Chapter 8

Autopilot and Flight Management Systems

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2019

1. Introduction

- Modern aircraft require a very close degree of integration between the **Autopilot (A/P)** and **Flight Management** systems, particularly in their respective control laws.
- The **basic function of the autopilot** is to control the flight of the aircraft and maintain it on a pre-determined path in space without any action being required by the pilot. (Once the pilot has selected the appropriate control mode(s) of the autopilot).
- The autopilot can thus relieve the pilot from the fatigue and tedium of having to maintain continuous control of the aircraft's flight path on a long duration flight so the pilot can concentrate on other tasks and the management of the mission.
- A well designed autopilot system which is properly integrated with the aircraft flight control system can achieve a faster response and maintain a more precise flight path than the pilot.

1. Introduction

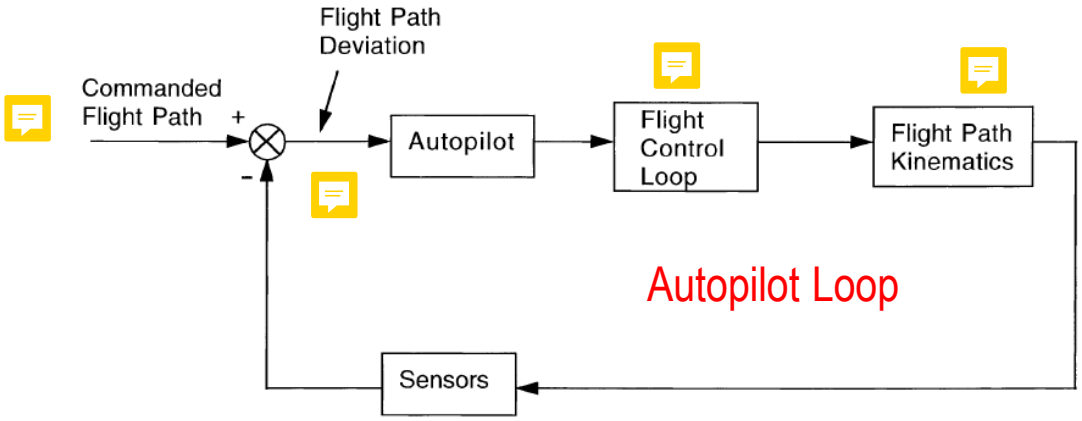
- Even more important, the autopilot response is always consistent whereas a pilot's response can be affected by fatigue and work load and stress.
- The autopilot is thus able to provide a very precise control of the aircraft's flight path for such applications as fully automatic landing in very poor, or even zero visibility conditions.
- In the case of a military strike aircraft, the autopilot in conjunction with a T/F (terrain following) guidance system can provide an all weather automatic terrain following capability.
- This enables the aircraft to fly at high speed (around 600 knots) at very low altitude (200 ft or less) automatically following the terrain profile to stay below the radar horizon of enemy radars.

1. Introduction

- The prime role of the **Flight Management System (FMS)** is to assist the pilot in managing the flight in an optimum manner by automating as many of the tasks as appropriate to reduce the pilot workload. The FMS thus performs a number of functions, such as:
  - Automatic navigation and guidance including '4D' navigation.
  - Presentation of information.
  - Management of aircraft systems.
  - Efficient management of fuel.
  - Reduction of operating costs.
- The detailed implementation of an FMS is a complex subject and can involve over 100 man-years of software engineering effort and very extensive (and expensive) flight trials before certification of the system can be obtained from the regulatory authorities.
- FMS has an equally important role in a military aircraft for accurate adherence to an optimum flight path and the ability to keep a rendezvous at a particular position and time.

