RNAV SENSORS
Target:

Learn basic concept on ground-side and satellite-side sensors
SENSORS

- **Part 1**: DME/DME RNAV
- **Part 2**: VOR/DME RNAV
- **Part 3**: GNSS
PAN OPS Reference

PAN OPS Vol II Sixt Edition

- Part III – Section 1 – Chapter 3
- Part III – Section 1 – Chapter 4
The A/C position is calculated by the RNAV system using inputs from one or more of the following:

- DME/DME
- VOR/DME
- GNSS
- IRS/INS
DME/DME General Concept

Design criteria for DME/DME RNAV in RNAV 1 and RNAV 2 navigation applications, which are applicable to operations in the continental en-route and terminal phases of flight, including SIDs, STARs and initial approaches up to, but not including final approach/missed approach.

It also addresses RNAV 5 applications, which are applicable to operations in the continental en-route phase of flight only.
AIRBORNE AND GROUND EQUIPMENT REQUIREMENTS

The standard assumptions for airborne and ground equipment on which DME/DME procedures are based are as follows:

a) DME station coordinates are referenced to WGS-84 and elevations in AMSL (where a DME is not exactly collocated with a VOR, the location and elevation of the DME should be published separately in the AIP).

b) Airborne equipment complies with the guidance laid down in the ICAO Performance-based Navigation (PBN) Manual (Doc 9613):
   1) Volume II, Part B, Chapter 2, Implementing RNAV 5; or
   2) Volume II, Part B, Chapter 3, Implementing RNAV 1 and RNAV 2.

c) Ground equipment complies with the criteria defined in ICAO Annex 10.
DME/DME Calculation

The system use accuracy (DTT) of airborne receiving systems is defined as:

\[
2\sigma = 2 \sqrt{\frac{\sigma_{1,air}^2 + \sigma_{1,sis}^2}{\sin \alpha} + \frac{\sigma_{2,air}^2 + \sigma_{2,sis}^2}{\sin \alpha}}
\]

where: \(\sigma_{sis} = 0.05\) NM, \(\sigma_{air} = \text{MAX}\{0.085\) NM, 0.125 per cent distance (as defined in RTCA DO-189 and TSO-C66c}\} for RNAV 1 and RNAV 2 and \(30 \leq \alpha \leq 150\).

The system computational tolerance (ST) is \(\pm 463\) m (0.25 NM). This tolerance is dependent upon the implementation of WGS-84.

\[
XTT = \sqrt{\text{DTT}^2 + \text{FTE}^2 + \text{ST}^2}
\]

\[
\text{ATT} = \sqrt{\text{DTT}^2 + \text{ST}^2}
\]

\[
\frac{1}{2} A/W = 1.5*\text{XTT} + \text{BV}
\]
### Table III-1-3-2. XTT, ATT and area semi-width for DME RNAV (RNAV 1) in en-route, arrival, initial/intermediate approach and departure phases of flight (NM)

<table>
<thead>
<tr>
<th>Altitude (ft)</th>
<th>En-route/STAR/SID (&lt;30 NM ARP)</th>
<th>STAR/IF/FAF (&lt;30 NM ARP)</th>
<th>SID (&lt;15 NM DER)</th>
<th>FAF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>XTT ATT ¾ A/W</td>
<td>XTT ATT ¾ A/W</td>
<td>XTT ATT ¾ A/W</td>
<td>XTT ATT ¾ A/W</td>
</tr>
<tr>
<td>15 000</td>
<td>1.24 1.13 2.85</td>
<td>1.24 1.13 2.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 000</td>
<td>1.20 1.10 2.81</td>
<td>1.20 1.10 2.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 000</td>
<td>1.17 1.06 2.76</td>
<td>1.17 1.06 2.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 000</td>
<td>1.14 1.02 2.71</td>
<td>1.14 1.02 2.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 000</td>
<td>1.11 0.99 2.66</td>
<td>1.11 0.99 2.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 000</td>
<td>1.07 0.95 2.61</td>
<td>1.07 0.95 2.11</td>
<td>0.98 0.95 1.97</td>
<td></td>
</tr>
<tr>
<td>9 000</td>
<td>1.04 0.91 2.55</td>
<td>1.04 0.91 2.05</td>
<td>0.94 0.91 1.91</td>
<td></td>
</tr>
<tr>
<td>8 000</td>
<td>1.00 0.86 2.50</td>
<td>1.00 0.86 2.00</td>
<td>0.90 0.86 1.85</td>
<td></td>
</tr>
<tr>
<td>7 000</td>
<td>0.96 0.82 2.44</td>
<td>0.96 0.82 1.94</td>
<td>0.86 0.82 1.79</td>
<td></td>
</tr>
<tr>
<td>6 000</td>
<td>0.92 0.77 2.38</td>
<td>0.92 0.77 1.88</td>
<td>0.81 0.77 1.72</td>
<td></td>
</tr>
<tr>
<td>5 000</td>
<td>0.88 0.72 2.32</td>
<td>0.88 0.72 1.82</td>
<td>0.76 0.72 1.65</td>
<td></td>
</tr>
<tr>
<td>4 000</td>
<td>0.83 0.67 2.25</td>
<td>0.83 0.67 1.75</td>
<td>0.71 0.67 1.57</td>
<td></td>
</tr>
<tr>
<td>1 000–3 000</td>
<td>0.79 0.61 2.18</td>
<td>0.79 0.61 1.68</td>
<td>0.66 0.61 1.49</td>
<td></td>
</tr>
</tbody>
</table>

