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CHAPTER 8 – CRITICAL POINT AND POINT OF NO RETURN

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CONTENTS .... PAGE

CHAPTER 8 – CRITICAL POINT AND POINT OF NO RETURN

POINT OF EQUAL TIME (PET) / EQUI-TIME POINT (ETP) / CRITICAL POINT (CP)

Due to the aircrew's workload during a flight, especially during emergencies, there is very little time left to make other judgements and decisions outside the normal operating procedures.

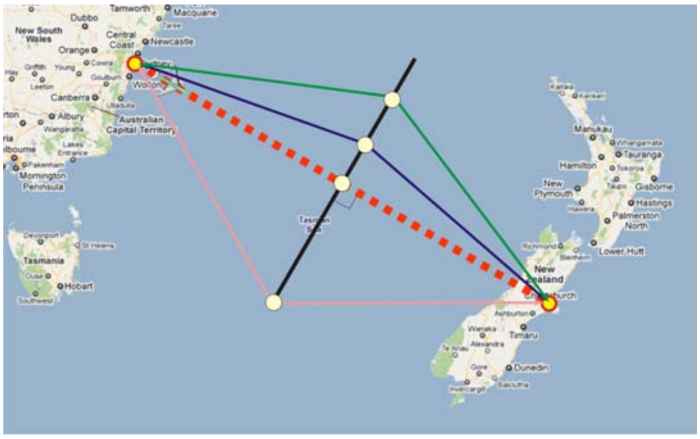
Determining the Point of Equal Time (PET) will help with decision making in flight regarding suitable airfields to which the aircraft can divert and land at in the event of an emergency.

BASIC CONCEPT

During flights it is necessary to know the location of the nearest suitable alternate airfield in case of an emergency or some other abnormality which may require you to land as soon as possible.

The PET can be calculated between the departure airfield and the destination airfield. This is normally the case if no alternate airfields are available along the planned track i.e. on flights over water.

In the event where other alternate airfields are available along the planned track, PET's can be calculated between all the suitable airfields as required.



In its simplest form, the Point of Equal Time is that point along track between the departure and destination airfields from which it will take the same amount of time to fly to either airfield. In nil wind conditions this point will be exactly halfway between the two airfields under consideration. The perpendicular bisector to the track between the two airfields joins all the points from which it will take equal amounts of time to fly to either airfield (in still air conditions).

PET FORMULA

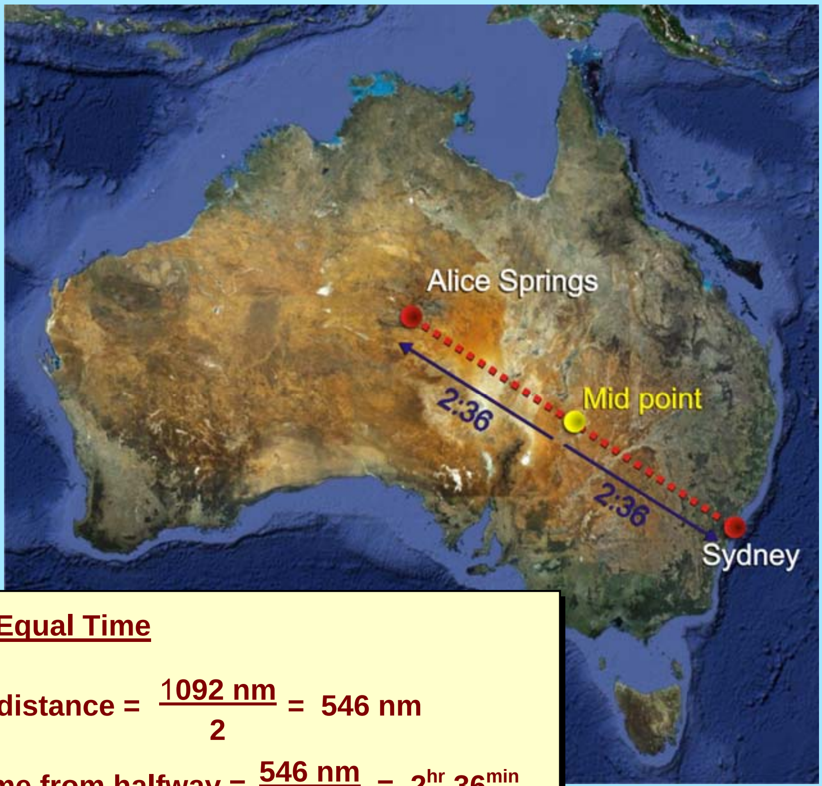
Point of Equal Time is entirely a time problem as we want to locate a point from which the flying time to diversion airfields will be equal.

For example, with a total distance of 3000 nm and a speed of 300 kts, the time from the PET to either the departure or destination points, will be 5 hours if there is no wind.

