An Introduction

Flight Management Systems
[SF] User-Interface [LS]
[LS] Vertical Guidance [LS]
[LS] Lateral Guidance [LS]
[SG] Aircraft State [LS]
[LS] Performance Database [SG]
[SG] Navigation Database [SG]

RMS Functions - An Introduction • RMS Architecture [SG] •
[LS] Levels of Automation [LS]
[LS] Cockpit Components [LS]

Cockpit Overview • Organization
COMMUNICATION (ATC and Airlines Operation Center)

AIRCRAFT SYSTEM MANAGEMENT
- Aircraft Position Fixing
- Flight Planning
- Guidance
- Control

NAVIGATION

Airline Pilot View:
COMMUNICATE (interact with ATC)
NAVIGATE (determine route and aircraft position)
AVIATE (fly the plane)

Cockpit System Tasks
Cockpit System Navigation Tasks
Role of Cockpit Automation
Avionics User Interface
Primary Flight Display

Aircraft is free-body moving through space

moments (pitch, roll, yaw)
path
acceleration (normal, flight)
airspeed, vertical speed
velocity (groundspeed, altitude, time)
position (latitude, longitude)

(path)
Interceptor -
climb/descent -
Level-off/Initiate -
Top-of-Descent (T/D) -
Top-of-Climb (T/C) -
Vertical Flight Plan -
magnetic line -
Waypoints/Fixes -
Lateral Flight Plan -
runways -
radio navigation beacons -
Waypoints/Fixes -
Aircraft Position Fixing -

Navigation Display - Map
Range: 5nm - 160nm
Center: Active Waypoint
Orientation: Aircraft

Map View

Range: 5nm - 160nm
Lees Page
Center: Top Waypoint on
Orientation: North - up

Plan View

Navigation Display - Plan
Stick, Rudder, & Throttles

- Pitch controls speed
- Thrust makes aircraft go up/down
- Rudder/Alitrons control roll
- Excess Thrust = \( \text{Excess Thrust} = 0 \)
- \( \text{WSin}(\gamma) \leq 0 \)
- \( \text{Level Flight Constant Speed} \)
- \( \text{Climbing Flight Constant Speed} \)
- Thrust cos\( \alpha \) - Drag - Weight sin\( \gamma \)

\[
\text{Acceleration} = \text{mass} \times \text{Excess Thrust}
\]
FMS Vertical Path
- Climb/descend, hold current altitude
- Climb/descend to alt at fixed rate-of-
to alt with max/ide thrust
- Control target altitude (climb/descend)

Set Altitude/Targe Mode
- Set altitude target
- Control lateral path, FMS lateral path
- Control target hdg/track, hold current
- Set heading/track target speed
- Control target speed, hold current
- V/S/Mach

Set Speed Target Mode

Mode Control Panel
Mode Control Panel
Multi-Function Control & Display
• EICAS
• Airbrake
• Flaps/Slat Handle
• Throttle Lever

Misc. Cockpit Input Devices
Quiz
tasks in certain situations

Pilots take over control of various cockpit systems

does not automate all circumstances
not seamless
introduced incrementally over time

Cockpit Automation

Levels of Automation
Aircraft follows MCDU F-PLN commands/Pilot monitors

Managed Operation (MCDU/MCP)
3) Managed

2) Selected

1) Manual

(1) NAV, PROF, FMS SPD, Autopilot
(2) Autopilot only
(3) Autopilot and FD

When you have pressed:
What is the source of the target/modes?

Quiz

Levels of Auto
NPM Architecture
Quiz
Navigation Database
Gate

Approaches (ILS, VOR/DME, GPS, etc)

Departures (SID, STAR, Arrivals)

Runways

Airport Data

Communications

Holding Patterns

Waypoints

Airways

Enroute Data

Navairs - Type, Frequency, Location, Elevation

Navigation Data Base Contents
(independent of winds, repeatable in different winds)
earth-referenced legs (earth-bounded track)
(not repeatable in different winds)
airmass legs (earth-bounded track determined by wind

Two types of legs:

-C-F (Course ends with Fix)
-V-I (Vector ends with Intercept)

Terminator is how the leg ends.
"path" is how you navigate
"path and terminator"

Legs used to construct routes

Navigation Data Base Legs
of other Leg Type instances
attributes, inserted into a string (linked list)
of the Leg Type Class, with specific data for
Flightplan (created by the pilot) is instances

- TO FIX
- FROM FIX

Example: TP Leg Class is defined by:

Attributes
Think of Leg Types as Classes with

Navigation Data Base Legs
Navigation Data Base Legs

Objective is to join a route
- IF, CF, DF, VI
- Frequently used

Departure

Mt.

