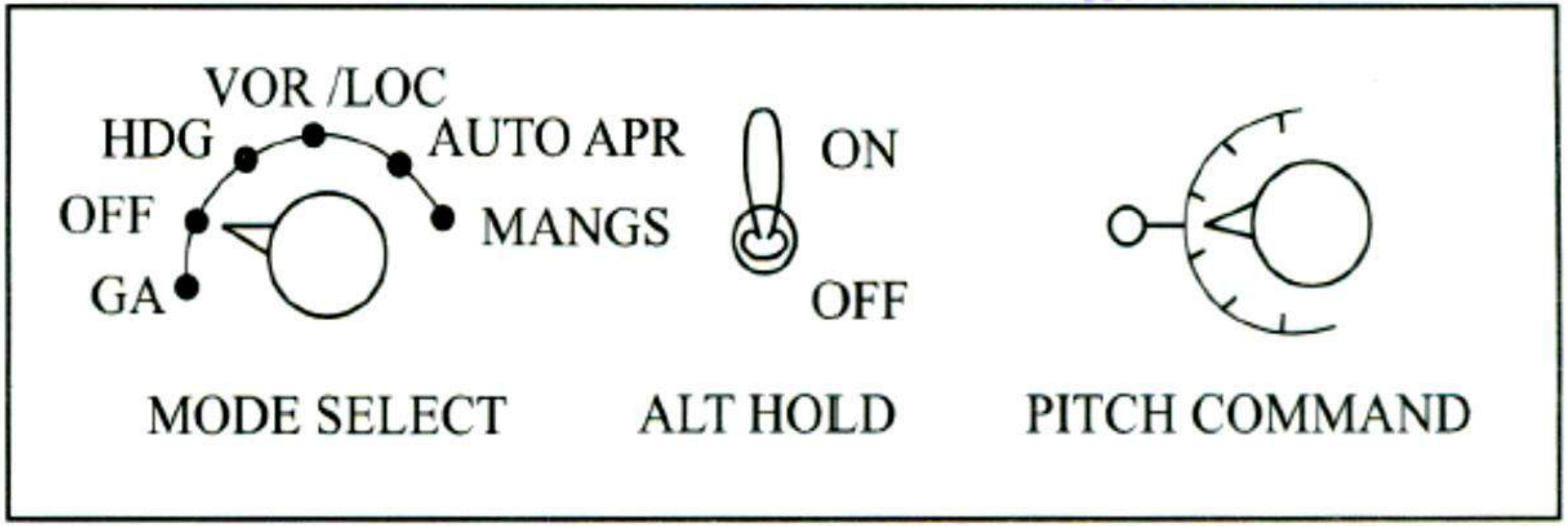


Fig. 10.3 Mode Control Panel (MCP) of an autopilot.

Different modes and their functionalities are listed in: Table 10.1 below:

Table 10.1 Different autopilot commands

Mode	Functionality
1. GA	Go Around mode. Aircraft is made to fly with wings level, pitch up and full throttle
2. HDG	Allows heading selection in HSI. In this mode the aircraft can be pitched up manually by Pitch Trim Wheels (PTW) or can be put on ALT Hold mode, with inputs from Air Data Computer
3. VOR/LOC	Allows selection of VOR radial. Alternatively a Localiser beam can be selected. Pitch channel, as in HDG mode, can be in Manual mode or ALT HOLD mode.

	Mode	Functionality
4.	AUTO APR	In this mode ILS beams (GS and LOC) are automatically selected. Any deviation in LOC beam operates the roll channel; and GS deviation operates the pitch channel.
5.	MAN. GS	This mode is operated to capture GS manually and when autopilot malfunctions
6.	ALT HOLD	Autopilot follows this command to fly at preselected altitude.
7.	PITCH COMMAND (Manual)	Pitch Command Knob can be rotated to select the pitch up (up to 15°) and pitch down (max 10°) for the pitch channel of Autopilot computer

- Modern autopilots use triple or quadraplex redundant computer, with a reliable software, to control the aircraft.
- The computers read the aircraft's position from an Inertial Navigation System.
- The basic sensors are gyros for angular positions and accelerometers for displacements.
- Computer-Aided Software Engineering (CASE) processes are used to develop the software required to steer the aircraft.
- Redundant channels are used to achieve the desired reliability figures.