However, because no-wind conditions rarely exist, the effect of the wind on the groundspeed must be taken into account. The value of the groundspeed will decrease if the aircraft experiences a headwind.

Although the airspeed is not affected by wind, any **headwind** component will **decrease** the groundspeed. The opposite is true of a tailwind.

For example, an aircraft flies from Sydney to Alice Springs (1092 nm) at 210 kts TAS, in no wind conditions.



Point of Equal Time

Halfway distance = $\dfrac{1092 \text{ nm}}{2} = 546 \text{ nm}$

Flying time from halfway = $\dfrac{546 \text{ nm}}{210 \text{ kts}} = 2^{hr}\ 36^{min}$

However, if the aircraft experiences a 30 kts headwind on the flight to Alice Springs the time from the mid point to Sydney and Alice Springs respectively will change substantially.

Time from the mid point to Sydney

Distance to Sydney $= \dfrac{1092 \text{ nm}}{2} = 546 \text{ nm}$

Groundspeed Home = 210 kts + 30 kts = 240 kts

Time to Sydney $= \dfrac{546 \text{ nm}}{240 \text{ kts}} = 2{:}17$

Time from the mid point to Alice Springs

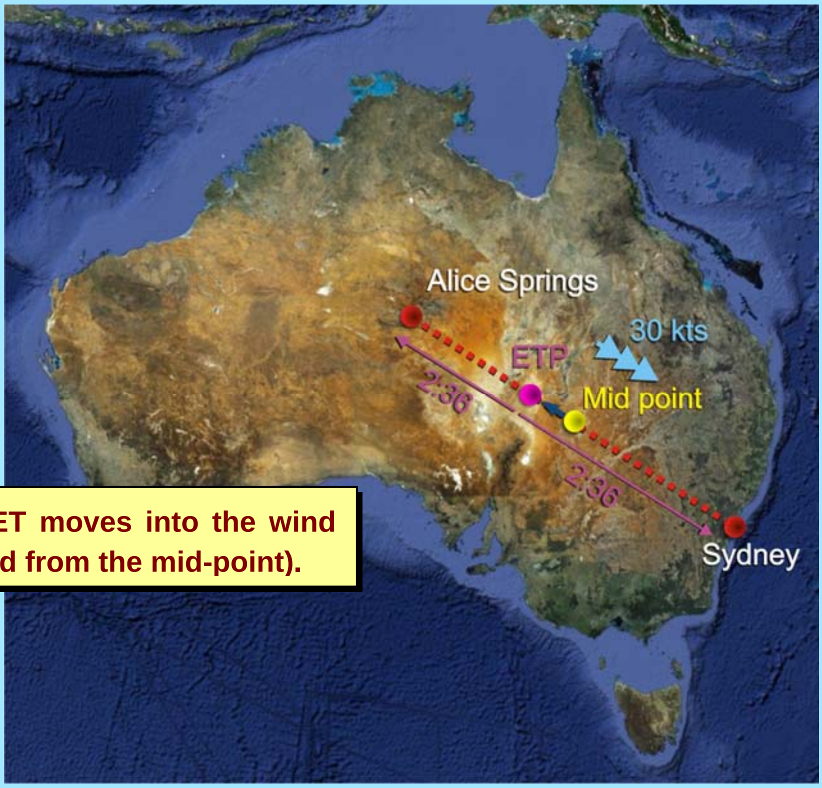
Distance to Alice Springs) $= \dfrac{1092 \text{ nm}}{2} = 546 \text{ nm}$

Groundspeed On = 210 kts – 30 kts = 180 kts

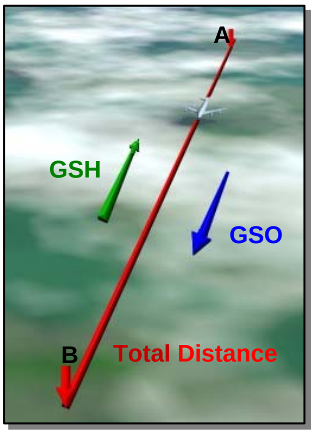
Time to ETP $= \dfrac{546 \text{ nm}}{180 \text{ kts}} = 3{:}02$

The time from the mid point to Sydney with a 30 kt tail wind will be 2^{hr} 17^{min} and the time from the mid point to Alice Springs with a 30 kt head wind will be 3^{hr} 02^{min}

It is clear that the mid point is no longer the PET. The aircraft flies at a faster groundspeed towards Sydney compared to its groundspeed towards Alice Springs. Therefore the distance from the PET to Sydney should be greater than the distance from the PET to Alice Springs.



The PET moves into the wind (upwind from the mid-point).



To calculate the exact distance to the PET, the ratio between the groundspeed from the departure point to destination, called Groundspeed On (**GSO**) and the groundspeed from destination to departure point, called Groundspeed Home (**GSH**), is applied to the **Total Distance**.