Wind
Navigation Data Base Legs

- Enroute
- TF
- Fly earth-referenced lateral path (great circle)
- Wind
- Traditional navigation equipment
- Many added to allow flying approach plates
- All A424 types used

Arrival

Navigation Data Base Legs
Two Kinds of Direction on a Sphere:

1. A Great Circle
2. A Rhumb Line

Routes and Direction of TF Legs
Great Circle: Routes and Direction of TR Legs
constant course of 80°

Example: a rhumb line from New York to London holds a

Rhumb Line:

Routes and Direction of TF Legs
1. Explain the difference between an "airmass" leg and an "earth-referenced" leg.

2. Give an example of an earth-referenced leg.

3. Give an example of an earth-referenced leg.
$0 > \lambda$  \hspace{1cm} \text{Descent} (n-dot = 0) \\
$0 < \lambda$  \hspace{1cm} \text{Climb} (n-dot = 0) \\
$\lambda = 0$  \hspace{1cm} \text{Level Flight (n-dot = 0)} \\

Forces in Pitch Plane axis:

Equations of motion:

$\theta = \lambda + \alpha$

Airframe Performance Model
Predicting the Aircraft Trajectory

Given fixed $\lambda = -3$ degrees and $T = idle$-thrust, what will the speed be in 5 nm? Given a fixed thrust, predict the downwash speed.

\[
\dot{\Lambda} = \frac{1}{\text{mass}} (\text{Thrust cos} \alpha - \text{Drag - Weight sin} \alpha) / n \text{-dot}
\]

where:

\[
\int_0^\infty \lambda = \dot{\Lambda}
\]
Structure of airlines
Choice of Cost Index reflects cost
- missed connections
- maintenance costs
- leasing costs
- crew costs

Time Related costs:

\[
\text{Fuel Costs (\$/lb of fuel)} \times \text{Time Related costs (\$/flight hour)} = \text{Cost Index}
\]

Fuel Cost Curves

Airline Cost Curves

Cost Index
Reduced time costs
Speed increases over light
Increased trip fuel costs
C_I = 999 Fastest time

Increased time costs
Speed decreases over light
Maximum range
Minimum trip fuel

C_I = 0

Optimum Speeds (Econ)
Aircraft CAS/Mach Profiles
Speed Profiles & Speed Envelope
1) When the aircraft is at constant speed in level flight?

(a) Thrust > Drag  (b) Thrust = Drag  (c) Thrust < Drag

2) When the aircraft is accelerating in level flight?

(a) Thrust = Drag  (b) Thrust < Drag  (c) Thrust > Drag

3) When the aircraft is at constant speed climbing?

(a) Thrust > Drag  (b) Thrust < Drag  (c) Thrust = Drag

4) What is the CAS/Mach CrossOver Altitude?

(a) Thrust - Drag = 0  (b) Thrust - Drag < 0  (c) Thrust - Drag > 0

Quiz
Approach (and Landing Runway)

Standard Instrument Arrival (STAR)

Departure Runway and Standard Instrument Departure (SID)

Company route, airways, jetways (en-route flightplan)

Destination

Origin

Built from NAV DB pre-planned segments:

Leg terminations and leg types

String of waypoints

Also known as "Route"

Flightplan
For descent prior to top of descent, heading vectors cleared direct to waypoint, or cleared aircraft trajectory to get back to the path (e.g. after "off-path"). Trajectory predictions may be "on-path" or "off-path". Model. Computed using Aircraft Performance. Decision-aiding information used by pilots. Down-path waypoints. Forecast aircraft position, velocities at...
Trip: Fuel burn/time remaining
Waypoints: ETAS, Winds