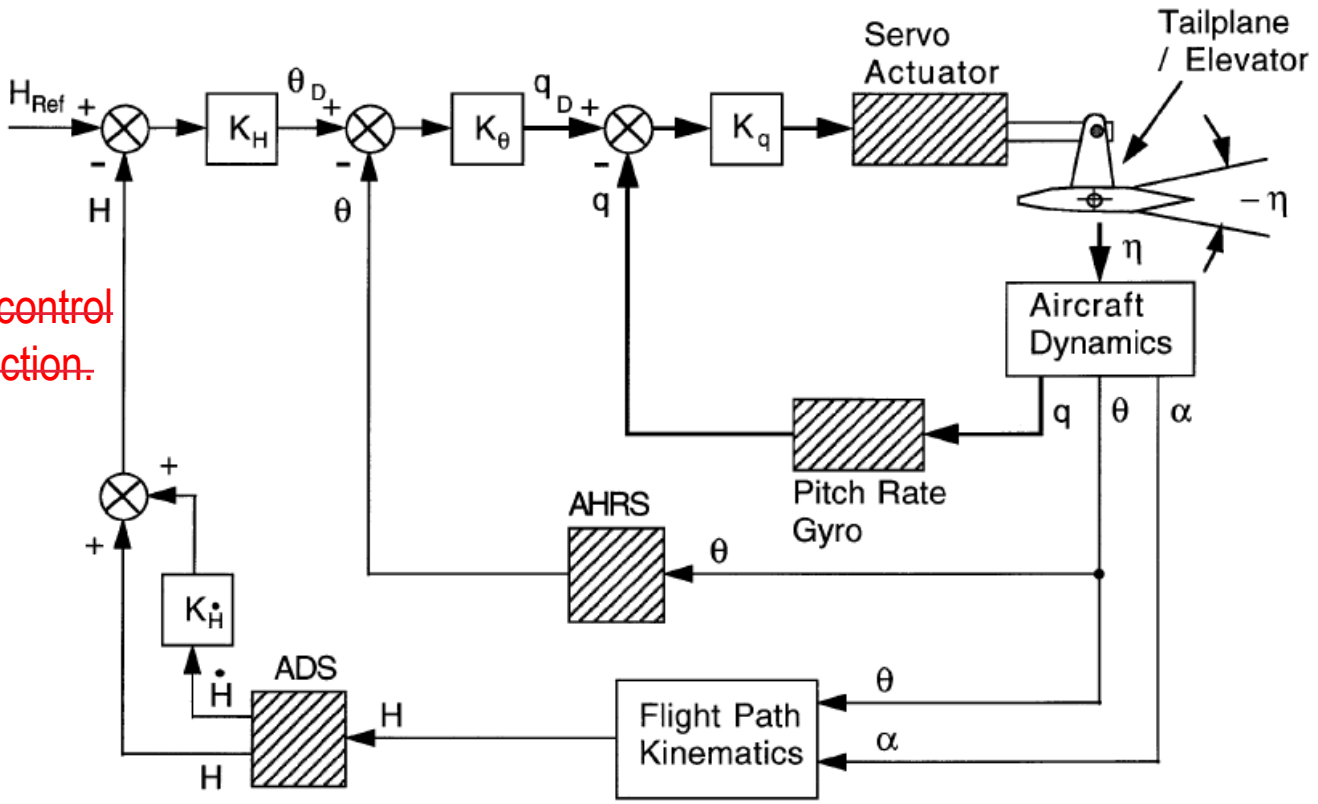
2. Autopilot

- The autopilot exercises a guidance function in the outer loop and generates commands to the inner flight control loop.
- These commands are generally attitude commands which operate the aircraft's control surfaces through a closed-loop control system so that the aircraft rotates about the pitch and roll axes until the measured pitch and bank angles are equal to the commanded angles.
- The changes in the aircraft's pitch and bank angles then cause the aircraft flight path to change through the flight path kinematics.



2. Autopilot

Altitude control A/P function.



Pitch rate gyro and AHRS are shown separately for clarity, along with the Altitude Derivation System.

