Chapter 2 AREA NAVIGATION

1. Area Navigation Principles

Area navigation (RNAV) is a term applied to navigation between any two selected points on the earth's surface. RNAV has been around since the 1960s and the earliest avionics used triangulation measurements from ground-based navigation aids to compute an RNAV flight path between waypoints.

A number of self-contained navigation systems which are independent of any ground based navigation systems have also been developed, including OMEGA (now obsolete) LORAN C, GPS, Glonass, Inertial Navigation Systems (INS) and Inertial Reference Systems (IRS).

Perhaps the most common type of RNAV system in use in commercial aviation today involves the use of IRS positioning updated by reference to ground-based radio navigation aids (DME and VOR) or GPS. Updating by reference to ground-based aids is limited by the availability of sufficient navigation aids, and in many parts of the world, including oceanic and remote areas, position updating is unavailable.

Commonly referred to by the generic term GNSS (Global Navigation Satellite System) satellite navigation has revolutionised area navigation and provides highly accurate and reliable positioning. For modern air transport operations area navigation is managed using a Flight Management System, using IRS position updated by GNSS.

However, as there are many and varied area navigation systems in use throughout the world, the PBN Manual provide a number of navigation specifications to accommodate a range of RNAV and RNP performance levels. One of the tasks of the operations approval inspector is to ensure that the equipment available meets the requirements of the relevant PBN operation.

2. Geodetic Reference

An area navigation system computed position must be translated to provide position relative to the real position on the earth's surface. Horizontal datums are used for describing a point on the earth's surface, in latitude and longitude or another coordinate system.

A specific point on the earth can have substantially different coordinates, depending on the datum used to make the measurement. There are hundreds of locally-developed horizontal datums around the world, usually referenced to some convenient local reference point. The

WGS 84 datum is the common standard datum now used in aviation.

3. Path Terminators

In its simplest form area navigation system computes a track between two selected waypoints. However the demands on aircraft navigation require the definition of complex flight paths, both lateral and vertical. The international standard for definition of path and terminator is ARINC 424. A flight path is described in coded ARINC 424 language which is interpreted by the RNAV system to provide the desired navigation function and inputs to flight guidance systems.

The path between any two waypoints can be specified, depending upon the coding. Each segment is also defined by a terminator or end statement, which provides information to the navigation system on the intended method of connection of one segment (path) with the next. For example two waypoints could be connected by a great circle track between two waypoints (TF) or perhaps by the arc of a circle of defined radius (RF). Other options include a path defined from the current position to a waypoint (DF), or a path defining a holding pattern (HF). In general usage path and terminator is commonly abbreviated to path terminator or sometimes leg type. A complex series or ARINC 424 rules govern the definition of leg types and their interaction with each other.

One example a common sequence of leg types is TF to TF. Effectively this is a series of "straight lines" as in the diagram below. In the normal case, the aircraft avionics interprets the ARINC 424 coding to require that the two legs are joined by a curved flight path, and the aircraft will "fly by" the intermediate waypoint.

