DOCUMENT
GSM-G-CPL.026

DOCUMENT TITLE

NAVIGATION 1

CHAPTER 10 – PILOT NAVIGATION

Version 2.0
October 2017

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PILOT NAVIGATION

10.1 Dead Reckoning Navigation

Dead Reckoning (DR) navigation is the calculation of Heading and Groundspeed using known values of Wind Velocity, Track and True Airspeed.

The wind velocity, however, is a forecast value. Actual wind may be quite different from that forecast. So, the heading calculated before flight may often not maintain the flight planned track. An in-flight heading correction may be required.

Although actual wind may differ from forecast wind, the pilot must also understand that inaccurate flying (Heading keeping) will also cause the aircraft to deviate from the flight planned track.

The in-flight work load of a single pilot demands that in-flight heading corrections must be quickly and accurately calculated. Mental calculations may be required to free the pilot to fly the aircraft and concentrate on other tasks such as radio work, monitoring fuel and engine(s), and keeping a lookout for other aircraft. In the classroom and for examination calculations a navigation computer will be used for DR navigation.

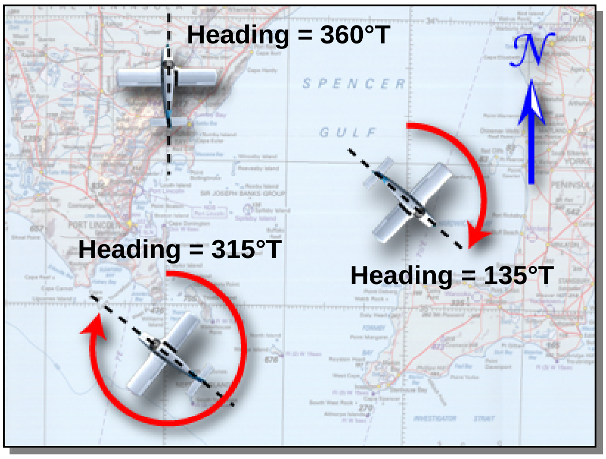
10.2 Terminology

DR navigation terms:

- Heading (HDG)
- Flight Plan Track (FPT)
- Track Made Good (TMG)
- Drift
- Track Error (TE)
- Closing Angle (CA)

10.2.1 Heading (HDG)

Heading is the angle measured clockwise from North to the fore and aft axis of the aircraft, and is expressed in degrees true, magnetic or compass.



10.2.2 Flight Plan Track (FPT)

FPT is the direction along the ground that the aircraft will follow during the flight.

Track is normally measured in degrees true and degrees magnetic, when variation is applied.

10.2.3 Track Made Good (TMG)

TMG is the direction of the actual path of the aircraft along the ground during the flight.

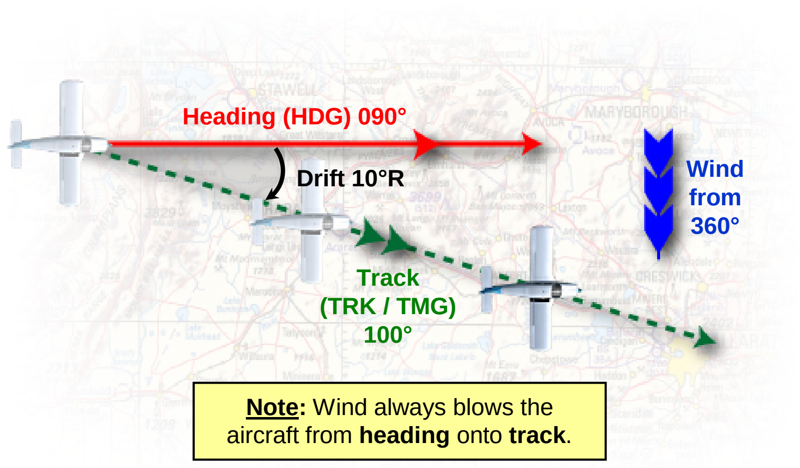
TMG is calculated from the current heading by applying drift or from the flight plan track by applying track error.

10.2.4 Drift

Drift is the angle between the heading and track of an aircraft resulting from wind effect. Drift is expressed in degrees left (port) or right (starboard) of the aircraft heading.