*For all altitudes*:

<table>
<thead>
<tr>
<th>Altitude (ft)</th>
<th>XTT ATT ¾ A/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 000</td>
<td>0.78 0.61</td>
</tr>
<tr>
<td>14 000</td>
<td>0.77 0.59</td>
</tr>
<tr>
<td>13 000</td>
<td>0.76 0.57</td>
</tr>
<tr>
<td>12 000</td>
<td>0.75 0.56</td>
</tr>
<tr>
<td>11 000</td>
<td>0.74 0.54</td>
</tr>
<tr>
<td>10 000</td>
<td>0.72 0.52</td>
</tr>
<tr>
<td>9 000</td>
<td>0.71 0.50</td>
</tr>
<tr>
<td>8 000</td>
<td>0.70 0.48</td>
</tr>
<tr>
<td>7 000</td>
<td>0.68 0.46</td>
</tr>
<tr>
<td>6 000</td>
<td>0.67 0.44</td>
</tr>
<tr>
<td>5 000</td>
<td>0.65 0.42</td>
</tr>
<tr>
<td>4 000</td>
<td>0.64 0.40</td>
</tr>
<tr>
<td>1 000–3 000</td>
<td>0.62 0.37</td>
</tr>
</tbody>
</table>

### Table III-1-3-3. XTT, ATT and area semi-width for DME RNAV (RNAV 2) in en-route, arrival, initial/intermediate approach and departure phases of flight (NM)

<table>
<thead>
<tr>
<th>Altitude (ft)</th>
<th>En-route/STAR/SID (&lt;30 NM ARP)</th>
<th>STAR/IF/FAF (&lt;30 NM ARP)</th>
<th>SID (&lt;15 NM DER)</th>
<th>FAF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>XTT ATT ¾ A/W</td>
<td>XTT ATT ¾ A/W</td>
<td>XTT ATT ¾ A/W</td>
<td>XTT ATT ¾ A/W</td>
</tr>
<tr>
<td>15 000</td>
<td>1.51 1.13 3.26</td>
<td>1.51 1.13 2.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 000</td>
<td>1.48 1.10 3.23</td>
<td>1.48 1.10 2.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 000</td>
<td>1.46 1.06 3.19</td>
<td>1.46 1.06 2.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 000</td>
<td>1.43 1.02 3.15</td>
<td>1.43 1.02 2.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 000</td>
<td>1.41 0.99 3.11</td>
<td>1.41 0.99 2.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 000</td>
<td>1.38 0.95 3.07</td>
<td>1.38 0.95 2.57</td>
<td>N/A N/A N/A</td>
<td></td>
</tr>
<tr>
<td>9 000</td>
<td>1.35 0.91 3.03</td>
<td>1.35 0.91 2.53</td>
<td>N/A N/A N/A</td>
<td></td>
</tr>
<tr>
<td>8 000</td>
<td>1.32 0.86 2.98</td>
<td>1.32 0.86 2.48</td>
<td>N/A N/A N/A</td>
<td></td>
</tr>
<tr>
<td>7 000</td>
<td>1.29 0.82 2.94</td>
<td>1.29 0.82 2.44</td>
<td>N/A N/A N/A</td>
<td></td>
</tr>
<tr>
<td>6 000</td>
<td>1.26 0.77 2.90</td>
<td>1.26 0.77 2.40</td>
<td>N/A N/A N/A</td>
<td></td>
</tr>
<tr>
<td>5 000</td>
<td>1.23 0.72 2.85</td>
<td>1.23 0.72 2.35</td>
<td>N/A N/A N/A</td>
<td></td>
</tr>
<tr>
<td>4 000</td>
<td>1.20 0.67 2.80</td>
<td>1.20 0.67 2.30</td>
<td>N/A N/A N/A</td>
<td></td>
</tr>
<tr>
<td>1 000–3 000</td>
<td>1.17 0.61 2.76</td>
<td>1.17 0.61 2.26</td>
<td>N/A N/A N/A</td>
<td></td>
</tr>
</tbody>
</table>