Auto throttle (AT)

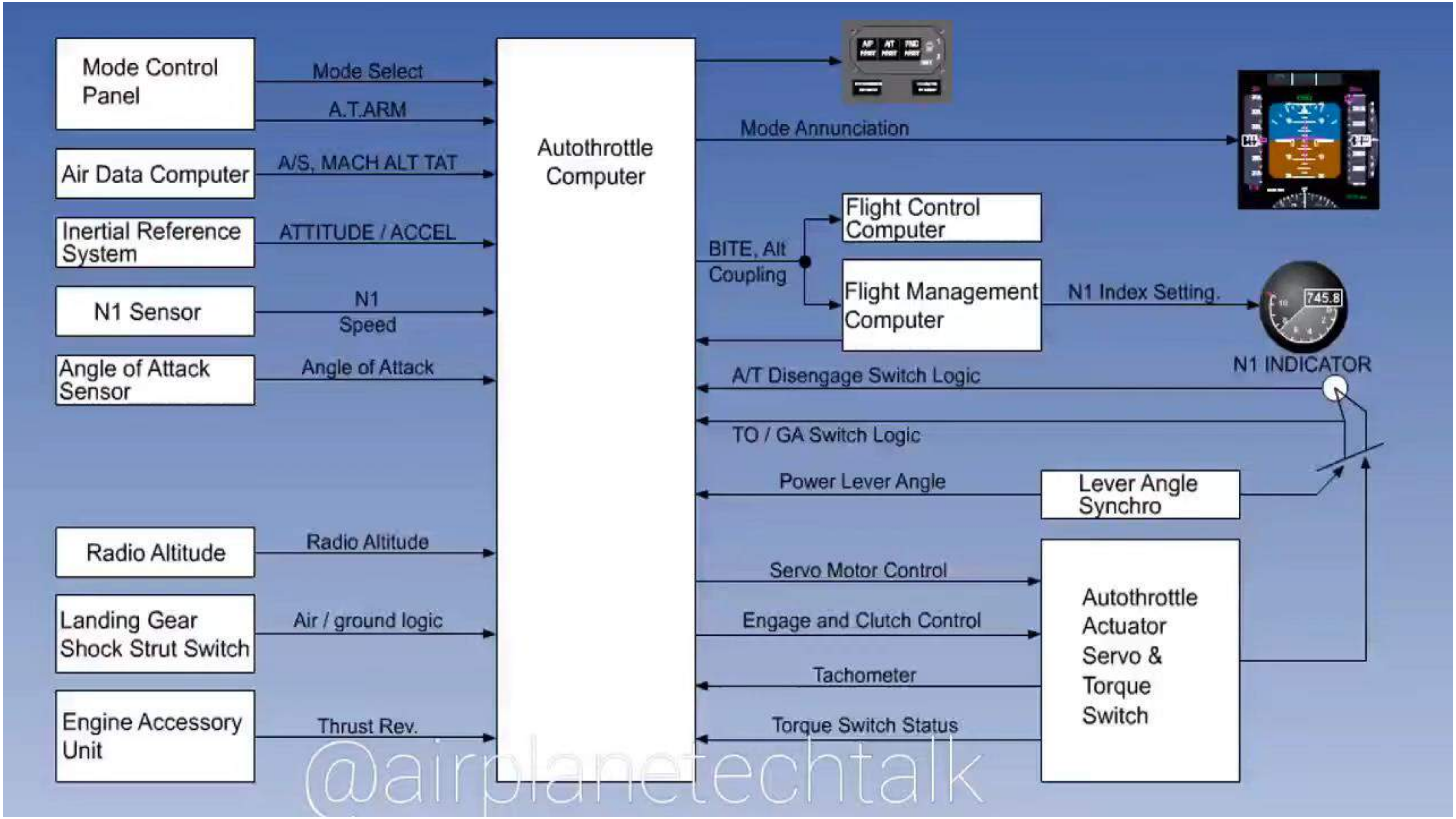
- Automatic Throttle (Autothrottle) is another constituent of AFCS.
- AT is yet another aid to pilot and enables him to control the fuel flow in predetermined manner.
- Pilot specifies the desired mode of operation and engages AT. Thereafter the AT takes over and relieves the pilot o continued attention.