There are two calculations to consider:

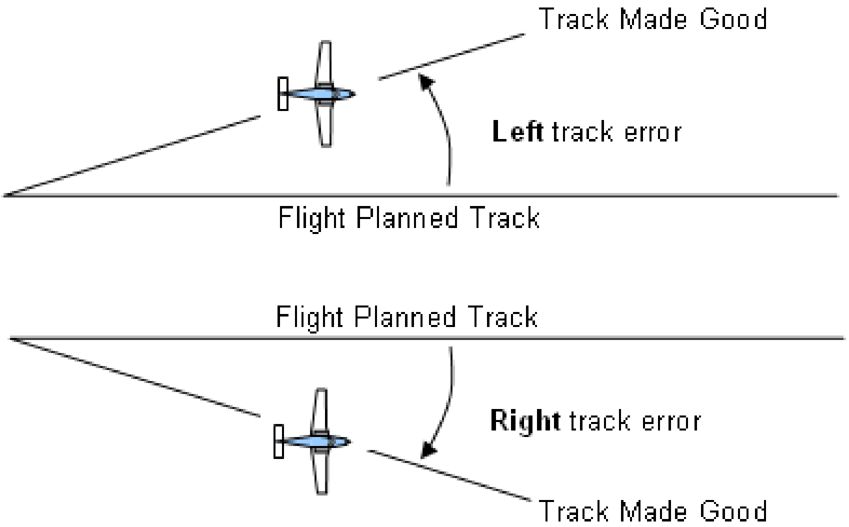
- Drift calculated at the flight planning stage, which is the angular difference between the heading and FPT.
- Drift during flight, being the angular difference between the heading and TMG.



10.2.5 Track Error (TE)

TE is the angle between Flight Planned Track (FPT) and Track Made Good (TMG).

- If the aircraft is **left** of FPT = **left** track error
- If the aircraft is **right** of FPT = **right** track error



If the TMG is different from the FPT calculate the heading correction angle and the heading to **regain** the FPT, thereafter calculate a heading to **maintain** the FPT.

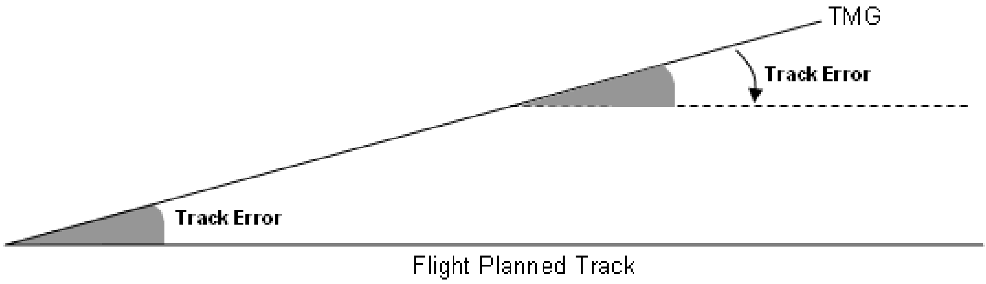
At a waypoint or checkpoint note the current time. After the aircraft is established on the heading required to regain track en-route or to destination, calculate the **actual** groundspeed (GS). GS is used to calculate a revised estimate to the next waypoint or destination.

> **Note** Track error is not drift. Drift is the angle between heading and track, whereas track error is the angle between two types of tracks. Both of these concepts can be used separately to navigate an aircraft along a FPT.

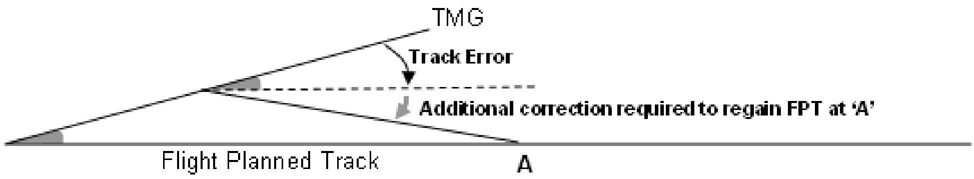
Applying drift to solve the velocity triangle during flight is a complicated and precise method to track keeping, comparing to applying track error.

10.3 In-Flight Track and Heading Corrections

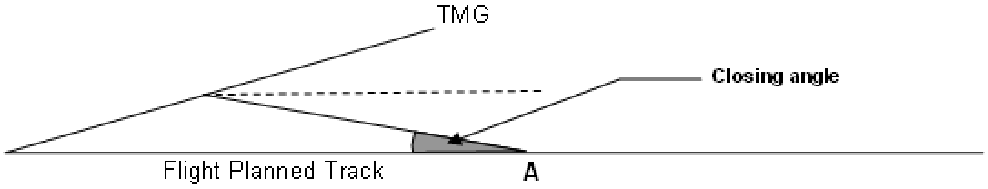
If TMG is altered by an amount equal to track error, the aircraft will travel **parallel** to the FPT.