Expressed as a formula, it will look as follows:

$$\textbf{PET Distance} = \frac{\textbf{Total Distance x GSH}}{\textbf{GSO + GSH}}$$

Note that the result of the calculation is in nautical miles because the ratio is applied to a nautical mile value (Total Distance).

Example: The distance from A to B is 843 nm. The GSO is 144 kts and the GSH is 204 kts.

1. What is the distance to the ETP?

$$\text{PET Distance} = \frac{204}{144 + 204} \times 843 \text{ nm}$$
$$= 494 \text{ nm}$$

2. What is the flying time to the ETP?

$$\text{Time to PET} = \frac{\text{Distance to PET}}{\text{GSO}}$$
$$= \frac{494 \text{ nm}}{144 \text{ kts}}$$
$$= 3 \text{ hours}$$

ASYMMETRIC PET

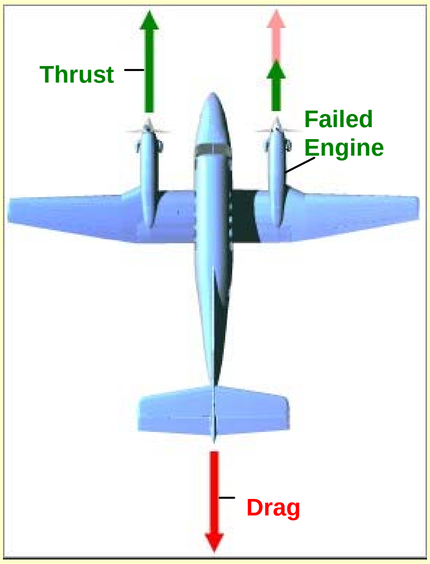
Previously it was stated that the reason the PET must be calculated is to facilitate a diversion in the event of an emergency on board the aircraft.

However, if the emergency is an engine failure on a multi-engine aircraft, the value of the airspeed will decrease.

During normal flight, thrust must balance drag.

If an engine should fail, the value of thrust will be reduced (virtually halved in a twin engined aircraft).

All other factors being unchanged, the decrease in trust available will now cause a reduction in the airspeed.



Because of this change in airspeed, the normal formula for PET time will give a different answer since the value of TAS has changed with one engine failed.

$$\text{PET Distance} = \frac{\text{GSH}}{\text{GSO + GSH}} \times \text{Total Distance}$$

The new answer is called the **Critical Point** and is defined as that point along the track, from where it takes the same flying time to either continue to the destination, or to return to the departure point, with **one engine failed**.

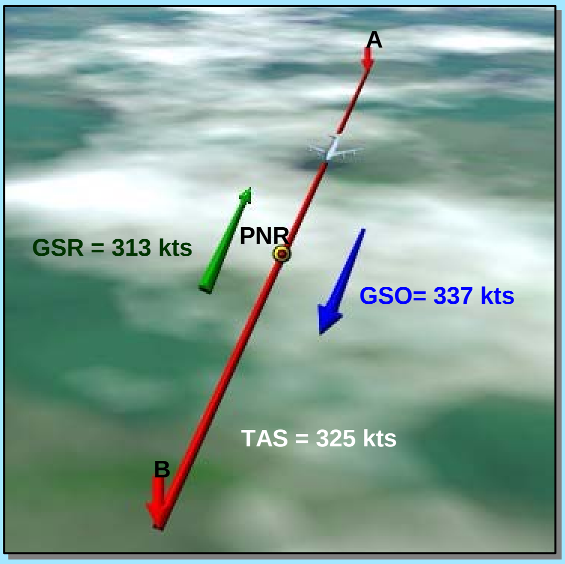
When using the formula, remember the following:

- The GSH and GSO values in the formula must use the asymmetric TAS (also referred to as reduced TAS with one engine failed).
- When calculating the flying time to the critical point, the normal TAS (all engines operative) must be used.

Example.

The distance from A to B is 786 nm. The TAS is 325 kts and the aircraft experiences a 12 kt tailwind en-route from A to B. The reduced TAS (one engine failed) is 250 kts.

What is the distance and time to the critical point?



1. **GSO = 337 kts.**
   GSR = 313 kts.
   Reduced GSO = 262 kts.
   Reduced GSR = 238 kts.

2. **Critical point distance**

$$\text{Critical point distance} = \frac{GSR}{GSO + GSR} \times \text{Total distance}$$

$$= \frac{238}{262 + 238} \times 786 \text{ nm}$$

$$= 374 \text{ nm}$$

3. **Critical point time**

Critical point time = 374 nm at 337 kts

= 1:07

The only difference in calculating the PETe and the Critical point is that the reduced GSO and GSR must be used in the case of the critical point.

MOVEMENT OF THE PET WITH WIND AND TAS CHANGES

As previously explained, the PET point always moves into wind away from the mid-point. This is true for the comparison between no wind and actual conditions. We also need to understand how the PET will move if the wind strength or weakens and/or the aircrafts TAS changes.

