Development and Validation of Procedures
Overview

From Procedure design to Database - The steps needed to ensure RNAV systems follow the procedure correctly

Learning Objectives

– The translation of procedure from origination into a data base
– Taking account of RNAV limitations if the procedure is to be followed correctly
– The validation of procedures
RNAV Procedure Description

• Instrument Flight Procedures
  – Published in AIP
  – Defined as textual descriptions supported by charts
  – The charts are used by the pilots and ATC
  – Database providers require clear and unambiguous procedure descriptions and use the charts to validate/check
Coding the Procedure

Procedure coding

- Translates textual description of route or a terminal procedure into a format usable in RNAV systems.

Two steps:

- Translation from AIP text/chart into ARINC 424 alphanumeric code

- Translation from ARINC 424 into avionic specific binary code (known as ‘packing’)

Successful translation into ARINC 424 depends upon a clear and unambiguous description of the route/procedure.
ARINC 424

- Industry standard for the transmission of data
- Navigation element uniquely defined and stored
- Can be accessed for any intended navigation purpose
- Developed to allow RNAV to be used on conventional procedures
- ICAO PANS-OPS references ARINC 424 rules and methodologies

Not developed for design of flight procedures,

BUT: understanding of ARINC 424 enables procedure designers to perform their tasks so that misinterpretations and errors are significantly reduced
<table>
<thead>
<tr>
<th>ARINC 424 Records</th>
<th>ARINC 424 Records</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VHF Navaids</strong></td>
<td><strong>Airport Communications</strong></td>
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<tr>
<td><strong>NDB Navaids</strong></td>
<td><strong>MSA</strong></td>
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<tr>
<td><strong>Waypoints</strong></td>
<td><strong>Airways Marker</strong></td>
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<tr>
<td><strong>Holding</strong></td>
<td><strong>Cruising Tables</strong></td>
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<td><strong>Airports</strong></td>
<td><strong>FIR/UIR</strong></td>
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<td><strong>SID/STAR APP</strong></td>
<td><strong>GRID MORA</strong></td>
</tr>
<tr>
<td><strong>Localiser and Glide</strong></td>
<td><strong>En-route Airways</strong></td>
</tr>
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<td><strong>Slope/MLS/GLS</strong></td>
<td><strong>En-route Airways</strong></td>
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<tr>
<td><strong>Company Route</strong></td>
<td><strong>Restrictive</strong></td>
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<tr>
<td><strong>Localiser Marker</strong></td>
<td><strong>En-route Communications</strong></td>
</tr>
<tr>
<td><strong>Path Points</strong></td>
<td><strong>Preferred Routes</strong></td>
</tr>
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<td></td>
<td><strong>Controlled Airspace</strong></td>
</tr>
</tbody>
</table>
En-Route Coding

- Individual airway legs defined by waypoint and altitude constraints
- En-route holds not associated with any aerodrome and identified as ‘ENRT’
Terminal Coding

- Procedure identified as SID, STAR or APCH
- Only one STAR allowed per route
- ENRT Transitions used to link STARs to APCHs.
- RWY Transitions used to link RWYs to SIDs
- Individual legs defined by heading, waypoint, waypoint transition, path terminator, speed constraint, altitude constraint as appropriate
Waypoint Transitions

Fly-by

Fly-over

Radius to Fix (RF)
Track Distances Between Turns

Fly-by WP

\[ \alpha_a \]

\[ \alpha_b \]

\[ Y_a \]

\[ Y_b \]

\[ r_a \]

Legdist

Fly-by WP

Fly-over WP

\[ \alpha_a \]

\[ r_{a1} \]

\[ Y_b \]
**RNAV – Path Terminator Leg Type**

<table>
<thead>
<tr>
<th>Path</th>
<th>Terminator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant DME arc</td>
<td>A</td>
</tr>
<tr>
<td>Course to</td>
<td>A</td>
</tr>
<tr>
<td>Direct Track</td>
<td>C</td>
</tr>
<tr>
<td>Course from a fix to</td>
<td>D</td>
</tr>
<tr>
<td>Holding pattern</td>
<td>F</td>
</tr>
<tr>
<td>Initial</td>
<td>H</td>
</tr>
<tr>
<td>Constant radius</td>
<td>I</td>
</tr>
<tr>
<td>Track between</td>
<td>R</td>
</tr>
<tr>
<td>Heading to</td>
<td>V</td>
</tr>
</tbody>
</table>