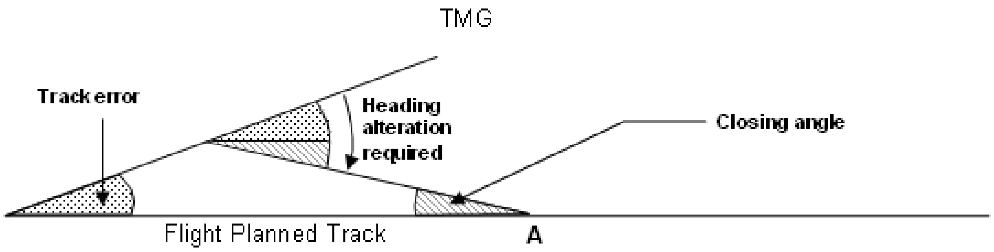
To **regain** track alter TMG by an additional correction to regain the FPT.



The angle at which to "close" the FPT or destination is **called closing angle**.



One of the rules of geometry state that the external angle of a triangle is equal to the sum of the opposite interior angles.



To regain FPT at a chosen position or at the destination, alter the TMG by an amount equal to the TE, plus the Closing Angle (CA)

During flight do mental calculation to calculate the values for TE and CA to simplify the task of navigation.

If TE and CA are each less than 15°, the pilot may assume that the required track change will be achieved by an equal heading change.

As the heading changes the wind effect on the aircraft, results in a slightly different track. For small angles (<15°) it is acceptable to assume that corrections made to current heading will result in the same correction to TMG. Therefore:

Heading to regain track or destination equals TE + CA.

In-flight track and heading corrections can be made without the use of a navigation computer to calculate heading using actual wind velocity.

Neither TE, CA nor TE + CA are equal to drift. Drift, TE and CA are all separate concepts and different ways of performing the corrections required to maintain a FPT.

Calculations to obtain heading:

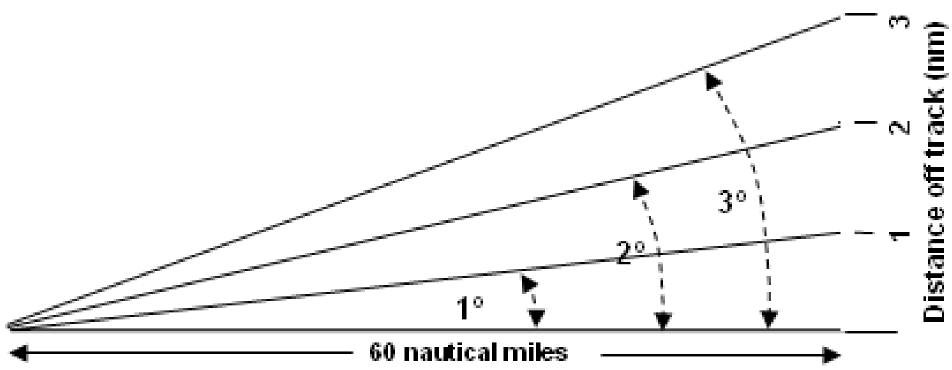
- Apply a known drift value to a required track to calculate a required heading
- Apply TE and CA to the current heading to intercept the FPT at a specific point.

10.4 Estimating TE and CA – The 1:60 Rule

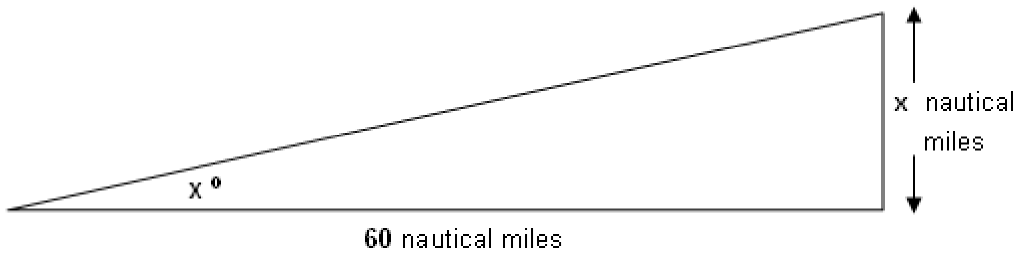
The 1 in 60 rules states:

"If 1nm off track in 60nm equals 1° off track"

If the aircraft is 2 nm off track after flying 60nm the TE is 2°, and if the aircraft is 3 nm off track after travelling 60nm the TE will be 3°, etc.



