Development and validation of procedures

07-10 April 2015
Procedure Design

- Procedure Design includes
  - ATS Routes (enroute, arrival, departure) and
  - Instrument Approach procedures
- Design criteria in ICAO Doc 8168 (Vol II) *Procedures for Air Navigation Services – Aircraft Operations (PANS OPS)*
  - RNP AR APCH design criteria in ICAO RNP AR Procedure Design Manual
- Ground validation
  - Obstacle clearance
  - Charting
  - Coding
  - Flyability
- Flight validation
  - Obstacle verification
  - Flyability
  - Infrastructure
- Database validation
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
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 useable 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

Note: ARINC 424 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
ARINC 424 Records

VHF Navaids
NDB Navaids
Waypoints
Holding
Airports
SID/STAR/APP
Localiser and Glide Slope/MLS/GLS
Company Route
Localiser Marker
Path Points

Airport Communications
MSA
Airways Marker
Cruising Tables
FIR/uir
GRID MORA
En-route Airways
En-route Airways Restrictive
En-route Communications
Preferred Routes
Controlled Airspace
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
# 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>C</td>
</tr>
<tr>
<td>Direct Track</td>
<td>D</td>
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<tr>
<td>Course from a fix to</td>
<td>F</td>
</tr>
<tr>
<td>Holding pattern</td>
<td>H</td>
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<tr>
<td>Initial</td>
<td>I</td>
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<tr>
<td>Constant radius</td>
<td>R</td>
</tr>
<tr>
<td>Track between</td>
<td>T</td>
</tr>
<tr>
<td>Heading to</td>
<td>V</td>
</tr>
<tr>
<td>Altitude</td>
<td>A</td>
</tr>
<tr>
<td>Distance</td>
<td>C</td>
</tr>
<tr>
<td>DME distance</td>
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<td>Fix</td>
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<td>Next leg</td>
<td>I</td>
</tr>
<tr>
<td>Manual termination</td>
<td>M</td>
</tr>
<tr>
<td>Radial termination</td>
<td>R</td>
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</table>
### 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

Unspecified Position

090°

CA Leg
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
From a Fix to a Manual Termination

FM leg is flown making adjustment for wind
Racetrack

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

RF Leg

Previous Segment

Arc Centre

Next Segment

A

B

C
Track to a Fix
Heading to an Altitude

No correction made for wind

090°
VA Leg

Unspecified Position

8000'
Heading to Manual Termination

No correction made for wind
Use Of Path Terminators

• **Available Path Terminators are defined in PBN Manual Nav Specifications**
  
  – If the RNAV system does not have leg type demanded by procedure, the 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
Constraints

- Terrain constraints
- Descent/Climb profiles
NAVAID coverage

- Geographical distribution
- Accuracy
- Continuity
- Availability
- Redundancy
RNAV performance

- **Navigation accuracy depends on**
  - Satellites in view
  - Geometry
  - Satellite serviceability
  - Accuracy (selective availability off 20 m
  - Use of RAIM prediction tools
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
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
## Tabular Description

### RNP APCH

<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>
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</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 Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>370</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-3º/50</td>
</tr>
<tr>
<td>FA</td>
<td>RW35L</td>
<td>-</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>
<td>-</td>
<td>-</td>
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<td>-</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 Y</td>
<td>345° (346.8°)</td>
<td>-</td>
<td>+5000</td>
<td>250</td>
<td>-</td>
<td>OKE</td>
<td>330/30</td>
<td>-</td>
</tr>
<tr>
<td>Description</td>
<td>Code</td>
<td>Action</td>
<td></td>
<td></td>
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<tr>
<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>
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<tr>
<td>Direct to ARDAG at 3000ft</td>
<td>→ARDAG[A3000]-</td>
<td>DF</td>
<td></td>
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<td></td>
<td></td>
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<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>
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<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>
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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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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>→WW039[F070+]-</td>
<td>DF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WW038[A5000]</td>
<td>TF</td>
<td></td>
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</tr>
</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, ALYKS, ALYKX, ALYCS, ALYCX, ALLYX)

• **Concept of strategic and tactical waypoints**
Procedure naming

• RNAV RWY XX
• RNAV_{(DME/DME)} RWY XX
• RNP RWY XX
• RNP RWY XX (AR)
• RNAV_{(GNSS)} RWY XX
• RNAV_{(RNP)} RWY XX
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
Validate Again with Different Conditions

B737-300 18.5k
ISA +40
Wind 300/20

B737-300 22k
ISA -20
Wind 250/20
Different Aircraft and Different Conditions

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

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

ICAO wind from 045°

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

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

ICAO wind from 045°

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

• **Specific requirements for FVP**
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
ATC System Integration (1)

• After procedure/route designs validated
• Implementation may require ATC system changes
  – Flight Data Processor
  – Radar Data Processor
  – Controller Display
  – Controller Support Tools
  – NOTAM Issuing Processes

• Need to account for extended timelines to implement and check system changes
  – Automation
  – Manual
ATC System Integration (2)

- **Additional integration challenges in a mixed aircraft equipage environment**
  - Mixed equipage likely the common scenario for transition period
  - Systems need to accommodate both new navigation specifications and legacy conventional navigation

- **Automation integration complexity increases**
  - System needs to recognize different capabilities from flight plans
  - Convey this information to ATC

- **Controller workload may increase in mixed equipage environment; factors include**
  - Ratio of PBN-based to conventional aircraft loads
  - Complexity and commonality of route structures

- **Need to limit implementation to what can be safely and efficiently managed**
  - Phased implementation?
Awareness and Training (1)

• Every implementation requires some level of information to be provided to both controllers and flight crews
• Complexity of implementation drives type of information needed
  – Awareness
  – Education
  – Training
Each Vol II Navigation Specification addresses knowledge and training for pilots and air traffic controllers
Establish Operational Implementation Date

- **Procedure/Route Airspace has been**
  - Designed
  - Validated (ground; flight)
  - ATC System (automation, manual) changes supporting the implementation are set
  - Required aircrew and pilot awareness/training/education identified and conducted
  - Publication (charting, AIP) effective date established
Post-Implementation Review

• Monitor implementation to ensure
  • Collect evidence for safety assessment to demonstrate that safety is maintained
  • Expected benefits (capacity, efficiency, fuels savings etc) are being realized

• Implementation team may need to institute mitigations to address unforeseen issues