2. Autopilot

ILS/MLS Coupled Autopilot Control

- ILS is a radio based approach guidance system installed at major airports and airfields where the runway length exceeds 1800 m which provides guidance in poor visibility conditions during the approach to the runway.
- A small number of major airports are also now equipped with MLS – microwave landing system. MLS is a later and more accurate system which is superior in all aspects to ILS.
- ILS, however, is a very widely used system and it will be a long time before it is completely replaced. It will thus be supported and maintained for many years to come.
- Satellite Based Augmentation Systems (SBAS). Support Cat. II
- Ground Based Augmentation System, (GBAS). Support Cat. III

Table 8.2 Visibility categories.

Category	Minimum Visibility Ceiling	Runway Visual Range
I	200 ft	800 m
II	100 ft	400 m
IIIa	12–35 ft	100–300 m
	Depending on aircraft type and size	
IIIb	12 ft	<100 m
IIIc	0 ft	0 m

2. Autopilot

ILS/MLS Coupled Autopilot Control

- The **runway approach guidance signals** from the ILS (or MLS) receivers in the aircraft can be coupled into the autopilot which then automatically steers the aircraft during the approach so that it is positioned along the centre line of the runway and on the descent path defined by the ILS (or MLS) beams.
- The autopilot control loops are basically the same for ILS or MLS coupling apart from some signal preconditioning.
- The ILS system basically comprises a **localizer transmitter** and a **glide slope transmitter** located by the airport runway together with two or three **radio marker beacons** located at set distances along the approach to the runway.

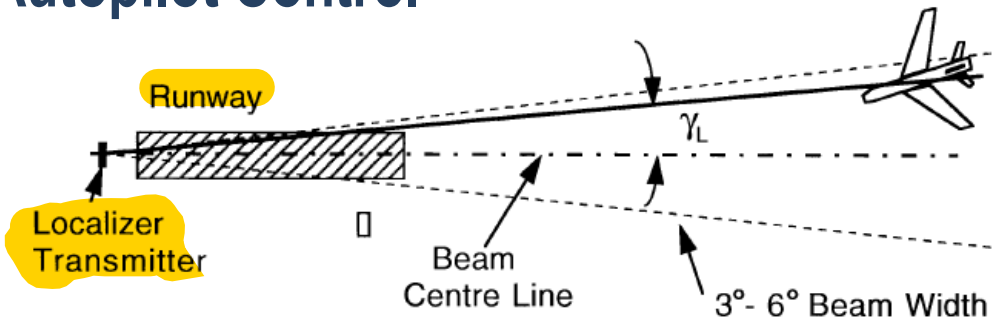
2. Autopilot

ILS/MLS Coupled Autopilot Control

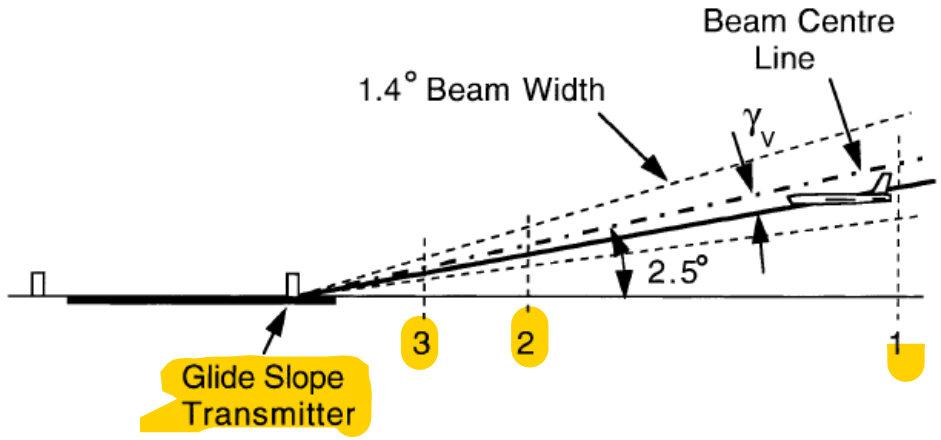
- The airborne equipment in the aircraft comprises **receivers and antennas for the localizer**, **glide slope and marker transmissions**.
- The localizer transmission, at VHF frequencies (108–122 MHz), provides information to the aircraft as to whether it is flying to the left or right of the centre line of the runway it is approaching.
- The glide slope (or glide path) transmission is at UHF frequencies (329.3–335 MHz) and provides information to the aircraft as to whether it is flying above or below the defined descent path of nominally 2.5◦, for the airport concerned.
- The marker beacon transmissions are at 75 MHz.