Wind

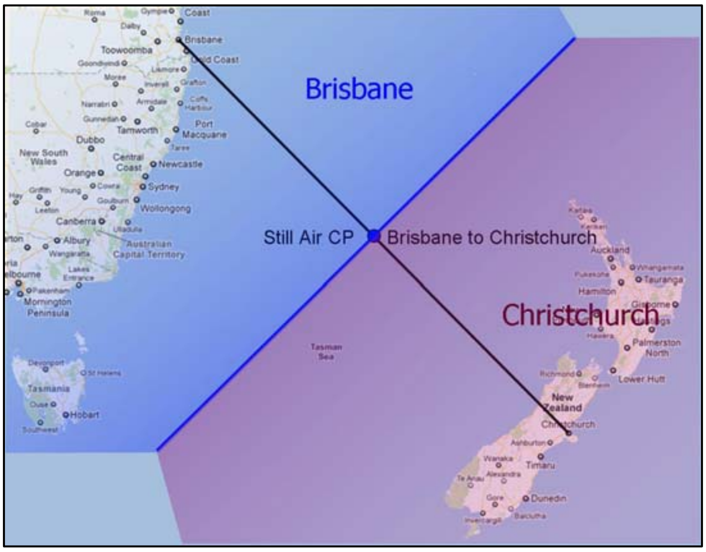
If the wind component increases, PET moves further up-wind from the mid-point.
If the wind component decreases, PET moves closer to the mid-point but remains up-wind of the mid-point.

TAS

If TAS increases, PET moves closer to the mid-point but remains up-wind of the mid-point.
If TAS decreases, PET moves further up-wind from the mid-point.

DETERMINING AN OFF-TRACK EQUI-TIME POINT

Consider a flight from Brisbane to Christchurch. Drawing a perpendicular bisector between Brisbane and Christchurch, it becomes clear in which sector, in no-wind conditions, Brisbane would be the closest airfield and the same for Christchurch.