*For all altitudes*:

<table>
<thead>
<tr>
<th>Altitude (ft)</th>
<th>XTT ATT ¾ A/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 000</td>
<td>0.78 0.61</td>
</tr>
<tr>
<td>14 000</td>
<td>0.77 0.59</td>
</tr>
<tr>
<td>13 000</td>
<td>0.76 0.57</td>
</tr>
<tr>
<td>12 000</td>
<td>0.75 0.56</td>
</tr>
<tr>
<td>11 000</td>
<td>0.74 0.54</td>
</tr>
<tr>
<td>10 000</td>
<td>0.72 0.52</td>
</tr>
<tr>
<td>9 000</td>
<td>0.71 0.50</td>
</tr>
<tr>
<td>8 000</td>
<td>0.70 0.48</td>
</tr>
<tr>
<td>7 000</td>
<td>0.68 0.46</td>
</tr>
<tr>
<td>6 000</td>
<td>0.67 0.44</td>
</tr>
<tr>
<td>5 000</td>
<td>0.65 0.42</td>
</tr>
<tr>
<td>4 000</td>
<td>0.64 0.40</td>
</tr>
<tr>
<td>1 000–3 000</td>
<td>0.62 0.37</td>
</tr>
</tbody>
</table>

### Table III-1-3-4. XTT, ATT and area semi-width for DME RNAV (RNAV 5) in en-route phase of flight (NM)

<table>
<thead>
<tr>
<th>Altitude (ft)</th>
<th>En-route/STAR/SID (&gt;30 NM ARP)</th>
<th>STAR/IF/FAF (&gt;30 NM ARP)</th>
<th>SID (&lt;15 NM DER)</th>
<th>FAF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>XTT ATT ¾ A/W</td>
<td>XTT ATT ¾ A/W</td>
<td>XTT ATT ¾ A/W</td>
<td>XTT ATT ¾ A/W</td>
</tr>
<tr>
<td>5 000</td>
<td>3.30 2.15 6.95</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table III-1-3-8. XTT, ATT, area semi-width for DME RNAV (RNAV 5) in the en-route phase of flight (NM)

<table>
<thead>
<tr>
<th>En-route/STAR/SID (&gt;30 NM ARP)</th>
<th>XTT ATT ¾ A/W</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For all altitudes</td>
</tr>
<tr>
<td>5 000</td>
<td>3.30 2.15 6.95</td>
</tr>
</tbody>
</table>
DME/DME COVERAGE (1/3)

As it is not possible to know which DME facilities the airborne system will use for a position update, a theoretical viability check should be made of the route to ensure that there is appropriate DME coverage available at any point along the proposed route, based upon at least two selected facilities.

The initial check should be carried out using a qualified DME screening model and should consider:

a) the promulgated maximum range of the DME facility, allowing a theoretical maximum radio horizon of the station of 300 km/160 NM;
b) maximum and minimum intersection angle of the DME stations (between 30° and 150°);
c) that DME facilities within 5.6 km (3 NM) of the design track cannot be used for navigation;
d) promulgated restrictions in designated operational coverage, if any.
MAXIMUM UPDATE AREA for 2 DME

Update-area where the 30°/150° rule is applicable

DME/DME UPDATE AREA FOR 2 DME STATIONS LOCATED AT A DISTANCE ‘D’ APART

Step 1 — A circle centred on each station with a radius equal to the Designated Operational Coverage (DOC) with a maximum of 370.4 km (200.0 NM) must be drawn.

Step 2 — The 30–150° DME intercept circles with a radius equal to the distance ‘D’ on either side of both DME stations must be drawn.

Step 3 — Then the no-update zone circles of 1.85 km (1.00 NM) centred on both DME stations are drawn.