- **Altitude**
- **Distance**
- **DME distance**
- **Fix**
- **Next leg**
- **Manual termination**
- **Radial termination**
Path Terminators
14 RNAV Types

- Course to an Altitude - CA
- Course to a Fix - CF
- Direct to a Fix - DF
- Fix to an Altitude - FA
- Fix to a Manual Termination - FM
- Racetrack Course Reversal (Alt Term) - HA
- Racetrack (Single Circuit - Fix Term) - HF
- Racetrack (Manual Termination) - HM
- Initial Fix - IF
- Track to a Fix - TF
- Constant Radius Arc - RF
- Heading to an Altitude - VA
- Heading to an Intercept - VI
- Heading to a Manual Termination - VM
Course to an Altitude

Course is flown making adjustment for wind

090°

CA Leg

Unspecified Position
Course to Fix

Course is flown making adjustment for wind
Direct to Fix

Unspecified position

Direct DF Leg

A
Fix to Altitude

FA leg is flown making adjustment for wind

FA Leg

Unspecified Position

A

080°

8000'

16
From a Fix to a Manual Termination

FM leg is flown making adjustment for wind

Radar Vectors

FM Leg

A

80°
HA - Terminates at an altitude
HF - Terminates at the fix after one orbit
HM - Manually terminated
Initial Fix
Radius to Fix

RF Leg

Previous Segment

Arc Centre

Next Segment

A

B

C
Track to a Fix

TF Leg

A ➔ B
Heading to an Altitude

No correction made for wind

090°
VA Leg

8000'

Unspecified Position
Heading to Manual Termination

110°

VM Leg

No correction made for wind

Radar Vectors
Health Warning

- Available Path Terminators defined in PBN Manual Nav Specifications
- If the RNAV system does not have leg type demanded by procedure data packers have to select one (or combination of) available leg types to give best approximation
- Risk incorrect execution
Aircraft Types you cater for

Local fast regionals

Occasional older visitors
– lack of functionality

Heavy slow long-hauls
RNAV Procedure Description

- RNAV procedures defined by:
  - Sequence of waypoints
    - Identifier
    - Co-ordinates
    - Fly-over/fly-by/fixed radius
  - Path Terminators - ARINC 424
  - Altitude restrictions
  - Speed restrictions
  - Direction of turn
  - Required navaid
What Pilots Need to Know

- Waypoint names and sequence
- Fly-over/fly-by/fixed radius
- Turn direction
- Speed restrictions
- Altitude restrictions
- Required navaid
- Leg distance and magnetic track for error checks
- Fixes at certain waypoints for gross error checks
Procedure Description for Pilots

Waypoint sequence
Fly-over/fly-by/fixed radius
Speed/Altitude Restrictions
Leg distance & magnetic track
Fix information
Turn direction
Speed and Altitude Constraints

- Speed constraints allow tighter turns and can assist airspace design and operation.
- Altitude constraints can provide separation from obstacles and other traffic - minimum climb gradients must still be published.
Procedure Description for Database Providers

- Textual description provide formal statement of procedure
  - Often open to interpretation.
- RNAV procedures require more specific details including path terminators
  - Can result in lengthy descriptions.
  - Alternative descriptive methods have been developed by IFPP (OCP) and adopted by ICAO
    - Tabular layout
    - Formalised textual description
    - Formalised short-hand description
### RNAV Approach

<table>
<thead>
<tr>
<th>Path Terminator</th>
<th>Waypoint Name</th>
<th>Fly Over</th>
<th>Course/Track/Heading °M (°T)</th>
<th>Turn Direction</th>
<th>Altitude Constraint</th>
<th>Speed Constraint</th>
<th>Required Navaid</th>
<th>Bearing/Range to Navaid</th>
<th>VPA/TCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF</td>
<td>SUSER</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+5000</td>
<td>250</td>
<td>-</td>
<td>LOM 262/29</td>
<td>-</td>
</tr>
<tr>
<td>TF</td>
<td>CV023</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4000</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CF</td>
<td>CV024</td>
<td>-</td>
<td>348° (347.8°)</td>
<td>-</td>
<td>2680</td>
<td>150</td>
<td>OKE</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TF</td>
<td>RW35L</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>370</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-3°/50</td>
</tr>
<tr>
<td>FA</td>
<td>RW35L</td>
<td>Y</td>
<td>348° (347.8°)</td>
<td>L</td>
<td>770</td>
<td>-</td>
<td>OKE</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DF</td>
<td>SUSER</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>5000</td>
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</table>