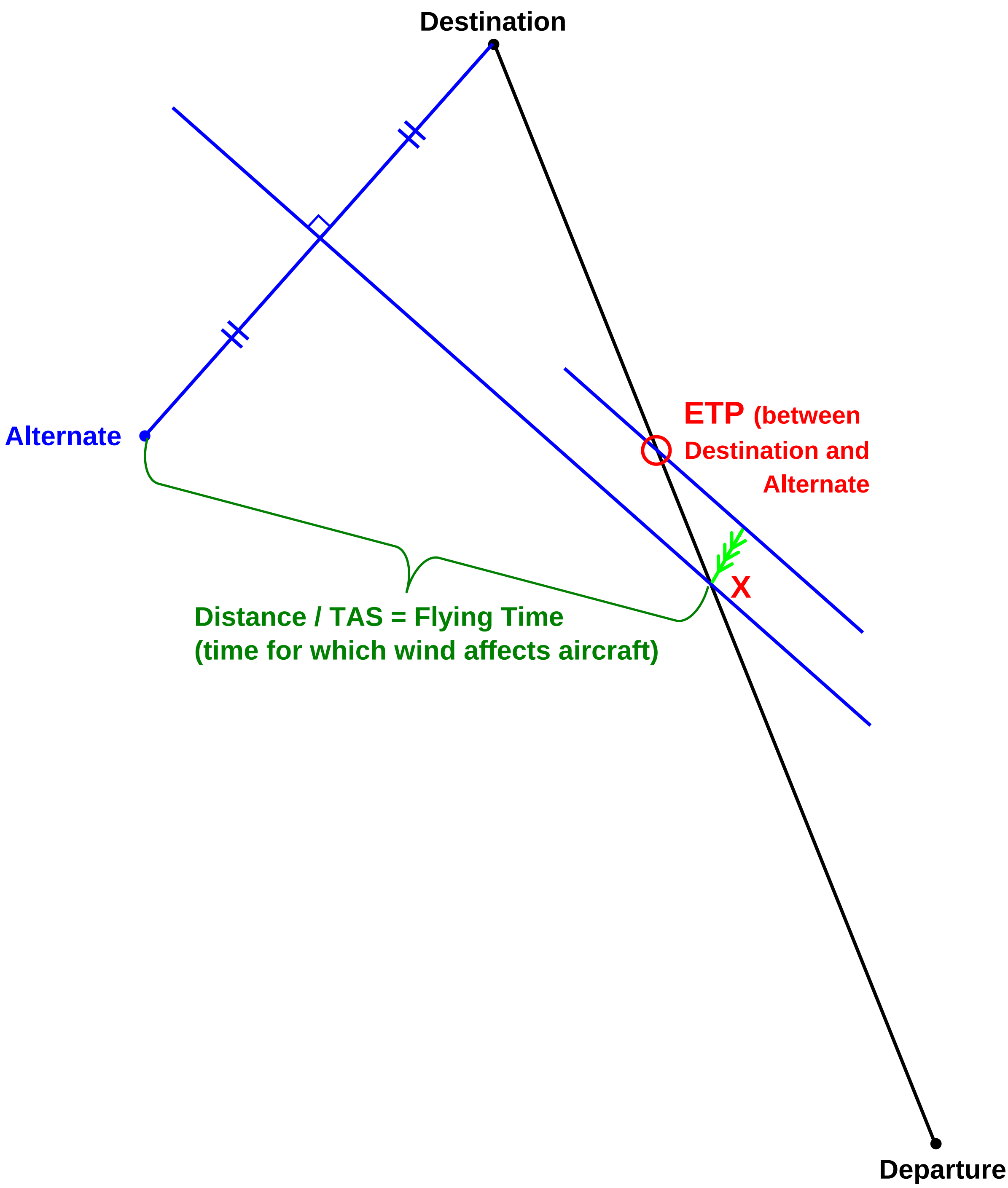


If Sydney is a suitable alternate airfield, it might be a very good idea in flight if we knew at which point along our track it would be **closest in time** to divert to Sydney rather than continue to Brisbane, should an emergency occur.

We will not be able to calculate this with the formula we used earlier as we do not know the GSO and GSH to Sydney until we have found at which point along the track the ETP to an off-track alternate occurs. We will also not know the distance between this ETP and the alternate until we find the point, which leaves us with a bit of a conundrum. The easiest solution would be to plot on the chart. There are various "shortcuts" demonstrated in other textbooks, but in most cases these take longer than a plotting solution. Only the plotting solution will be discussed in this textbook.

We already know that in no-wind conditions the ETP would be midway between two airfields. It is also known that the ETP moves upwind from the midpoint, and the distance it moves upwind depends on the TAS of the aircraft and the amount of wind influence. We can very simply plot all of these on a chart (see diagram on next page).

- Draw a perpendicular bisector between Destination and Alternate (off-track airfield).
- Determine where this line crosses the track between Departure and Destination.
- Measure the **distance** from this point **(X)** to either **Destination or Alternate** (distance must be the same to both as this is an ETP in still air). This distance at the TAS of the aircraft represents the amount of time for which the wind will affect the aircraft. (Distance 183nm @ TAS 250kts = **44 mins**)
- Draw in a wind vector **UPWIND** from **X** as the ETP always moves upwind with wind. (W/V 030M/35 – so plot in a wind vector for **44 mins, 26 nm upwind**)
- Draw in a line parallel to the original perpendicular bisector through the end of the wind vector. Where this construction line crosses the track represents the **Equi-time point** between **the Destination and Alternate** airfield.


Destination
Alternate
ETP (between Destination and Alternate
X
Distance / TAS = Flying Time
(time for which wind affects aircraft)
Departure

POINT OF NO RETURN

As mentioned earlier aircrew workload during a flight is very high and most of their time is spent making normal operational judgements and decisions.

All the calculations that can be made during planning, without operational pressures will reduce workload in flight and could also reduce the risk of making calculation errors once under pressure.

Consider the situation where an aircraft is en-route between Sydney and Alice Springs.

At a point A, past the PET, it experiences a technical problem. This problem can only be fixed back in Sydney (not in Alice Springs). The question that the aircrew must now answer is; "can they return to Sydney"?

What they must consider is the amount of fuel the aircraft has on board. The aircraft **endurance** must therefore be calculated.

Endurance.

The total time the aircraft can remain airborne with the fuel on board, without using the mandatory reserve fuel.

At some point, there will **not** be sufficient fuel to return to Sydney. This is known as the **Point of No Return** (**PNR**).

The Point of No Return is that point on the track to which the aircraft can fly and return to the departure point, with all the mandatory fuel reserves intact.

PNR is a different concept to that of PET (Equi-time point). PNR is entirely reliant on the fuel available, in other words an endurance problem, whereas PET is only concerned with flight time (no fuel consideration only leg distance).

ENDURANCE

Determining the endurance is an important part of the calculation of the PNR. The endurance can be expressed in one of two ways:

1. Total endurance. Absolute endurance is the total time the aircraft can remain airborne with all the fuel on board. The aircraft will thus fly until the tanks are totally empty. **Absolute endurance will never be used when calculating the PNR.**

2. Safe endurance. Safe endurance is the total time the aircraft can remain airborne, using all the fuel on board excluding the fuel required for **variable reserve, fixed reserve, holding, start and taxi**. The aircraft will thus fly until there remains a specified mandatory amount of fuel in the tanks.