The area with dual DME update is comprised within an area where both the following conditions exist:
1. the area within the DOC/370.4 km (200.0 NM) and
2. the area of the 30/150 degrees intersect angle.

Excluded from DME/DME coverage is the area comprised within:
1. the no-update zone circles and
2. the area between the two DME stations.
MAXIMUM UPDATE AREA for 2 DME

\[ a + b = 180^\circ \]

\[ y = 2a \]
The theoretical viability check should determine the coverage and redundancy over the route. If, at any point on the procedure, the positioning can only be achieved using a specific DME pair, then those DMEs are considered to be critical to the procedure. Procedures with critical DMEs have no redundancy. Critical DMEs shall be noted on the procedure chart.

If a TACAN, not meeting the DME-ranging requirements of Annex 10, falls within the possible update range, this station shall not be published in the civil AIP in order to discourage storage in an electronic airborne navigation database.

A DME station may be located above the nominal flight path provided that the performance is confirmed to be acceptable by flight inspection and the operational acceptability is closely monitored during the initial months of operation (at least 3 months).
Where continuous DME/DME coverage cannot be achieved, the design must take account of the limitation by the use of a dead reckoning segment. The protected area shall splay 15° either side of track, starting from the edge of the primary area at the point where coverage is not available. The track distance outside coverage shall not exceed 19 km (10 NM).

Note. — Airborne systems use all DME facilities within a maximum range and determine the most suitable facilities for position estimation.
**DME/DME VALIDATION**

**Ground validation:**
Initial validation of the proposed procedure may be made using flight simulators and/or FMC simulation software tools to check the predicted flight path for continuity and repeatability of the route. Such validation should include the effect of minimum and maximum IAS, winds, type and mass of aircraft and type of FMC.

**Flight inspection**
The flight inspection organization should be provided with full details of the pre-design checks, including details of any critical DMEs.
VOR/DME general concept

VOR/DME infrastructure allows RNAV 5 navigation applications, for the continental en-route phase of flight only.

Not possible to know which VOR/DME facility the airborne system will use for a position update, however check to ensure that there is appropriate coverage available from at least one reference facility within a:

- 60 NM range, or 75 NM for Doppler VOR.

The designer should select the VOR/DME facility that provides the optimum geometry for the track guidance solution at each waypoint, to calculate the XTT, ATT and ½ A/W at those waypoints.
a) VOR/DME station coordinates are published in WGS-84 and elevations in AMSL. (Where a DME is not exactly collocated with a VOR, the location and elevation of the DME should be published separately in the AIP.)


c) Ground equipment complies with the criteria defined in ICAO Annex 10.
VOR/DME system accuracy

The factors on which the navigation accuracy of VOR/DME RNAV depends are:

a) ground station tolerance;
b) airborne receiving system tolerance (0.25NM);
c) flight technical tolerance;
d) system computation tolerance; and

e) distance from the reference facility.

The system use accuracy of the VOR is equal to the VOR system use accuracy of a facility not providing track, which is ± 4.5 degrees.

The system use accuracy of the DME is equal to the DME system use accuracy (DTT) of a facility not providing track guidance, which is

\[
2\sigma = 2\sqrt{\left(\sigma_{1,\text{air}}^2 + \sigma_{1,\text{sis}}^2\right)}
\]

\[
\sigma_{\text{sis}} = 0.05 \text{ NM},
\]

\[
\sigma_{\text{air}} = \text{MAX}\{0.085 \text{ NM, 0.125 per cent distance (as defined in RTCA DO-189 and TSO-C66c)}\}.
\]
VOR/DME Calculation (1/2)

D is the distance from the reference facility to the waypoint; $D = \sqrt{D_1^2 + D_2^2}$

$D_1$ is the distance from the reference facility to the tangent point.

$D_2$ is the distance from the waypoint to the tangent point.

$\alpha$ = VOR system use accuracy (degrees)

$\Delta T T$ = DME system use accuracy

$\theta$ = $\arctan(D_2/D_1)$ (degrees) (if $D_1 = 0$, $\theta = 90^\circ$)

$V_T = D_1 - D \cos(\theta + \alpha)$

$D_T = DTT \cos \theta$

$A V_T = D_2 - D \sin(\theta - \alpha)$

$A D_T = DTT \sin \theta$

$XTT = \sqrt{V_T^2 + D_T^2 + FTT^2 + ST^2}$

$A T T = \sqrt{AV_T^2 + AD_T^2 + ST^2}$

$\frac{1}{2} A/W = 1.5*XTT + BV$

NOT FOR COMMERCIAL PURPOSES
ATT and XTT are track dependent. Thus when a turn is specified at a fix, the ATT and XTT are different before and after the turn due to the individual fix geometry.
## VOR/DME Table