There are two modes of AT, namely:

- Speed mode, and
- Thrust mode.
- In the Speed mode, pilot selects the target speed. AT thereafter controls the aircraft speed within safe operating limits.
- In the Thrust mode, different thrust values are used for different phases of flight. As an example, during take-off, a constant take-off thrust is maintained by the AT, till the end of take-off phase.

- Boeing uses AT in all phases of flight except during taxing. AT mode selection is automatic and does not involve pilot action.
- However, pilot can disengage AT and manually takeover at any time and during any phase of flight.
- AT is part of AFCS and FMS (more recent), for efficient engine operation and fuel savings.

- In Boeing aircraft, the thrust lever moves as and when different thrusts are selected by the AT during different phases of flight. In some other planes such as Airbus aircraft, thrust lever does not move with changing thrust settings.


Mode Control Panel
Mode Select
A.T.ARM
Air Data Computer
A/S, MACH ALT TAT
Inertial Reference System
ATTITUDE / ACCEL
N1 Sensor
N1
Speed
Angle of Attack Sensor
Angle of Attack
Radio Altitude
Radio Altitude
Landing Gear Shock Strut Switch
Air / ground logic
Engine Accessory Unit
Thrust Rev.
Autothrottle Computer
Mode Annunciation
Flight Control Computer
BITE, Alt Coupling
Flight Management Computer
N1 Index Setting.
745.8
N1 INDICATOR
A/T Disengage Switch Logic
TO / GA Switch Logic
Power Lever Angle
Lever Angle Synchro
Servo Motor Control
Engage and Clutch Control
Tachometer
Torque Switch Status
Autothrottle Actuator Servo & Torque Switch
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Automatic Flight Control System (AFCS)

- Modem aircraft such as Boeing -747, -777- new 787, Airbus 320, 330, 340, latest 380, use AFCS (a more complex Autopilot) essentially to help the pilot in the following tasks:

(i) Navigation

(ii) Flight management

(iii) Stability augmentation of inherently unstable aircraft.

- Autopilot, Autothrotle, caution and warning systems etc. are all integrated in AFCS.
- Usually, there will be an associated control system for each of the three body-fixed axes, viz., pitch, roll, and yaw, as well as altitude and lattitude/longitude.

- Autopilots were initially developed to reduce pilot workload particularly under stressful situations, and the main functions of AFCS are:

1. To reduce pilot workload

(i) Attitude (pitch, roll and yaw control)

(ii) Speed control (to hold IAS and Mach number)

(iii) Altitude hold (to capture and maintain desired altitude).

2. Stability augmentation systems

(i) Modem fighters, are intentionally made unstable with the objective of achieving higher speed of response (agility).

(ii) To improve handling qualities (HQ) of aircraft, so that pilot feels comfortable in the response of the aircraft to his control actions.

3. Instrument Landing System (ILS)

(i) for glide slope (GS) capture to fly the aircraft to ride along the electronic beam to the runway-this is the control in the vertical plane.

(ii) for localiser capture to align the aircraft with the centre line of runway-control the aircraft in the lateral plane, and

(iii) for flare control to make smooth and safe transition from as to touch down on the runway.

- Pilot controls the following control surfaces to fly the aircraft:

(i) Primary Control Surfaces

- The primary control surfaces are:
- elevator (for pitching up or down the aircraft).
- ailerons (for roll control),
- rudder (for yaw/directional control).

(ii) Secondary Control Surfaces

- These control surfaces generate much smaller control forces and are colocated as small tabs in the respective pitch, roll and yaw control surfaces as described below:

(i) pitch trim to eliminate continuous pilot pressure to maintain the desired pitch attitude of the aircraft so that the pilot need not exert constant pressure to hold the pitch attitude

(ii) rudder trim, for similar purpose in directional attitude

(iii) aileron trim, for roll trim.

- In addition there will be other useful secondary surfaces such as:

(i) **wing flaps,** which are extensions of wing, to provide additional lift at low aircraft speeds as, for example, during take-off and landing.