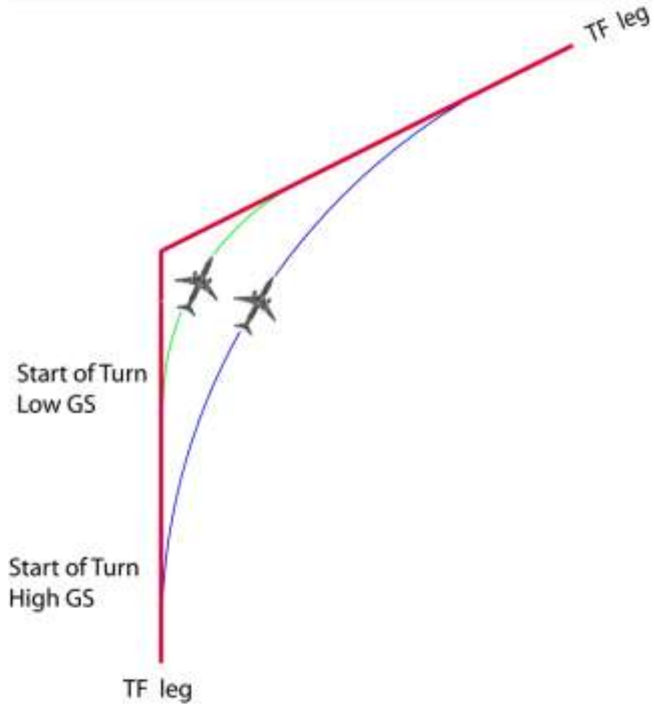

Figure 2.1: TF to TF Transition

The aircraft navigation system is programmed to provide a start of turn prompt (turn anticipation) based the current groundspeed and a programmed bank angle, which will normally provide a turn of sufficient radius to allow the subsequent segment to be intercepted. As each aircraft will compute a different start of turn point the result is a spread of turns, between the tracks of faster aircraft using lower bank angles, to slow aircraft with larger bank angles.

Turn anticipation does not provide track guidance during the turn, and until the aircraft is established on the subsequent leg, cross-track error cannot be monitored. The effectiveness of the turn anticipation algorithm is limited by variation in groundspeed during the turn (e.g. headwind to tailwind) and the achieved bank angle. Undershooting or overshooting of the turn can occur and crew intervention may be required.

Using a range of leg types available with ARINC 424 coding, (approx 18) complex fight paths can be designed. However it must be noted that not all navigation systems are capable of accommodating all leg types. Two common examples of leg types that may not be supported are RF and CA legs.

An RF or Radius to Fix leg defines a circle of specified radius enabling an aircraft to fly a precise curved flight path relative to the surface of the earth, rather than an undefined path as in the previous example of a TF/TF.

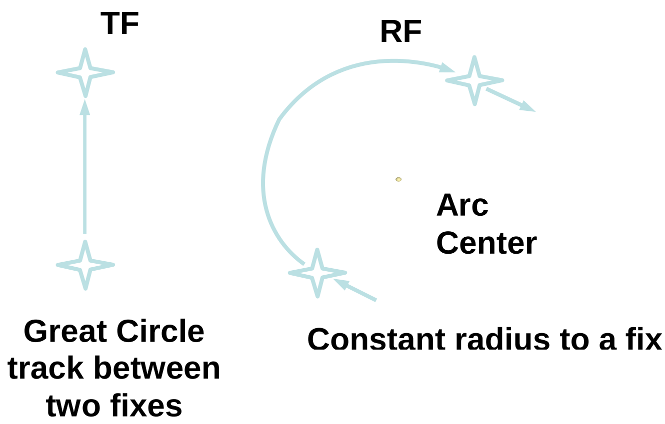

Figure 2.2: Common Path Terminators

A CA or Course to Altitude leg defines a nominated course until a specified altitude is reached. On reaching the altitude the path is “terminated” and the avionics will follow the path defined by the next leg or path and terminator. The CA leg which is commonly used to specify the initial leg of a departure is not normally supported by general aviation GPS receivers, which are not usually integrated with the aircraft’s vertical navigation system. Consequently the flight planned departure route may not be followed and pilot intervention (manual selection of next leg) is required.

In the example in Figure 2.3 two aircraft are cleared on a departure with the same instruction. Depending on the climb performance, the position at which the aircraft reaches 3000ft and the CA leg is terminated will vary. If the aircraft is equipped with an integrated vertical navigation system the termination will be automatic and the active route will sequence to the next leg which may be (for example) a Direct to Fix (DF) leg.

If vertical navigation capability is not available, the termination must be initiated by the flight crew. For manually sequenced navigation systems the track to the next fix will depend on the point at which the direct to function is selected. In the example, the pilot has selected Direct To immediately on reaching 3000ft and the track is generated from that position. If Direct To is selected after the turn a different track will be displayed. In this and similar examples, the actual flight path is variable and may not meet operational requirements. A different sequence of Path Terminators may be needed to better define the flight path but may result in the inability to place a minimum altitude requirement on the turn initiation.