   To understand how safe endurance is calculated it is useful to look at a typical fuel planning table.

   a. Flight Fuel. This is the fuel needed for the climb, cruise and alternate (if needed). In the table the flight fuel will be the fuel in the ***sub-total*** row.

   b. Variable Reserves. This is 15% of the flight fuel.

   c. Fixed Reserves. This is 45 minutes of fuel at the cruise consumption rate or as determined by the operators' operations manual.

Fuel Calculation	***Min***	***L or kg***	***Min***	***L or kg***
Climb				
Cruise				
Alternate				
Sub-Total				
Variable Reserve				
Fixed reserve				
Holding				
Taxi				
Fuel Required				
Fuel Margin				
Endurance				
From				

Refer to CAAP 234-1 Guideline for Aircraft Fuel Requirements

   d. Holding. This is fuel needed for holding due to operational, weather, traffic or any other reason. In some situations carrying an alternate will remove the need to carry holding fuel or carrying holding fuel will remove the need to carry an alternate, for example when a TEMPO or INTER weather event is forecast at the arrival ETA.

   e. Taxi. This is the fuel needed for starting and taxi at the departure airfield.

f. Fuel Required. This is the sum of the flight fuel, variable and fixed reserves, holding and taxi fuel.

g. Fuel Margin. This is any additional fuel that is available on board. This additional fuel is used for calculating safe endurance

Example 1

The total usable fuel on board at start up is 210 gal, fuel flow is 25 gph. Fuel allowance for start and taxi is 3 gal and for fixed reserves is 15 gal. Climb fuel is 13 gal and cruise time for the flight is 3 hr 25 min. For the flight no alternate is required when 60 minutes of holding fuel is carried.

The Safe Endurance is calculated using the sum of the Flight Fuel (99 gal) and the Fuel Margin (53 gal), 152 gal at the cruise fuel flow of 25 gph.

$$\text{Safe Endurance} = \frac{152\text{ gal}}{25\text{ gph}} = 6^{\text{ hr}}\ 04^{\text{ min}}$$

Fuel Calculation	***Min***	***L or kg***
Climb		13 gal
Cruise	205	86 gal
Alternate	-	-
Sub-Total		99 gal
Variable Reserve		15 gal
Fixed reserve		15 gal
Holding	60	25 gal
Taxi		3 gal
Fuel Required		157 gal
Fuel Margin		53 gal
Endurance		210 gal
From		

Example 2

The total usable fuel on board at start up is 144 ltr, fuel flow is 35 ltr/hr and the allowance for taxi is 18 ltr and for fixed reserves is 35ltr.

Fuel available less the taxi and fixed reserve fuel is 115% of the flight fuel

144 ltr –(35 ltr + 18 ltr) = 91 ltr (Flight fuel + 15% variable reserve)

Flight fuel is calculated by dividing the available fuel by 1.15%

$$\frac{91\text{ ltr}}{1.15\%} = 79.13\text{ ltr, use 79 ltr to calculate Safe Endurance}$$

With this Flight Fuel value and the cruise fuel flow the Safe Endurance can be calculated

$$\text{Safe Endurance} = \frac{79\text{ ltr}}{35\text{ ltr/hr}} = 135.42\text{ min}$$

Safe Endurance is 135 min (always round down)

Fuel Calculation	***Min***	***L or kg***
Climb		
Cruise		
Alternate		
Sub-Total		79 ltr
Variable Reserve		12 ltr
Fixed reserve		35 ltr
Holding		
Taxi		18 ltr
Fuel Required		
Fuel Margin		
Endurance		144 ltr
From		

For the purpose of calculating the PNR, the safe endurance must be used.

PNR FORMULA

The calculation of the PNR uses a similar formula to PET, but taking the aircraft endurance into account. It will then look as follows:

$$\text{Time to PNR} = \frac{\text{GSH x Safe Endurance}}{\text{GSO + GSH}}$$

Note that the **safe endurance** is used and that the answer is a time value. To determine the distance to the PNR, this time is multiplied by the GSO.

Example

Distance from A to B is 483 nm. GSO is 195 kts and GSH is 222 kts. The safe endurance is 6 hours 16 min.

What is the time to the PNR?

$$\text{PNR Time} = \frac{\text{GSH x Safe Endurance}}{\text{GSO + GSH}}$$

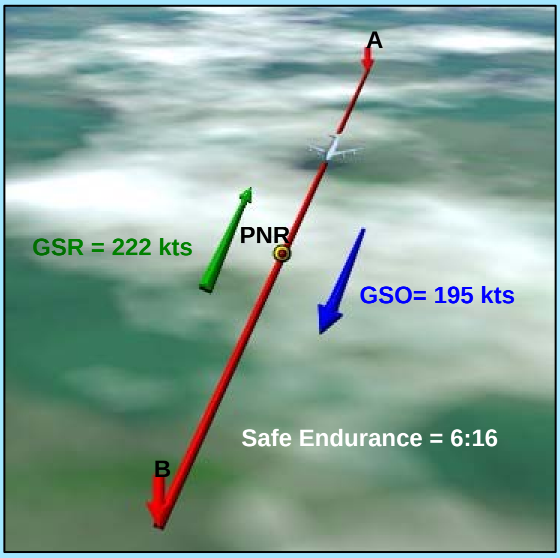
$$= \frac{\text{222 kts x 6,267 hrs}}{\text{195 kts + 222 kts}}$$