The 1 in 60 rule is based on the basic trigonometric function tan, and uses distance along track from departure to the point on track abeam the pinpoint.



We use the approximation : $\tan x = \frac{x}{60}$

This is not exactly correct, since $\tan 1° = \frac{1.05}{60}$ not $\frac{1}{60}$

and $\tan 2° = \frac{2.10}{60}$ not $\frac{2}{60}$ etc.

For an angle less than 20° the approximation is acceptable.

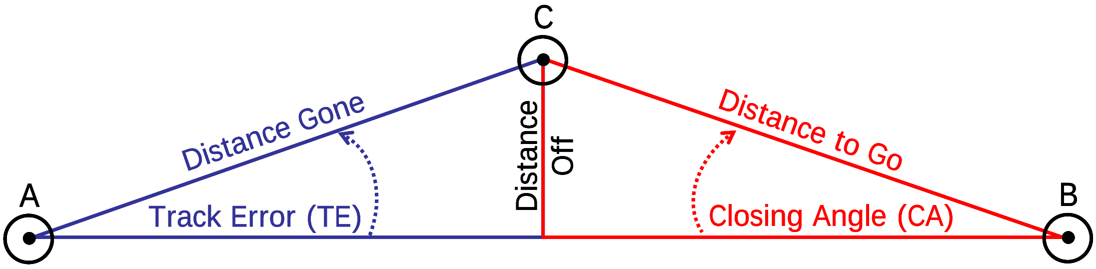
The 1 in 60 rule is useful to relate **distance (**on the map and outside the aircraft) **to an angle as** to calculate a heading correction for track keeping purposes.

The relationship "1nm off track in 60nm along track equals a TE of 1°" calculates the TE (and CA) corresponding to any combination of off track and along track distances.

10.4.1 Solving 1:60 Problems – Formula Method

There are two formulae that can be used to solve 1 in 60 rule calculations. These formulae are best suited for classroom and examination environments, although it can be used in practical flying.

In the diagram below the FPT is drawn between A and B. After travelling a certain distance along track, the aircraft is pinpointed at C, which is a certain distance off track.



$$\frac{\text{Track Error (TE)}}{60} = \frac{\text{Distance Off}}{\text{Distance Gone}} \qquad \frac{\text{Closing Angle (CA)}}{60} = \frac{\text{Distance Off}}{\text{Distance to Go}}$$

These formulae are used to calculate any one of the three values in the equation by rearranging the formula as required. To calculate TE and CA the following formulae apply:

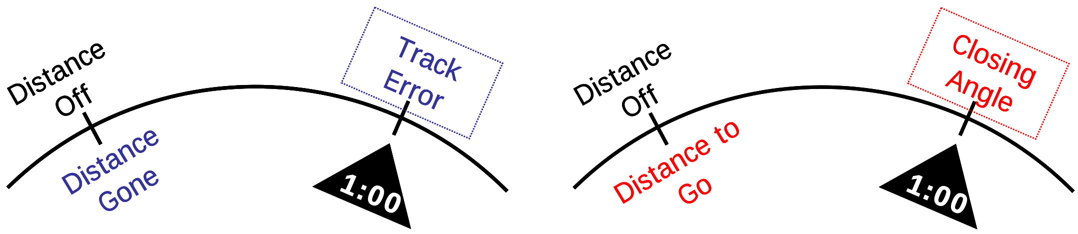
$$\text{Track Error (TE)} = \frac{\text{Distance Off} \times 60}{\text{Distance Gone}} \qquad \text{Closing Angle (CA)} = \frac{\text{Distance Off} \times 60}{\text{Distance to Go}}$$

10.4.2 1:60 Rule – Navigation Computer Method

The circular navigation computer can be used to resolve the the 1 in 60 rule on the front (calculator) side by using the inner and outer scales. This method of calculating the TE and CA is the preferred method during flight.