2. Autopilot

ILS/MLS Coupled Autopilot Control



ILS localizer and glide slope geometry.



1 Outer Marker
2 Middle Marker
3 Inner Marker

2. Autopilot

ILS/MLS Coupled Autopilot Control

- The middle marker beacon is located at a distance of between 1,000 and 2,000 m from the runway threshold and the outer marker beacon is situated at a distance of between 4,500 and 7,500 m from the middle marker.
- The inner marker beacon is only installed with an airport ILS system which is certified to **Category III** landing information standards and is located at a distance of 305 m (1,000 ft) from the runway threshold.
- Visibility conditions are divided into three categories, namely Category I, Category II and Category III, depending on the vertical visibility ceiling and the runway visual range (RVR); the visibility conditions deteriorate as the category number increases.

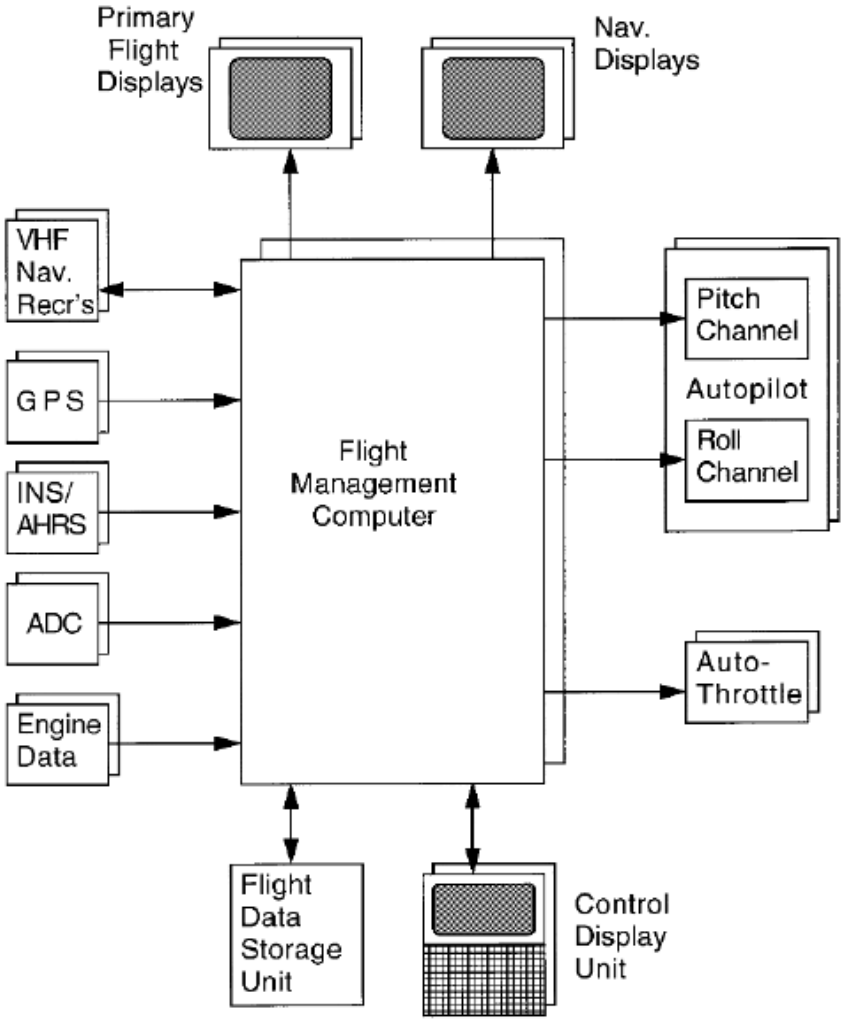
3. Flight Management System

- The FMS has become one of the key avionics systems because of the major reduction in pilot work load which is achieved by its use.
- In the case of military aircraft, they have enabled single crew operation of advanced strike aircraft.
  - Quantifiable economic benefits – provision of automatic navigation and flight path guidance to optimize the aircraft's performance and hence minimize flight costs.
  - Air traffic – growth of air traffic density and consequently more stringent ATC requirements, particularly the importance of 4D navigation.
  - Accurate navigation sources – availability of accurate navigation sources. For example, INS /IRS, GPS, VOR and ILS / MLS.