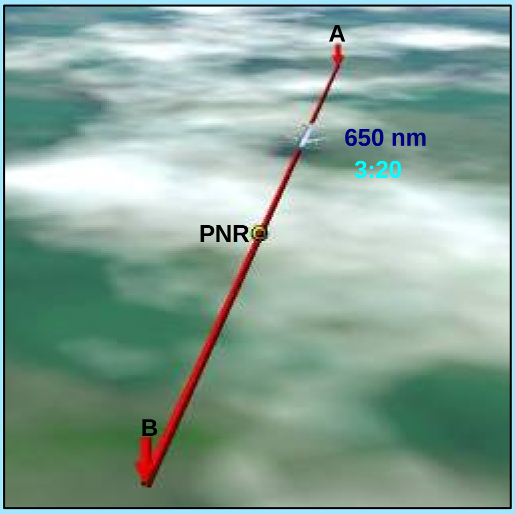
$$= \text{3.336 hrs} \rightarrow \text{3 hr 20 min}$$

What is the distance to the PNR?

PNR Distance = 3:20 at 195 kts

= 650 nm





There is another formula to directly calculate the distance to the PNR. It uses the endurance and the specific fuel consumption of the aircraft. The fuel consumption is expressed as kilogram (kg) per **Ground Nautical Mile** (**gnm**).

$$\text{PNR distance} = \frac{\text{Endurance in kg}}{\text{kg/GNM OUT} + \text{kg/GNM HOME}}$$

Kilogram per Ground nautical mile.

The groundspeed of an aircraft is usually expressed as nm per hour. The fuel consumption is expressed as kg per hour. To get kilogram per ground nautical miles we have to divide the consumption with the groundspeed.

$$\frac{\frac{kg}{hr}}{\frac{nm}{hr}} = \frac{kg}{\cancel{hr}} \times \frac{\cancel{hr}}{nm} = \frac{kg}{nm}$$

Example:

Safe endurance = 7879 kg.

Performance out = 4.37 kg/gnm.

Performance home = 3.95 kg/gnm.

Calculate the distance to the PNR.

$$\text{PNR distance} = \frac{7879\ \text{kg}}{8.32\ \text{kg/gnm}}$$

$$= 947\ \text{nm}$$

In the formula, the kilogram values can be substituted with any measure of weight (lbs, litres, etc.), as long as it is done both above and below the line.

MOVEMENT OF THE PNR WITH WIND AND TAS CHANGES

Wind

If the wind component increases, PNR moves closer to Departure Airfield.
If the wind component decreases, PNR moves further away from Departure Airfield.

TAS

If TAS increases, PNR moves further from Departure Airfield.
If TAS decreases, PNR moves closer to Departure Airfield.