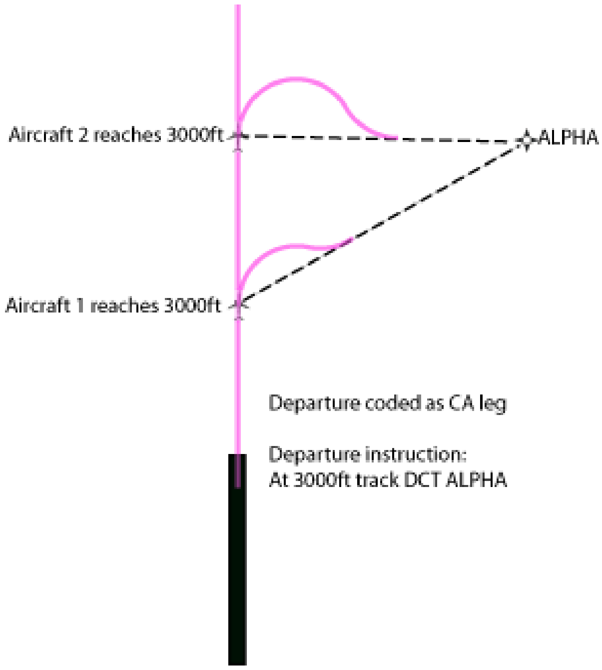

Figure 2.3: CA Path Terminator Example

It is necessary that operational approval inspectors gain a working knowledge of common path terminators, the basics of flight path design, and the functionality of aircraft avionics and flight control systems in order to properly manage operational approvals. For example, while an operation might meet the requirements of a specific PBN Manual navigation specification, the operational approval may need to ensure that crew procedures are defined in order to fly a certain type of procedure, as in the case of the CA example described above.

4. Radius to Fix segments

The use of an RF segment or multiple segments including TF and RF legs provides great flexibility in route design enabling flight paths to be designed to avoid terrain, manage noise footprint, better utilise airspace and provide many other benefits.

RF leg capability is available on most late model FMS equipped aircraft but the lack of general availability can limit its broader use. Currently only the RNP AR APCH navigation specification supports the use of RF legs but it is expected that application will be extended in due course.

Capability for RF legs, while extremely useful, is not without limitation, and it is important that the FMS functionality, aircraft flight control logic, and the application of RF legs to flight procedure design are properly understood.

A segment coded as an RF leg creates a circular flight path over the surface of the earth, defined by a start and end point, a turn radius and an origin. ARINC 424 coded segments before and after the RF legs must join at a tangent to the circle defined by the RF leg. Consequently the sequence of legs used can be TF/RF or RF/TF and RF/RF. Joining of RF legs to other RF legs is acceptable and turn reversal and change of radius may occur. This capability allows great flexibility in design.

While complex flight paths can now be designed and displayed as the active route, the aircraft must have the capability to accurately follow the defined flight path. Pilots are familiar with flying turns at a constant airspeed and angle of bank which enables a circular flight path to be flown *with reference to the air mass* and are trained to manually compensate for the presence of wind if necessary. Pilots now need to understand that the FMS will fly an exact circular flight path *over the ground* and the angle of bank will be adjusted by the flight control system to maintain that circular flight path.

The physics of flight are such that the radius of a circle (over the ground) is limited by groundspeed and angle of bank. The minimum radius that can be flown is therefore limited by the maximum available bank angle, and the groundspeed.

Bank angle limits are determined by the aircraft manufacturer, and are also limited by crew selection, aircraft configuration and phase of flight. In normal approach/departure configuration a typical bank angle capability for modern jet transport aircraft is 30° but may be as low as 20°. The bank angle limit can be 8° or less at low altitude, and similarly bank angle limits are also applied at high altitude. The RNP AR APCH navigation specification requires aircraft to be capable of 25° angle of bank in normal circumstances and 8° below 400ft. The procedure designer uses these limits in the design of RF turns, and pilots need to be aware of the aircraft capability in all flight phases. Inspectors should familiarise themselves with aircraft capability documentation during the operational approval process, for aircraft that will utilise RF leg capability.

Groundspeed is a function of TAS, and consequently IAS, plus or minus the ambient tailwind or headwind component. In order to ensure that the flight path during an RF turn can be maintained under all normal weather conditions the procedure designer allows for a maximum tailwind component or “rare-normal” wind. The maximum tailwind component is selected from a wind model which is intended to represent the maximum winds likely to be encountered at various altitudes, generally increasing with altitude. A tailwind component of up to 100KT may be applied in some cases.