- (ii) slats and slots are respectively leading and trailing edge aerodynamic surfaces, deployed to enhance lift during landing.
- (iii) air brakes, which extend vertically above the wing to wash off air speeds during landing.

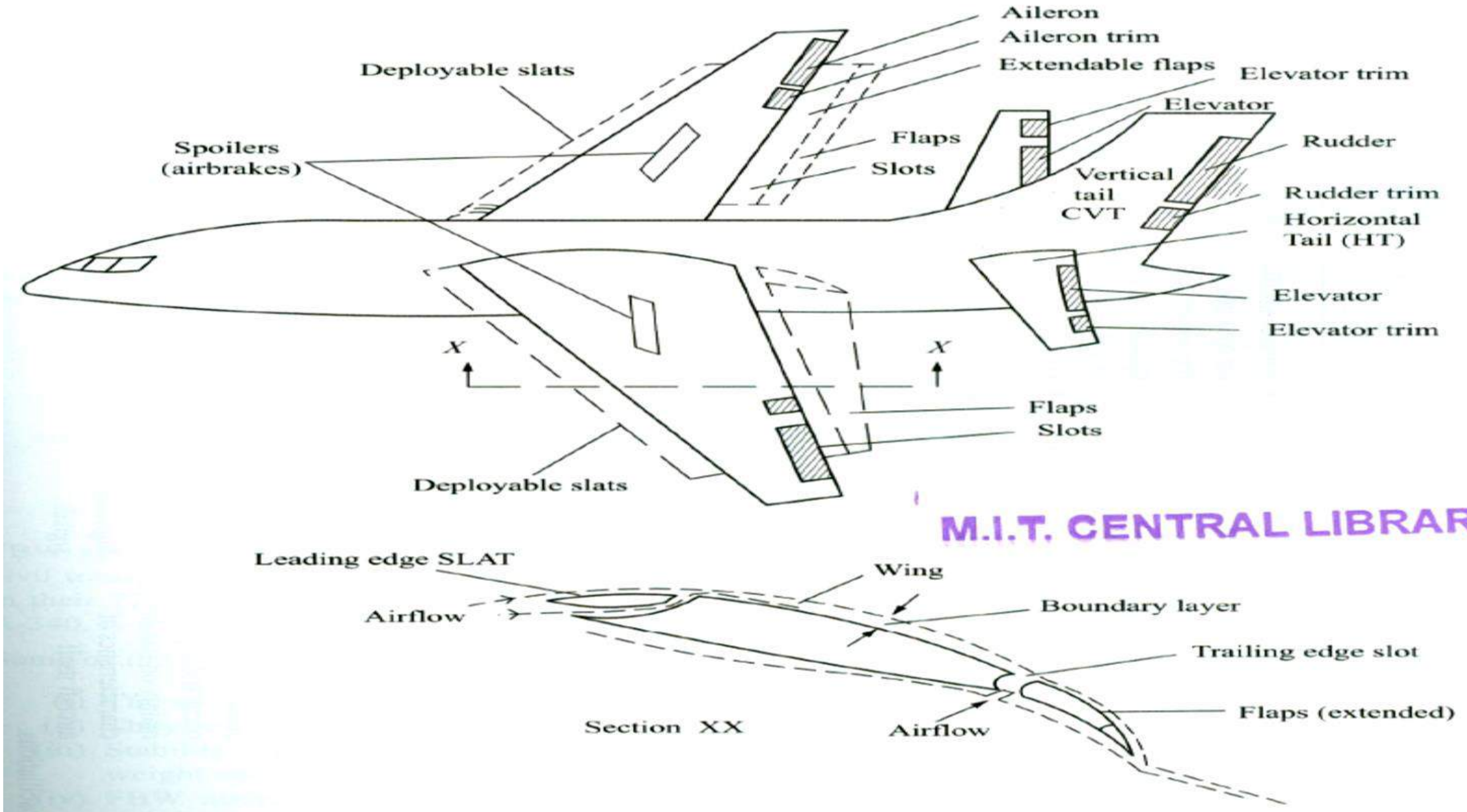

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Fig. 10.7 Aircraft primary and secondary control surfaces.