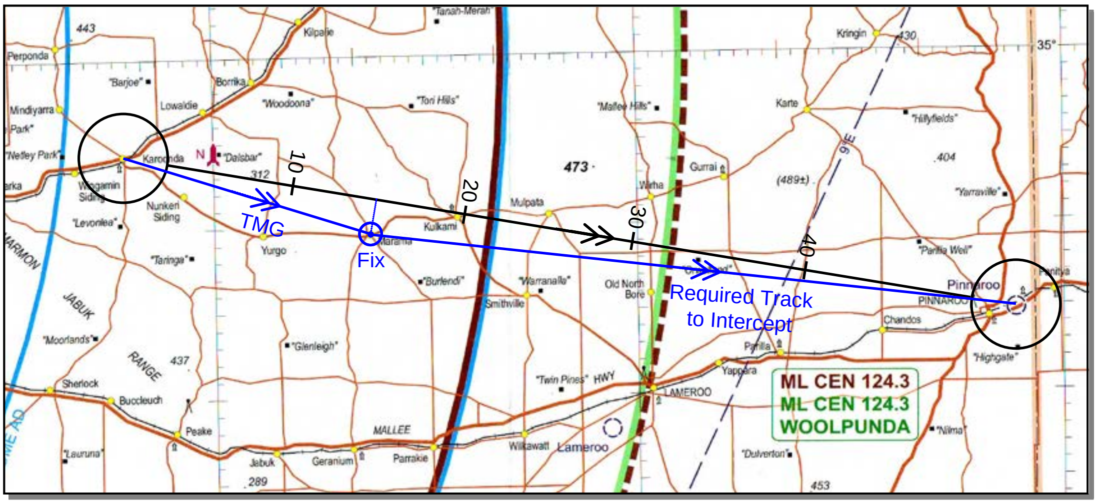
The values contained in the formulae are placed as follows:

- The top value of the equation on the outer scale
- The bottom value of the equation on the inner scale
- TE or CA is shown on the outside scale opposite the black 1:00 triangle.



The advantage is that no matter which value in the formula needs to be calculated, the elements will remain on the same scales of the navigation computer.

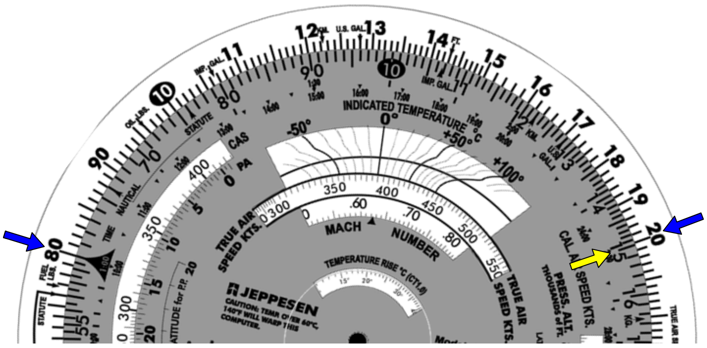
Example: The leg distance between Karoonda and Pinnaroo is 53 nm. After flying 15 nm, steering the planned heading, the aircraft is pinpointed overhead Marama township, 2 nm to the right of track. Calculate the heading change at the fix to steer directly to destination.



The heading change required to intercept the FPT at Pinnaroo is equal to the sum of the TE and CA.

In the example the total distance, distance flown and distance off track were given and can also be measured on the map if not given.

- Set the distance right of track (2nm) on the outer scale opposite distance flown (15nm) on the inner scale and read the **track error (8°)** on the outer scale opposite the black 1:00 triangle.

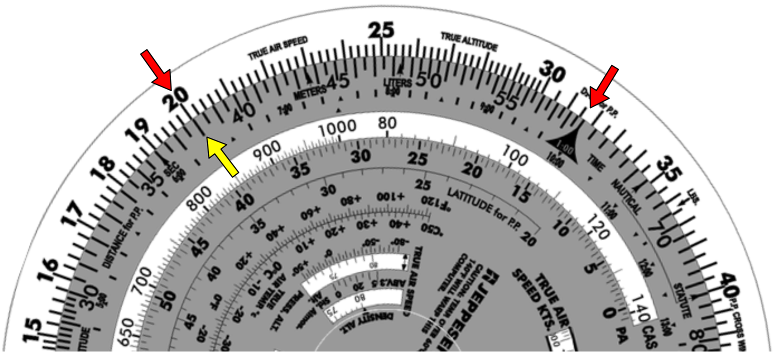


The navigation computer does not present the magnitude of the answer, it is necessary to estimate the magnitude based on the values of the calculation.

With reference to the 1 in 60 rule, if the aircraft is 2nm off track after 60nm flown, the TE equals 2°. In this example the aircraft is 2nm off track after 15nm flown, therefore the angle will be greater than 2°. The answer of 8° would be correct as it can't be 0.8° or 80°

Also observe that since the actual distance flown was 15nm (a **quarter** of 60nm) the value of the track error was **four times** what the value would have been for 60nm flown.