As groundspeed is also affected by TAS, the flight crew needs to manage the IAS within acceptable limits to ensure that the bank angle limits, and hence the ability to maintain the flight path, are not exceeded in circumstances where high winds exist. In normal routine operations, where ambient winds are generally light, quite low bank angles are sufficient to maintain RF turns of average radius. However, if the IAS is allowed to exceed normal limits, the limiting bank angle may be reached at less than the maximum design tailwind component, leading to a potential loss of track adherence.

Generally applicable maximum indicated airspeeds are specified in the RNP AR APCH navigation specification; however the designer may impose specific limiting speeds in some cases.

Flight crews needs to be thoroughly conversant with the principles and practice of RF turns, limiting airspeeds, bank angle/aircraft configuration, the effect of high winds, and contingency procedures for manual intervention which although rare, may be required.

5. Area Navigation Systems

Although there are many different types of area navigation systems the most common systems are:

Legacy systems. Self contained DME/DME and VOR/DME navigation systems.

Stand-alone GNSS systems comprising a receiver and a pilot interface which may be combined with the receiver unit, or installed as a separate control and display unit.

(Note: A control and display unit (CDU) should not be confused with a Flight Management System as the interface unit (CDU) is similar.)

Figure 2.4: Typical Stand-alone GNSS Receiver

This type of GNSS installation should provide steering commands to HSI or CDI displays in the pilot's primary field of view. Many GNSS units provide an integrated navigation display and/or map display as part of the receiver unit, however in many cases the size, resolution and location of the display may not be suitable nor in the pilot's primary field of view.

Flight Management System There are many types of flight management systems with varying complexity and some attention is required to determine the capability of each particular installation. In modern transport operations the FMS usually incorporates two Flight Management Computers which are provided with position updating from a number of sensors. These sensors will normally be inertial, radio and GNSS (as installed).The inertial information is normally provided by two or more Inertial Reference Systems (IRS) with radio and GNSS information provided by two or more Multi Mode Receivers (MMR). Prior to the FMC accepting a sensors positional update, a gross error check is performed to ensure that the sensor position falls within the ANP or EPE value.

The computed aircraft position is commonly a composite position based on the IRS position corrected by inputs from the navigation information received from the MMR. Recently manufactured aircraft will usually be equipped with GNSS and the computed position in this case will normally be based on IRS updated by GNSS, excluding less accurate inputs from ground-based navigation aids.

Figure 2.5: FMS Equipped Aircraft with Large Screen Multifunction Displays

6. Data Management

In all but the simplest area navigation systems, navigation data is contained in an airborne database. From a human factors standpoint navigation data should only be extracted from a valid database, although some PBN Manual navigation specifications permit pilot entry of waypoint information. Where pilot entry of co-ordinates is permitted it should be limited to en-route operations only and above the minimum obstacle clearance altitude. For all other operations pilot entry or modification of waypoint data should be prohibited.

Arrival, approach and departure operations should be extracted from the database by the selection of a named flight procedure. (See Figure 2.6.) User construction of procedures even if waypoints are extracted from an airborne database should be prohibited.

PBN operations are dependent upon valid navigation data. Unlike conventional navigation where the basic navigation guidance is originated from a physical point (e.g. a VOR transmitter) area navigation is totally dependent on electronic data and gross errors can occur due to erroneous data or mismanagement of valid data. In general PBN Manual navigation specifications require or recommend that data is obtained from an approved supplier who has implemented appropriate quality control procedures. Despite a data supplier meeting such quality control standards, there still remains a risk that invalid data may be contained in the airborne database and caution should be exercised. In the case of operations conducted where collision with terrain is a risk, (approach/departure) additional checks at each data update cycle are required. Electronic comparison of data against a controlled source is preferred, but manual or simulator checks may be used where this method is not available.

It should also be noted that whilst every precaution may be taken to ensure the validity of the airborne database, that valid data can in some circumstances be incorrectly interpreted and managed by the airborne navigation system. It is extremely difficult to protect against this type of problem, however in evaluating PBN operating procedures, due attention should be made to ensure that crew review procedures are appropriate and sufficient to constitute a last line of defence.