Table III-1-4-2. XTT, ATT, area semi-width for VOR/DME RNAV in the en-route phase of flight (RNAV 5) (NM)

<table>
<thead>
<tr>
<th>D1</th>
<th>D2</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>XTT</td>
<td>2.5</td>
<td>2.6</td>
<td>2.9</td>
<td>3.3</td>
<td>3.8</td>
<td>4.3</td>
<td>4.9</td>
<td>5.5</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>ATT</td>
<td>0.3</td>
<td>0.7</td>
<td>1.4</td>
<td>2.1</td>
<td>2.8</td>
<td>3.5</td>
<td>4.2</td>
<td>4.9</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>A/W</td>
<td>5.8</td>
<td>4.9</td>
<td>4.8</td>
<td>4.9</td>
<td>5.6</td>
<td>6.4</td>
<td>9.3</td>
<td>9.2</td>
<td>9.5</td>
</tr>
<tr>
<td>10</td>
<td>XTT</td>
<td>2.5</td>
<td>2.6</td>
<td>3.0</td>
<td>3.5</td>
<td>4.0</td>
<td>4.7</td>
<td>5.4</td>
<td>6.1</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>ATT</td>
<td>0.3</td>
<td>0.9</td>
<td>1.6</td>
<td>2.4</td>
<td>3.2</td>
<td>4.0</td>
<td>4.7</td>
<td>5.5</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>A/W</td>
<td>5.8</td>
<td>6.0</td>
<td>6.5</td>
<td>7.2</td>
<td>8.1</td>
<td>9.0</td>
<td>10.0</td>
<td>11.1</td>
<td>12.2</td>
</tr>
<tr>
<td>20</td>
<td>XTT</td>
<td>2.5</td>
<td>2.7</td>
<td>3.0</td>
<td>3.5</td>
<td>4.1</td>
<td>4.7</td>
<td>5.4</td>
<td>6.1</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>ATT</td>
<td>0.3</td>
<td>0.9</td>
<td>1.7</td>
<td>2.4</td>
<td>3.2</td>
<td>4.0</td>
<td>4.8</td>
<td>5.6</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>A/W</td>
<td>5.8</td>
<td>6.0</td>
<td>6.5</td>
<td>7.3</td>
<td>8.1</td>
<td>9.1</td>
<td>10.1</td>
<td>11.2</td>
<td>12.2</td>
</tr>
<tr>
<td>30</td>
<td>XTT</td>
<td>2.5</td>
<td>2.7</td>
<td>3.0</td>
<td>3.5</td>
<td>4.1</td>
<td>4.7</td>
<td>5.4</td>
<td>6.1</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>ATT</td>
<td>0.3</td>
<td>0.9</td>
<td>1.7</td>
<td>2.5</td>
<td>3.2</td>
<td>4.0</td>
<td>4.8</td>
<td>5.6</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>A/W</td>
<td>5.8</td>
<td>6.0</td>
<td>6.5</td>
<td>7.3</td>
<td>8.1</td>
<td>9.1</td>
<td>10.1</td>
<td>11.2</td>
<td>12.3</td>
</tr>
<tr>
<td>40</td>
<td>XTT</td>
<td>2.5</td>
<td>2.7</td>
<td>3.0</td>
<td>3.5</td>
<td>4.1</td>
<td>4.8</td>
<td>5.4</td>
<td>6.2</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>ATT</td>
<td>0.3</td>
<td>0.9</td>
<td>1.7</td>
<td>2.5</td>
<td>3.3</td>
<td>4.1</td>
<td>4.8</td>
<td>5.6</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>A/W</td>
<td>5.8</td>
<td>6.0</td>
<td>6.5</td>
<td>7.3</td>
<td>8.2</td>
<td>9.1</td>
<td>10.2</td>
<td>11.2</td>
<td>12.3</td>
</tr>
<tr>
<td>50</td>
<td>XTT</td>
<td>2.5</td>
<td>2.7</td>
<td>3.0</td>
<td>3.6</td>
<td>4.1</td>
<td>4.8</td>
<td>5.5</td>
<td>6.2</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>ATT</td>
<td>0.3</td>
<td>1.0</td>
<td>1.7</td>
<td>2.5</td>
<td>3.3</td>
<td>4.1</td>
<td>4.9</td>
<td>5.7</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>A/W</td>
<td>5.8</td>
<td>6.0</td>
<td>6.6</td>
<td>7.3</td>
<td>8.2</td>
<td>9.2</td>
<td>10.2</td>
<td>11.3</td>
<td>12.4</td>
</tr>
<tr>
<td>60</td>
<td>XTT</td>
<td>2.5</td>
<td>2.7</td>
<td>3.1</td>
<td>3.6</td>
<td>4.2</td>
<td>4.8</td>
<td>5.5</td>
<td>6.2</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>ATT</td>
<td>0.3</td>
<td>1.0</td>
<td>1.8</td>
<td>2.6</td>
<td>3.3</td>
<td>4.1</td>
<td>4.9</td>
<td>5.7</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>A/W</td>
<td>5.8</td>
<td>6.0</td>
<td>6.6</td>
<td>7.4</td>
<td>8.3</td>
<td>9.2</td>
<td>10.3</td>
<td>11.3</td>
<td>12.4</td>
</tr>
<tr>
<td>70</td>
<td>XTT</td>
<td>2.5</td>
<td>2.7</td>
<td>3.1</td>
<td>3.6</td>
<td>4.2</td>
<td>4.8</td>
<td>5.5</td>
<td>6.2</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>ATT</td>
<td>0.3</td>
<td>1.0</td>
<td>1.8</td>
<td>2.6</td>
<td>3.4</td>
<td>4.1</td>
<td>4.9</td>
<td>5.7</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>A/W</td>
<td>5.8</td>
<td>6.1</td>
<td>6.6</td>
<td>7.4</td>
<td>8.3</td>
<td>9.3</td>
<td>10.3</td>
<td>11.4</td>
<td>12.4</td>
</tr>
<tr>
<td>80</td>
<td>XTT</td>
<td>2.5</td>
<td>2.7</td>
<td>3.1</td>
<td>3.6</td>
<td>4.2</td>
<td>4.9</td>
<td>5.6</td>
<td>6.3</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>ATT</td>
<td>0.4</td>
<td>1.1</td>
<td>1.8</td>
<td>2.6</td>
<td>3.4</td>
<td>4.2</td>
<td>5.0</td>
<td>5.7</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>A/W</td>
<td>5.8</td>
<td>6.1</td>
<td>6.7</td>
<td>7.4</td>
<td>8.3</td>
<td>9.3</td>
<td>10.3</td>
<td>11.4</td>
<td>12.5</td>
</tr>
</tbody>
</table>
DEMETER (1/2)