Los Angeles to San Francisco

Flightplan Trajectory Predictions
- NOT constructed for takeoff, climb, or cruise (airmass
- Vertical path
  - Includes turn geometries for leg transitions
- NOT constructed for heading legs (e.g. V1)
- NOT constructed for all track legs (TF, CF, DF, HF, HM, ..)
- Lateral path
- Reference targets used by Guidance
- 4-D desired trajectory

Fishing Plan Paths
Vertical Path

Lateral Path

Flight Path Plan Paths
When the aircraft is at the gate, 
(d) predict the aircraft trajectory on the 
(c) construct a path to satisfy the flight plan 
(b) modify a flight plan 
(a) build a flight plan 

methods would be included in this class to:

Consider the flight plan as a class. What

Quiz
Airborne Air Data Computers (pilot tubes)
Airborne Inertial Reference Units (gyroscopes)
Ground-based Radio Navigation Beacons
Satellite Global Positioning System

Uses best sensor data from:
Known as "navigation" by engineers
Known as "position fixing" by pilots
accelerations
Computes aircraft position, velocities,

Aircraft State
- Airborne Air Data Computers (pitot tubes)
  - Long-term
  - Accurate over short-term, small errors compounded over
    - Airborne Inertial Reference Units (gyroscopes)
  - Noisy over short-term, accurate over long-term
    - Ground-based Radio Navigation Beacons
      - Availability/reliability questions
        - Accurate over short and long-term
    - Satellite Global Positioning System
  - Position Mixing

Aircraft State
Lateral Guidance
LC - Autopilot Interface
Operational Procedures

1) Maintaining Legs
   - Rules for maintaining each leg (e.g. TF, CF, VI, HM, …)

2) Transitioning Between Legs

3) Recapturing Lateral Leg
Operational Procedures
other intercepts «
45° intercept «
Within 10nm Abeam:

LNAV armed, no FMS action «

More than 10nm Abeam:
Airframe/flight course (heading)
Factors: abeam distance between aircraft and leg,

3) Recapturing Lateral Leg

Operational Procedures
Vertical Guidance
VC - Autopilot Interface
- Pitch/Thrust Control Modes (6)
- Vertical speed targets (2)
- Speed targets (26)
- Altitude targets (16)
- Operational Procedures (11)

Select targets and pitch/thrust control modes

**Vertical Guidance Operational Procedures:**

Vertical Guidance
Operational Procedures

Hold to Manual Termination

Speed Protection on Path

* Maintain VNAV Alt (above)

Return to Path From Late

(Below)

Converge to Path From Early

Descend on Path to VNAV Alt

Descend Phase

Climb Phase

* Maintain VNAV Alt

Climb to VNAV Alt

Climb Phase

* Maintain VNAV Alt

Climb to VNAV Alt

Climb Phase

Step Descent to New Cruise FL

Step Climb to New Cruise FL

Maintain Cruise Flight Level

Cruise Phase

* Maintain VNAV Alt

Step Descent to New Cruise FL

Maintain VNAV Alt

Flight Level

Cruise Phase

* Maintain VNAV Alt

Step Climb to New Cruise FL

Maintain VNAV Alt
VTEC: Vertical Guidance Terminology

- Mach
- Speed Segments (Decel, CAS)
- Path Segments (Idle, Fixed FPA)
- Descent/Approach Path
- (GPS, VFR)
- Approach Type (ILS, RNAV, NDB)
- Glide Slope/Glide Slope Intercept
- Minimum Descent Altitude
- Go Around Acceleration Altitude
- Go Around Thrust Reduction
- Destination Altitude
- Takeoff Acceleration Altitude
- Altitude
- Takeoff Thrust Reduction
- Origin Altitude
- Speed Constraint (CILP, DES)
- Climb/Descent Speed Limit
- Cruise Flight Level
- Altitude Constraints (CILP, DES)
2) Describe the Descent Speed Limit. What is it for?

d) Aircraft captures the optimum Descent/Approach Path.

T/D

c) ATC requests an immediate descent from the Climb FL prior to the

Quiz
User-Interface - CDU
B737

MCP - User Interface - MCP

MD10 (FPC)
Stages of a Typical Flight