  - Computing power – availability of very powerful, reliable, affordable computers.
  - Data bus systems – ability to interconnect the various sub-systems.

3. Flight Management System

- The FMS carries out the following tasks:
  - Flight guidance and lateral and vertical control of the aircraft flight path.
  - Monitoring the aircraft flight envelope and computing the optimum speed for each phase of the flight and ensuring safe margins are maintained with respect to the minimum and maximum speeds over the flight envelope.
  - Automatic control of the engine thrust to control the aircraft speed.
- In addition the FMS plays a major role in the flight planning task, provides a computerized flight planning aid to the pilot and enables major revisions to the flight plan to be made in flight, if necessary, to cope with changes in circumstances.

3. Flight Management System



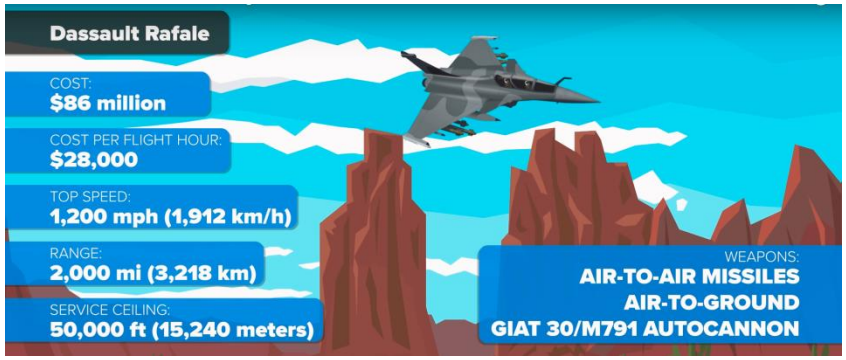
Flight Management System Block Diagram

3. Flight Management System

- Important functions carried out by the FMS :
- **Radio Navigation Tuning**: The FMS automatically tunes the radio navigation aids, (NAVAIDs), used for the radio position computation, the NAVAIDS for display on the Navigation Displays and the landing system NAVAIDS.
- **Navigation**: The FMS combines the data from the navigational sources, comprising the inertial systems, GPS and the radio navigation systems, to derive the best estimate of the aircraft position.
- **Flight Planning**: The FMS computes and displays the speed, altitude, time, and fuel predictions that are associated with the flight plan.