DEMETER (Distance Measuring Equipment Tracer) is a software tool which supports the implementation of Performance Based Navigation (PBN) and the rationalization of navigation infrastructure.

The main features of DEMETER are:

- The new version of DEMETER was developed using uDig (User-friendly Desktop Internet GIS), an open source Geographical Information System platform;
- Navaid database for VOR, DME, VOR-DME, TACAN, VORTAC and NDB. The database can be updated from both EAD and ARINC424 data files;
- High-quality terrain database supporting GTOPO30 and DTED levels 0, 1 and 2. Best quality data available in the database is selected by the application and used for calculations. DEMETER comes with GTOPO30 and DTED level 0 data for ECAC;
- Possibility of visualising the terrain configuration in 3D using NASA WorldWind (open source application). Both DEMETER terrain database and NASA WorldWind terrain database can be used (Internet connection required to connect to NASA WorldWind database);
- DME-DME coverage and performance assessment (available pairs, subtended angle, redundancy, and Navigation System Error-NSE);
- VOR-DME coverage and redundancy assessment;
- Procedure definition using pre-defined ICAO identifiers, or user-defined positions;
- Procedure performance calculation giving the DME-DME subtended angle values (worst value and centre line value) along the procedure. The calculation takes into account the procedure width, the aircraft velocity and the 30-seconds rule;
- Procedure coverage in vertical profile (by individual navails);
- Procedure coverage report showing available DME pairs along the procedure. This feature supports the planning of flight inspections for defined procedures;
- Flight inspection data import function that allows the display of measured parameters and comparison of predicted and achieved coverage;
- Estimation of best location for a new DME site that together with the existing navigation infrastructure is to improve the DME-DME signal coverage in a designated area of interest;
- Import of user layers in shapefile format;
- Import and display of route segments from EAD SDO reports converted to CSV format. New procedure definition based on imported route segments;
- Import of vertex points from EAD SDO reports converted to CSV format;
- Batch processing for area calculations.
EMACS (1/2)

EMACS is made up of a set of modules each devoted to a specific type of computational analysis or equipment-specific analysis.