- Calculate the distance to go by subtracting the distance flown from the total distance. 53nm – 15nm = **38nm to go**.
- Set distance off track (2nm) on the outer scale opposite distance to go (38nm) on the inner scale and read the **CA (3.16°)** on the outer scale opposite the black 1:00 triangle. Round the angles calculated to the nearest whole degree. **3.16° ≈ 3°**.



With reference to the 1 in 60 rule, if the aircraft is 2nm off track after 60nm, the CA equals 2°. In this example the aircraft has 38nm to go (just more than half of 60nm) and 2nm off track, the angle must be just less than double the value of 2°, therefore the answer of 3.16**° ≈ 3°** would be correct as it cannot be 0.316° or 31.6°

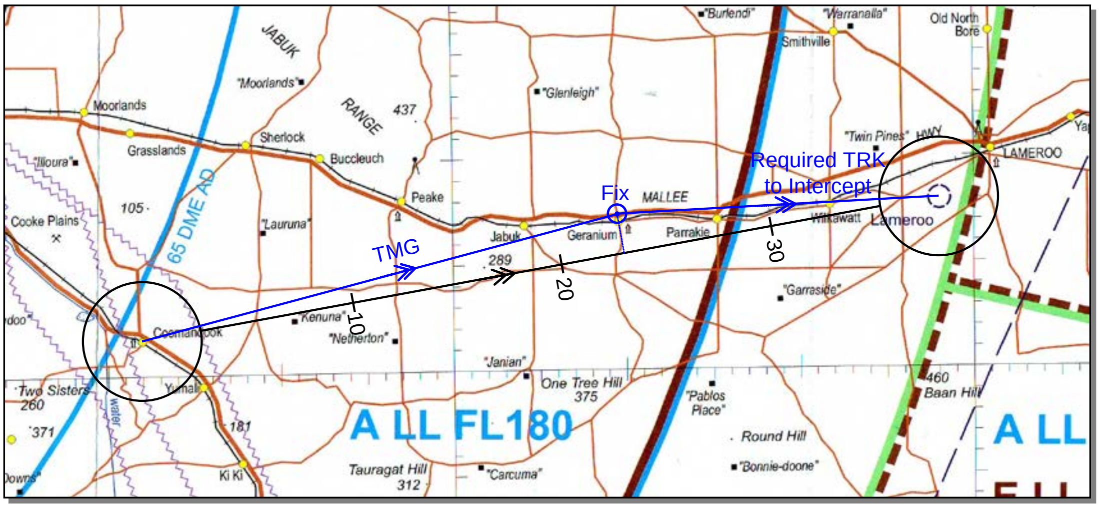
- Calculate the total correction required at the fix by adding the TE to the CA. 8° TE + 3° CA = **11° total correction to heading**.
- Since the aircraft was right of track at the fix, the heading change will be to the left, **so alter heading 11° to the left**.

Example 2: A flight has been planned from Coomandook to Lameroo. The total distance is 38nm and the planned track 071°M.

The planned heading of 080°M was flown since departing Coomandook and the aircraft's position was pinpointed overhead an intersection, just north of the township of Geranium. If the aircraft has travelled 23nm since departing Coomandook and is 2nm left of track at this fix, calculate the following:

1. Track Error
2. Closing Angle
3. Track Made Good
4. Heading to Parallel the Flight Plan Track

5. Heading to intercept the Flight Plan Track at Lameroo



- Calculate the TE by setting the distance off track (2nm) on the outer scale of the navigation computer, opposite the distance flown (23nm) on the inner scale. Read the track error (5.23°) on the outer scale opposite the black 1:00 triangle on the inner scale. Round the track error to the nearest whole degree, 5.23° **≈ 5° track error**.
- Calculate the distance to go by subtracting the distance flown from the total distance. 38nm total distance – 23nm distance flown = **15nm distance to go**.
- Calculate the CA by setting the distance off track (2nm) on the outer scale, opposite the distance to go (15nm) on the inner scale and read the **closing angle (8°)** on the outer scale opposite the black 1:00 triangle on the inner scale.
- Calculate the TMG by applying the TE to the FPT. Since the aircraft was to left of FPT, the TMG is the left of the FPT. 071°M FPT – 5° TE = **066°M TMG**.
- Calculate the heading to parallel the FPT by applying the TE to the current heading at the fix. Apply 5° (TE) to the heading of 080°M as a right turn is required to parallel track, therefore the **heading to parallel** would be 080°M + 5° = **085°M**.
- The total heading change required to intercept track is the sum of the TE and CA, i.e 5° TE + 8° CA = **13° total correction**.
- Calculate the heading to intercept the FPT at Lameroo by applying the total correction to the heading at the fix. As the aircraft is left of track a turn to the right is required to intercept the FPT. Current heading 080°M + 13° total correction = **093°M**.