FLIGHT CONTROL SYSTEMS

Mechanical/ Manual

- Used in smaller aircraft
- Pilot is able to move control surfaces directly with some leverage.
- Uses chains, rods, bell cranks to transfer pilot force to control surfaces
- Aerodynamic assistance by servo tabs to control surfaces as in early piston engines and jet transport aircraft

Hydromechanical Units (HMU)

- Hydraulic boost using hydraulic cylinders/pistons
- Requires artificial feel, or else pilot can move surfaces into dangerous flight conditions such as stall, spin and PIOs*
- Uses stick shakers to alert pilots of incipient stall, even before stalling occurs
- HMUs use heavy-pumps, accumulators
- Requires careful routing of mechanical linkages and hydraulic pipes
- Dangerous flight conditions can still occur and depend mainly on stability characteristics of aircraft itself

Digital Fly-by-Wire DFBW

- Mechanical linkages are eliminated, instead pilot commands are transferred using electrical signals via cables.
- Reduces weight and complexity of signal routing
- Improves reliability by using multiple redundant systems
- Uses computer control
- Provides stability augmentation electronically
- Still uses hydraulic systems, cylinders actuators, and servovalves.
- Uses digital buses (ARINC 429/629, AFDX, MIL-STD-1553) to provide a highway for digital signals.

Fly-by-Light FBL

- Same as DFBW except signals are transmitted using optical signals and fibres
- Uses optical bus MIL-STD-1773
- Still uses massive hydraulic systems to actuate control surfaces.

Electrical Actuators

- Uses electrical motors, solenoids instead of hydraulic actuators
- Otherwise same as DEBW

Intelligent Flight Control Systems

- An extension of DFBW to intelligently *compensate* for aircraft damage and failure during flight.
- Compensates for loss of:
  - hydraulics (most common)
  - rudder
  - ailerons
  - engines
- Compensation by using only engine thrust and other avionic systems.

* Pilot induced oscillations.

- Some of the key advantages of FBW aircraft are summarized below:

(i) The weight of the aircraft is reduced.

(ii) They respond more flexibly to changing aerodynamic conditions.

(iii) Stability augmentation results in certain desirable features such as further reduction in weight and improved agility (response speed).

(iv) FBW aircraft require less maintenance, while mechanical and HMU aircraft require periodic lubrication, tension adjustments, leak checks, fluid changes, etc.

(v) Having redundant computer channels between the pilot and aircraft enhances safety of flight, for example, the control system can anticipate and prevent stall.

Fly-by-Light System: Instead of using electric wires in FBW, as per MIL-STD-1553 data bus, FBL uses fibre-optic communication link, which has several advantages such as:

- immunity against EMI
- radiation resistant
- saving in weight
- improved reliability.

Intelligent Flight Control System (IFCS)

- IFCS is an extension of digital Fly-by-wire system.
- The major objective of IFCS is to intelligently compensate any damage or failure of aircraft systems during flight.
- There will be usually loss in hydraulics which disables the flight control surfaces and hence the pilot loses his control over the aircraft.
- IFCS enables the aircraft to be flown, when their control surfaces become inoperable.

- In aileron failure situations, intelligently varying engine thrust, pitch can be controlled.
- Engines are mounted below the center of gravity (CG) of aircraft.
- As the thrust is increased the aircraft pitches up and vice versa.

- Similarly, when the rudder becomes inoperative, flight direction can be altered by asymmetric thrust by the engines.
- If left engine is idled and right engine's thrust is increased, a left turn is initiated and vice versa.
- If the aircraft is turning left, right wing will be moving faster and therefore will produce greater lift on the right wing.
- This results in a rolling moment and this helps in making a left turn- sort of coordinated (airleron/rudder control) turn.

Future Trend

1. AFCS functions have further evolved into Flight Management System taking data from many subsystems and taking appropriate automatic actions, without overloading the pilot

2. Instead of heavy, cumbersome and messy hydraulic systems high voltage and high power electric motors (270 VDC/several kWs) are used in all-electric actuation of control surfaces.

3. Fault tolerant and damage-resistant systems will be developed, particularly for supersonic fighter aircraft, to survive battle damage.

4. Pilotless unmanned air vehicles have already replaced conventional fighter planes in the recent wars in Iraq and Afghanistan, by US. This will not only be economical, but also saves pilot's life.

THANK YOU