Computational analysis

- **Windturbine** - Wind Farms impact assessment
- **EMI** - Electromagnetic Interference evaluation around CNS equipment
- **MLAT** - Airport Multilateration systems performance analysis
- **WAM** - Wide Area Multilateration systems performance analyses and simulation
- **ASUV** - RNAV performance evaluation

Equipment-specific analysis

- **ILS** - Instrument Landing System precision analysis
- **VOR** - VHF Omnidirectional Range precision analysis
- **DME** - Distance Measuring Equipment precision analysis
- **Radar** - Radar systems performance evaluation
- **Ground-Air communications** - VHF link analysis
GNSS “Infrastructure”

- Geostationary Satellite Based Augmentation System (SBAS)
- GPS
- GLONASS
- Aircraft Based Augmentation System (ABAS)
- Ground Based Augmentation System (GBAS)
- GALILEO (TBD)

- RAIM Receiver Autonomous Integrity Monitoring
- AAIM Aircraft Autonomous Integrity Monitoring
GNSS Satellite Systems:

- GPS (Global Positioning System) USA management

- GLONASS (Global'naja Navigacionnaja Sputnikovaja Sistema) RUSSIA Management. In October 2011, the full orbital constellation of 24 satellites was restored, enabling full global coverage

- GALILEO EU management. Full completion of the 30-satellite Galileo system (27 operational and three active spares) is expected by 2019.

Differential Global Positioning System (DGPS) is an enhancement to Global Positioning System that provides improved location accuracy, from the 15-meter nominal GPS accuracy to about 10 cm in case of the best implementations. DGPS uses a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions.
Satellite Signal

The GPS signal contains three different bits of information — a pseudo random code, almanac data and ephemeris data.

- The **pseudo random code** is simply an I. D. code that identifies which satellite is transmitting information.

- **Almanac data** is data that describes the orbital courses of the satellites. Your GPS receiver uses this data to determine which satellites it expects to see in the local sky. It can then determine which satellites it should track.

- **Ephemeris data** is data that tells the GPS receiver where each GPS satellite should be at any time throughout the day. Each satellite will broadcast its OWN ephemeris data showing the orbital information for that satellite only.
Satellite Signal ERROR (1/2)

Factors that can degrade the GPS signal and thus affect accuracy include the following:

• **Ionosphere and troposphere delays** — The satellite signal slows as it passes through the atmosphere. The GPS system uses a built-in model that calculates an average amount of delay to partially correct for this type of error.

• **Signal multi path** — This occurs when the GPS signal is reflected off objects such as tall buildings or large rock surfaces before it reaches the receiver. This increases the travel time of the signal, thereby causing errors.

• **Receiver clock errors** — A receiver's built-in clock is not as accurate as the atomic clocks onboard the GPS satellites. Therefore, it may have very slight timing errors.
Satellite Signal ERROR (2/2)

- **Orbital errors** — Also known as ephemeris errors, these are inaccuracies of the satellite's reported location.
- **Number of satellites visible** — The more satellites a GPS receiver can "see," the better the accuracy. Buildings, terrain, electronic interference, or sometimes even dense foliage can block signal reception, causing position errors or possibly no position reading at all. GPS units typically will not work indoors, underwater or underground.
- **Satellite geometry/shading** — This refers to the relative position of the satellites at any given time. Ideal satellite geometry exits when the satellites are located at wide angles relative to each other. Poor geometry results when the satellites are located in a line or in a tight grouping.
- **Intentional degradation of the satellite signal** — Selective Availability (SA) is an intentional degradation of the signal once imposed by the U.S. DoD. SA was intended to prevent military adversaries from using the highly accurate GPS signals. The government turned off SA in May 2000, which significantly improved the accuracy of civilian GPS receivers.
Augmentation of GNSS is a method of improving the navigation system's attributes, such as accuracy, reliability, and availability, through the integration of external information into the calculation process. There are many such systems in place and they are generally named or described based on how the GNSS sensor receives the external information.