> **Note:** The heading to intercept can also be calculated from the heading to parallel by applying the CA to the parallel heading, i.e. 085°M parallel heading + 8° CA = **093°M intercept heading**.

10.4.3 Double Track Error Method

Half-way along track there is no need to calculate the CA, since the TE is equal to the CA as the distances of two triangles are the same. Therefore, the required heading correction at the fix to intercept track is double the track error.

The time it will take the aircraft to intercept track is equal to the time difference between the first two fixes.

Only assume TE equals CA if the distance flown and distance to go are identical. When the distances are not the same separate calculations are required.

The example below illustrates the double TE method.

> **<u>Example 3</u>:** The aircraft is tracking from Truro Flat Airpark to Renmark aerodrome on a heading of 084°M. The total distance is 65 nm and the flight departed at 0400Z. The pilot pinpoints the aircraft 3nm left of track over Kanni at 0416Z after having flown 32 nm. Calculate the heading to intercept track at Renmark and the time overhead the destination.

Note that **the fix is almost half way along track** as the distance to Renmark is 33nm.

- Calculate the TE by setting the distance off track (3 nm) on the outer scale of the navigation computer opposite the distance gone (32nm) on the inner scale. Read the track error (5.63°) on the outer scale opposite the black 1:00

triangle on the inner scale. Round the track error to the nearest whole degree, 5.63° **≈ 6° track error**.

- The distance to go (33nm) is similar as the distance gone (32nm) and no CA calculation is required, it is assumed that the CA being the same as the TE when the distances are identical. Therefore, **the closing angle will be 6°**.

The double TE method is used to save time by not doing a separate CA calculation during flight.

CA calculated with the distance off track of 3nm and the distance to go of 33nm, the closing angle equals 5.45° and rounded to 5°. A one degree inaccuracy is acceptable in practical DR navigation.

- Calculate the heading to intercept by applying both the TE and CA to the current heading at the fix. As the aircraft is left of track the heading change would be to the right. Heading at the fix is 084°M + 6° TE + 6° CA = **096°M heading to intercept**.

Double the TE value was added to the heading to determine the intercept heading. (084°M + 12° = 096°M).

The fix being halfway between the two waypoints has the benefit that the elapsed time to the fix, will equal the time to proceed to destination.

This is only true when the distance flown and distance to go are similar, if leg times are different, separate calculations will apply.

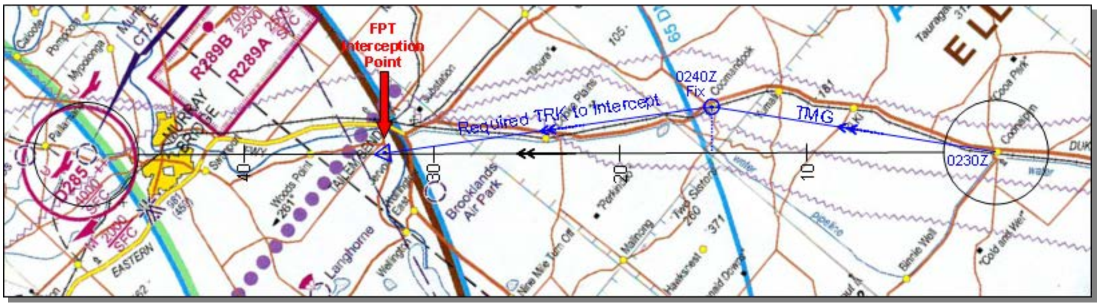
- In the example the aircraft was overhead Truro Flat Airpark at 0400Z and arrived at the fix at Kanni at 0416Z. Therefore, it is assumed that it will take another 16 minutes to fly to Renmark. **Estimated Time of Arrival (ETA)** = **0432Z** (0416Z + 16)

10.4.4 Regaining Track at a Chosen Point Enroute

Example 4: The aircraft is tracking from Coonalpyn to Murray Bridge aerodrome. The FPT is 312°M and the planned heading of 307°M has been maintained since passing overhead Coonalpyn at 0230Z. At 0240Z, after flying for 15nm, the aircraft's position is fixed, 3nm right of track over Coomandook. Calculate the heading to intercept the FPT at Jervois, the distance to Jervois is 18nm.