### RNAV SID

<table>
<thead>
<tr>
<th>Path Terminator</th>
<th>Waypoint Name</th>
<th>Fly Over</th>
<th>Course/Track/Heading °M (°T)</th>
<th>Turn Direction</th>
<th>Altitude Constraint</th>
<th>Speed Constraint</th>
<th>Required Navaid</th>
<th>Bearing/Range to Navaid</th>
<th>Vertical Path Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA</td>
<td>RW20</td>
<td>-</td>
<td>201° (203.3°)</td>
<td>R</td>
<td>400</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DF</td>
<td>FOKSI</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TF</td>
<td>PF213</td>
<td>Y</td>
<td>345° (346.8°)</td>
<td>-</td>
<td>+5000</td>
<td>250</td>
<td>-</td>
<td>OKE 330/30</td>
<td>-</td>
</tr>
<tr>
<td>Formalised Description</td>
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<td></td>
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<tr>
<td>Climb on track 047° M, at or above 800ft, turn right</td>
<td>[A800+; M047; R]-</td>
<td>FA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct to ARDAG at 3000ft</td>
<td>➔ ARDAG[A3000]-</td>
<td>DF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To PF035 at or below 5000ft, turn left</td>
<td>-PF035[A5000-; L]-</td>
<td>TF (Fly-over)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To OTR on course 090°M at 210kts</td>
<td>-OTR[M090; K210]-</td>
<td>CF</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>From STO at or above FL100, turn left direct to WW039 at or above FL070, to WW038 at 5000ft</td>
<td>STO[F100+; L]-</td>
<td>TF (Fly-over)</td>
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</tr>
<tr>
<td></td>
<td>➔ WW039[F070+]-</td>
<td>DF</td>
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<tr>
<td></td>
<td>WW038[A5000]</td>
<td>TF</td>
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</tbody>
</table>
Waypoint Identification

• Significant points
  – identified by co-located navaid or by unique five-letter pronounceable “name-code” (5LNC)
• Some waypoints in the terminal area used for vectoring for sequencing and must be easy to enter in an RNAV system
  – 5LNCs not appropriate for this
  – Proceed direct ALECS (or ALEKX, ALECS, ALECX, ALLEX, ALIKS, ALIKX, ALICX, ALLIX, ALEYKS, ALEYKX, ALEYCS, ALEYCX, ALEYX)
• Concept of strategic and tactical waypoints
Charting Altitude Restrictions

An altitude window: FL220
10,000

An “at or above” altitude: 7000

A “hard” altitude: 3000

An “at or below” altitude: 5000
Where Are We?

Having designed an RNAV procedure to meet operational requirements we have:

– considered the need to translate to a Nav DB
– Reviewed the ARINC 424 leg types
– Introduced means for describing the procedure in an unambiguous manner

Now:

– How to ensure that the procedure is correct and will be flown correctly
Validation Activities

- Ground Validation
  - Obstacle clearance
  - Charting
  - Coding
  - Flyability
- Flight Validation
  - Obstacle verification (optional)
  - Flyability (workload, charting, manoeuvring)
  - Infrastructure
- Database Validation
Ground Validation

• Obstacle clearance
  – Independent review by procedure designer

• Charting
  – Independent review

• Coding
  – Software tool (e.g. Smiths PDT) or
  – Expert review

• Flyability – software tools (from PC-based to full flight simulator)
  – Not necessarily an issue with standard procedures (e.g. ‘T’ approaches), but critical for some aircraft types
  – Range of aircraft and meteo conditions
Validate the Procedure Flyability

**Procedure Editor for **BU11Z

- **Airport**: EBBR
- **Loaded NDB**: TST1-01
- **Type**: SID
- **User NDB**: Test

**Procedure ID**: BU11Z  **Transition Alt**: 4500

<table>
<thead>
<tr>
<th>TYPE</th>
<th>IDENT</th>
<th>PTH/TRL</th>
<th>TG FIK</th>
<th>WP DESC</th>
<th>HD/G/CRS</th>
<th>TURN DIR</th>
<th>ALT (ALT)</th>
<th>SPD LIMIT</th>
<th>REC NAV</th>
<th>TD/DR</th>
<th>FIX RAD</th>
<th>VERT ANG</th>
<th>ARC CTR</th>
<th>RNP</th>
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</thead>
<tbody>
<tr>
<td>BASE</td>
<td>RW25R</td>
<td>FA</td>
<td>RW25R</td>
<td>G</td>
<td>246</td>
<td></td>
<td>4000</td>
<td></td>
<td>EUB</td>
<td></td>
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<td></td>
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<td>BASE</td>
<td>RW25R</td>
<td>CF</td>
<td>BRW01</td>
<td>E</td>
<td>150</td>
<td></td>
<td>6000</td>
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<td>HUL</td>
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<td>BASE</td>
<td>RW25R</td>
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<td>HUL</td>
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<td></td>
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</tr>
<tr>
<td>BASE</td>
<td>RW25R</td>
<td>TF</td>
<td>BULUX</td>
<td>E</td>
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<td></td>
<td></td>
<td>+ 17000</td>
<td></td>
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</tr>
<tr>
<td>BASE</td>
<td>RW25R</td>
<td>TF</td>
<td>BULTO</td>
<td>EE</td>
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</tbody>
</table>