**SBAS Satellite-based augmentation system** is a system that supports wide-area or regional augmentation through the use of additional satellite-broadcast messages. Such systems are commonly composed of multiple ground stations, located at accurately-surveyed points. The ground stations take measurements of one or more of the GNSS satellites, the satellite signals, or other environmental factors which may impact the signal received by the users. Using these measurements, information messages are created and sent to one or more satellites for broadcast to the end users. SBAS is sometimes synonymous with WADGPS, wide-area DGPS.
GNSS Augmentation system

**GBAS ground-based augmentation system** (GBAS) describe a system that supports augmentation through the use of terrestrial radio messages. As with the *satellite based augmentation systems* detailed above, ground based augmentation systems are commonly composed of one or more accurately surveyed ground stations, which take measurements concerning the GNSS, and one or more radio transmitters, which transmit the information directly to the end user.

**ABAS Aircraft-Based Augmentation System** is achieved by features of the onboard equipment designed to overcome the performance limitations of the GNSS constellations. The two systems currently in use are Receiver Autonomous Integrity Monitoring (RAIM) and the Aircraft Autonomous Integrity Monitor (AAIM).

RAIM may be either Fault Detection (FD) or Fault Detection & Exclusion (FDE).

ABAS/RAIM is a GNSS-based navigation technology that is widely used in aviation. The RAIM algorithm performs a consistency check of the position solution: it requires a sufficient number of GPS satellites in view and a favourable geometric arrangement of these satellites. GPS/RAIM availability prediction can be computed with the AUGUR tool.
GNSS “Infrastructure”
SBAS SYSTEM

- **WAAS (Wide Area Augmentation System)**: developed for civil aviation by FAA (Federal Aviation Administration). Accuracy at least 7.6M (95% of the time)

- **EGNOS (European geostationary Navigation Overlay Service)**: developed for civil aviation by ESA (European Space Agency). Accuracy at least 2M (99% of the time)

- **MSAS (Multifunctional Satellite Augmentation System)**: developed for civil aviation by JAPAN. It consist of MTSAT-1R and MTSAT-2

- **QZSS (Quasi Zenith Satellite System)**: developed for mobile application by JAPAN. It consist of 3 satellite

- **GAGAN (GPS Aided Geo Augmented Navigation)**: developed for mobile application by Indian Government. It consist of 3 satellite

- **SDCM (System for differential correction and monitoring)** - Russia

[NOT FOR COMMERCIAL PURPOSES]
Determination of Position by Satellites

- 4 Satellites to define Receiver 3D (x,y,z) position
- +1 Satellite to define Time (t) to correct receiver internal clock error
- +1 satellite to exclude satellite if it’s not correctly working
RAIM Prediction - AUGUR (1/3)

From 1 July 2012, AUGUR coverage will be limited to ECAC airspace only.

AUGUR is a web-based tool which checks the availability of GPS integrity (RAIM) for different operations including B-RNAV, P-RNAV and RNP APCH to LNAV minima.

**AUGUR provides one function per type of operation:**
- the **“en-route” function** for B-RNAV routes (RNAV 5)
- the **“terminal” function** for TMA where GPS-based P-RNAV procedures are published (RNAV 1); and
- the **“approach” function** for airports where RNP APCH to LNAV minima procedures are published.

This allows airspace users to be informed about the number of operational satellites and provides a means by which the availability of GPS integrity can be confirmed for an intended flight.
RAIM Prediction - AUGUR (2/3)

AUGUR  GPS RAIM Prediction Tool - Terminal/Approach Tool

Warning: From 1 July 2012, AUGUR coverage will be limited to ECAC airspace only. Please email the helpdesk (augur.helpdesk@ecacnav.com) for further information.

Airports

Airport 01  LIRF
Airport 02  LIPB
Airport 03  LIRA
Airport 04  LIML
Airport 05  LIMW
Airport 06  LICO
Airport 07  LIEO
Airport 08
Airport 09
Airport 10

Output

Terminal/Approach Check

Scenario Start: 06/02/2015 00:00:00 UTC  Scenario Stop: 06/02/2016 00:00:00 UTC
Mask Angle: 5.00, Algorithm: Fault Detection Only (FD), Mode: TERMINAL
Active NANS:

Configuration

Mask Angle 5.00 degrees
Algorithm FD
Mode TERMINAL

Result

Format Graphic

Check Terminal/Approach

Time (UTC)

RAIM Unavailable Baro Aided Non Baro Aided

ENAV

NOT FOR COMMERCIAL PURPOSES
RAIM Prediction - AUGUR (3/3)
Wrap-up

- RNAV Infrastructure
- VOR/DME
- DME/DME
- GNSS
- Satellite Error
- Augmentation
Grazie