3. Flight Management System

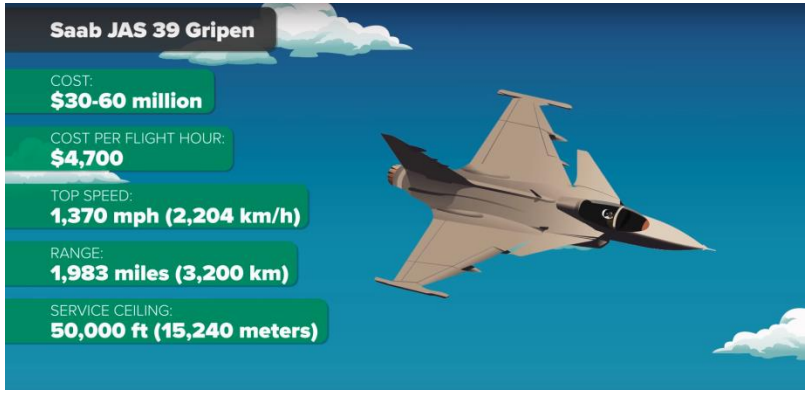
- **Performance Prediction and Flight Path Optimization**: The FMS is able to optimize specific aspects of the flight plan from a knowledge of the aircraft type, weight, engines and performance characteristics, information on the wind and air temperature and the aircraft state- airspeed, Mach number, height, etc.
- **Control of the Vertical Flight Path Profile**: The FMS selects the speeds, altitudes and engine power settings during climbs, cruises and descents taking into account the flight plan, the prevailing conditions and the optimization of the operation of the aircraft.

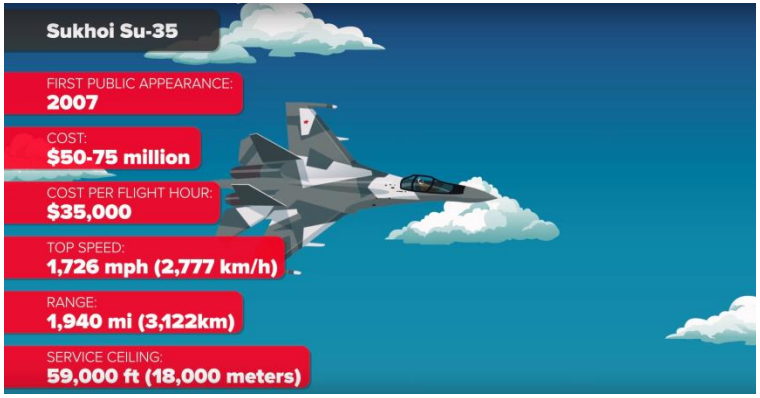

Dassault Rafale
COST:
$86 million
COST PER FLIGHT HOUR:
$28,000
TOP SPEED:
1,200 mph (1,912 km/h)
RANGE:
2,000 mi (3,218 km)
SERVICE CEILING:
50,000 ft (15,240 meters)
WEAPONS:
AIR-TO-AIR MISSILES
AIR-TO-GROUND
GIAT 30/M791 AUTOCANNON


Eurofighter Typhoon
COST:
$140 million
COST PER FLIGHT HOUR:
$14,000
TOP SPEED:
1,550 mph (2,495 km/h)
RANGE:
1,800 mi (2,900 km)
SERVICE CEILING:
65,000 ft (19,812 meters)


Lockheed Martin F-22 Raptor
COST:
$339 million
COST PER FLIGHT HOUR:
$68,362
TOP SPEED:
1,500 mph (2,414 km/h)
RANGE:
1,840 mi (2,961 km)
SERVICE CEILING:
65,616 ft (20,000 meters)


Lockheed Martin F-35 Lightning II
COST:
$95.6-122.8 million
COST PER FLIGHT HOUR:
$42,169
TOP SPEED:
1,200 mph (1,912km/h)
RANGE:
1,367 mi (2,200km)
SERVICE CEILING:
60,000 ft (18.288 meters)


Saab JAS 39 Gripen
COST:
$30-60 million
COST PER FLIGHT HOUR:
$4,700
TOP SPEED:
1,370 mph (2,204 km/h)
RANGE:
1,983 miles (3,200 km)
SERVICE CEILING:
50,000 ft (15,240 meters)


Sukhoi Su-35
FIRST PUBLIC APPEARANCE:
2007
COST:
$50-75 million
COST PER FLIGHT HOUR:
$35,000
TOP SPEED:
1,726 mph (2,777 km/h)
RANGE:
1,940 mi (3,122km)
SERVICE CEILING:
59,000 ft (18,000 meters)