**Plot Window for**: EBBR → EBBR

- **Latitude**: N50°54'10.99" E04°12'45.65"
- **Longitude**: E04°12'45.65" E04°12'45.65"
- **No terrain data loaded**
B737-300 18.5k
ISA +40
Wind 300/20

B737-300 22k
ISA -20
Wind 250/20

Validate Again with Different Conditions
Different Aircraft and Different Conditions

CA 500ft agl; DF LL001; TF FARKS; TF...
No wind
A319
B737/400
B747/400
A340/300
Wind Effect

CA 500 ft agl; DF
LL001; TF FARKS;
TF...

ICAO wind from 045°

A319
B737/400
B747/400
A340/300
Countered by Speed Restriction

CA 500ft agl; DF
LL001; TF FARKS [210kts]; TF...

ICAO wind from 045°

A319
B737/400
B747/400
A340/300
Leg Length Too Short

CA 2000ft agl; DF BRW02
No wind
ATR42
B 747-400
A340-300
Leg Length
Acceptable

CA 2000ft agl; DF
BRW02
No wind
ATR42
B 747-400
A340-300
Flight Validation

- Obstacle verification
  - Necessary where full obstacle survey cannot be assured
- Flyability
  - Detailed workload and charting assessments, but
  - High level qualitative assessment of manoeuvring only (rely mainly on Ground Validation)
- Infrastructure assessment
  - Runway markings, lighting, communications, navigation etc
Flight Inspection

• Flight Inspection addresses:
  – **Navaid performance** for DME/DME RNAV
  – **Unintentional interference** for GNSS
DME Tasks

- Need to confirm valid DME pairs
  - Expected coverage and field strength
    - If gaps are present, need to know exact area
  - Range accuracy within Annex 10

- Need to identify DME’s that degrade the navigation solution
  - Propagation distortions
    - Either effect can be removed (small local reflector) or
    - Pilot needs to deselect
RNAV DME Flight Inspection Planning

Infrastructure Assessment preparation to make inspection efficient

Identify:

– Candidate DME pairs and associated coverage
  ➢ Including expected gaps in coverage, if any

– Candidates for exclusion:
  ➢ Propagation path near horizon or significant terrain
  ➢ Second DME on same channel within line of sight
  ➢ ILS/DME facilities (offset bias?)

– Minimum/maximum height profile for nav aid coverage validation

PANS-OPS, ATC Operations, Engineering and Flight Inspection Organization jointly plan inspection flight
Database Validation

- RNAV procedures coded using ARINC 424 path terminators to define specific nominal tracks
- Coded procedures not available in operational databases until effective date
  - recommend implementation date 3 to 10 days after effective date
- Test databases may be provided for flight validation
- Flight does not validate integrity of procedure subsequently coded in operational database
- State must find other means of validating the operational database
Data Origination

ICAO Documents
Annex 15 SARPS
Doc 8071 Flight Inspection Manual

EUROCONTROL Guidance Material
Integrity of Aeronautical Information
  - Aeronautical Data Origination
    AFN/NAV/DAT/ORG/DOC001-150404
    Survey and procedure Design Requirements

FAA Guidance Material
  • FAA Specification 405 Standards for Aeronautical Surveys
    and Related Products
  • FAA Order 8260.19 Flight Procedures and Airspace
Requirements Addressed in Documents

- Survey – WGS84
- Training for designers
- Software Tool Qualification
- Data management
- Quality Assurance
- Verification of Procedure Designs
- Publication
- Validation tests
  - Flyability – under range of wind conditions for appropriate aircraft types
  - Navigation aid coverage
Presentation Summary

• Waypoint transitions
• ARINC 424 Path terminators
• Procedure Coding
• Charting Issues
• Validation:
  – Flyability
  – Flight Inspection
Thank You