If the aircraft flew direct from the fix at Coomandook to Murray Bridge, the track would be dangerously close to the Restricted Areas R289A and R289B, located to the east of Murray Bridge township.

To avoid the Restricted Areas, the pilot decides to regain track at Jervois, after which the aircraft's track will continue towards Murray Bridge aerodrome, remaining to the left of the freeway and clear of the Restricted Areas.



- Calculate the TE by setting the distance off track (3nm) on the outer scale opposite the distance gone (15nm) on the inner scale of the navigation computer. Read the TE on the outer scale, opposite the black 1:00 triangle on the inner scale. **TE = 12°**.
- Calculate the closing angle by setting the distance off track (3nm) on the outer scale opposite the distance to go (18nm) on the inner scale. Read the CA on the outer scale, opposite the black 1:00 triangle on the inner scale. **CA = 10°**.
- Calculate the total correction to the heading required at the fix to intercept the FPT at the chosen point by adding the track error to the CA. 12° TE + 10° CA = **22° total correction**. Since the aircraft is right of track, the correction to heading will be to the left.
- The heading to intercept the FPT at Jervois will be the current heading at the fix (307°M) minus the total correction. 307°M – 22° = **285°M to intercept FPT at Jervois**.

This example illustrates the 1:60 rule. Due to the aircraft being almost halfway between the two fixes the double TE method could apply.

The inaccuracy caused by the using the double TE method in a calculation can be overcome by effective map reading, using the freeway leading to Murray Bridge as a line feature along FPT to ensure the aircraft remains clear of the Restricted Areas.

10.4.5 Procedure After Regaining Track En Route

Referring to example 4 it is clear that the heading needs to be altered after intercepting the FPT at Jervois.

To maintain FPT steer a heading to the right at Jervois by an amount equal to the CA, to avoid going through the FPT and ending up left of track requiring additional corrections to heading to be made.

The heading to intercept the FPT at Jervois is 285°M and the CA 10°.

The required **heading to continue** along the FPT **285°M + 10° = 295°M**.

10.4.6 Calculating the Time to Intercept FPT

Anticipating a heading correction is just as important as knowing the magnitude of the correction required.

In example 4 above, the pilot needed to make a second heading correction when the flight plan track was intercepted at Jervois. The pilot would need to start map reading some time before reaching Jervois in order to identify the town and turn overhead.

By calculating the time when the aircraft will intercept the flight plan track, the pilot will have the means of organising the cockpit workload in such a manner as to allow enough time to begin map reading before the aircraft reaches the point of interception.

Track interception:

- Calculate the elapsed time between the current fix position and the last known ground position. Referring to example 4, the time between passing overhead Coonalpyn and the fix overhead Coomandook. 0230Z to 0240Z is **10mins elapsed time**.
- Since the distance flown is 15nm, calculate the current groundspeed with the navigation computer. **GS = 90kts**.
- The distance to go to the interception point at Jervois is 18nm and therefore the time to intercept can be calculated by using the groundspeed of 90kts. **Time to go = 12mins**.
- Calculate the ETA for the point of interception by adding the time to go to the current fix time. 0240Z + 12mins = **0252Z interception time**.

After altering heading back to the FPT at the fix, the pilot can continue with other tasks in the cockpit and a few minutes prior to the interception time, resume map reading and perform the calculated heading change required at the interception point.

10.4.7 Procedure to Determine Drift

TE and CA are not the same as drift. Each is part of a separate navigation technique.

Wind affects the aircraft as it is flown on a heading and the aircraft is making good a track, the difference between the current heading and TMG can be calculated as drift.

To calculate current drift in a 1:60 calculation, the following is required (refer to example 4):

- Calculate the TMG by applying the TE to the FPT, since the aircraft is right of track the TMG is right of the FPT, therefore 312°M + 12° = **324°M TMG**.

- Calculate the drift by comparing the heading at the fix to the TMG. Drift is measured from heading to track. With a heading of 307°M and a TMG of 324°M, the **drift** angle is **17° right**.

If the planned heading and planned track is compared in example 4, the planned drift can be calculated as 5° right. The wind that the aircraft experienced during the flight is stronger than the anticipated wind when the planning was done, which explains the reason for the aircraft being right of track.

10.5 Summary

Track and heading corrections using the 1 in 60 rule:

- Alter heading by TE to parallel FPT
- Make a further heading correction by an amount equal to CA, so that the aircraft follows a new track to destination or to intercept FPT at the desired point
- After intercepting the track make another heading correction back through CA to maintain FPT.