DETERMINING THE LAST POINT OF SAFE DIVERSION

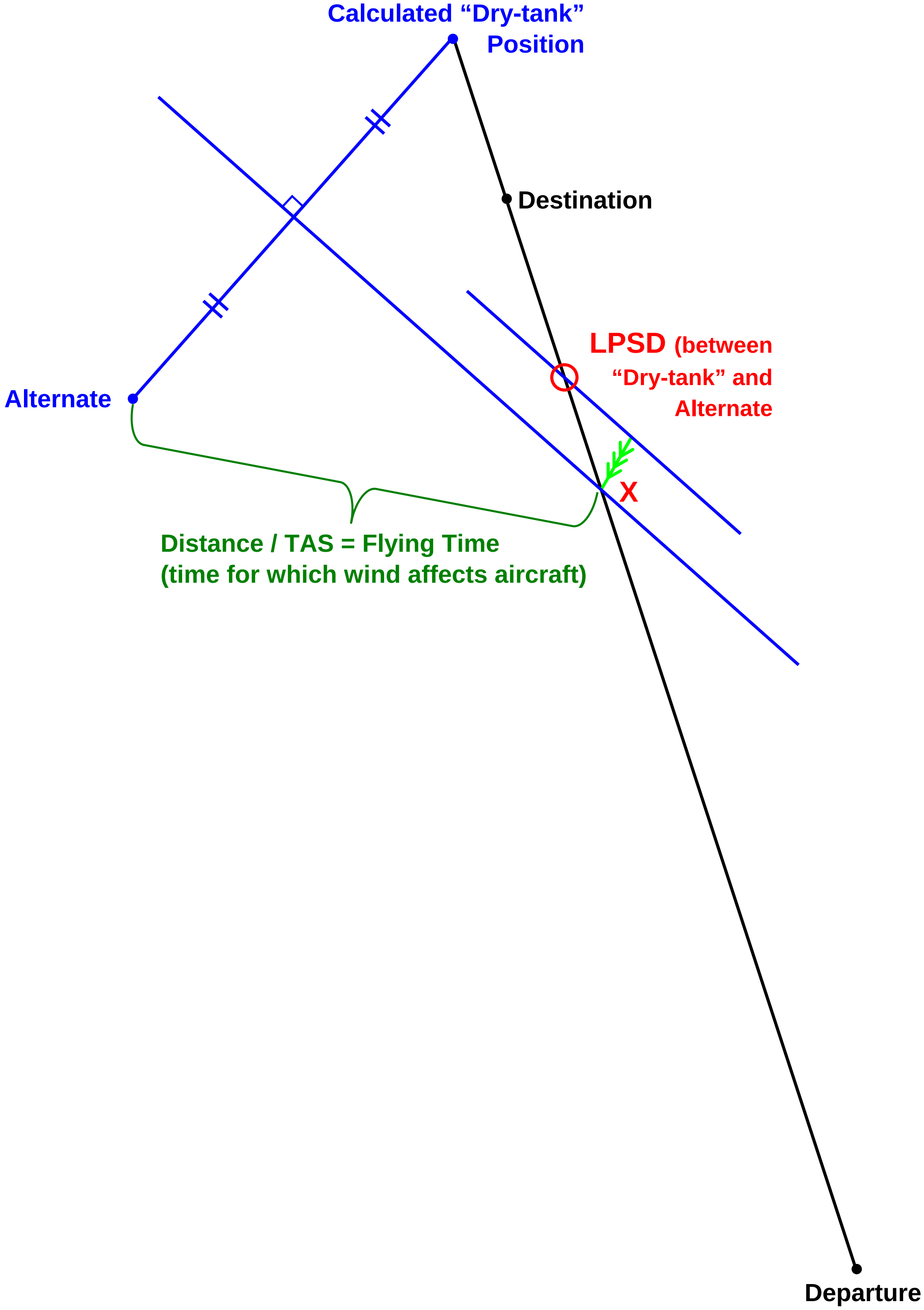
When flying between two airfields along a specific route, we can calculate where on this track the PNR will be. As we now know this represents the points furthest from Departure to where the aircraft can fly and then still return to Departure, without using any reserve fuel.

In flight however, there might be times when we will want to determine the last point along our track at which we can still divert safely to an Alternate airfield should weather deteriorate at our Destination. We cannot readily solve this kind of problem using the normal PNR formula, and once again have to resort to plotting as the simplest means of solving a Last Point of Safe Diversion (LPSD), or off-track PNR. The solution is essentially the same as for the normal on track PNR, as you want to determine the point beyond which you will have insufficient fuel to divert to an Alternate airport. It is however a bit more complicated due to the off-track Alternate.

We can very simply plot all of these on a chart (see diagram on next page).

- First we **calculate** a **theoretical "dry-tank" position** from the information provided. This is done by extending the track past the Destination, and determining how far we can fly **past** the **Destination** using the **Safe Endurance**. Once establishing this "dry-tank" position, we can treat it similar to the off-track ETP construction. We can either fly towards the "dry-tank" position using our safe endurance, or when we are halfway between the two, turn towards our Alternate. We would be able to reach either the Alternate or the "dry-tank" position using only our safe endurance. In essence, we have determined a still-air ETP between Alternate and the "dry-tank" position.
- Draw a perpendicular bisector between Alternate and "dry-tank" position.
- Determine where this line crosses the track between Departure and Destination.
- Measure the **distance** from this point **(X)** to either **"dry-tank" position or Alternate** (distance must be the same to both as this is an ETP in still air). This distance at the TAS of the aircraft represents the amount of time for which the wind will affect the aircraft. (Distance 170nm @ TAS 250kts = **41 mins**)
- Draw in a wind vector **UPWIND** from **X** as the ETP always moves upwind with wind. (W/V 030M/35 – so plot in a wind vector for **41 mins, 24 nm upwind**)
- Draw in a line parallel to the original perpendicular bisector through the end of the wind vector. Where this construction line crosses the track represents the **Last Point of Safe Diversion** between **the "dry-tank" position and Alternate** airfield.

Alternatively, in an examination sitting you can decide to choose one of the mid-range answers as the LPSD, and work out the flying time to this point, and then by measuring a track from this point to the Alternate, calculate the Hdg/GS on the Navigation Computer to obtain a flying time. The time to the LPSD and the Alternate should add up to the Safe Endurance Time.


Calculated “Dry-tank” Position
Destination
LPSD (between “Dry-tank” and Alternate
Alternate
X
Distance / TAS = Flying Time
(time for which wind affects aircraft)
Departure