DOCUMENT

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DOCUMENT TITLE

ATPL NAVIGATION (AUS)

CHAPTER 7 – CLIMB, DESCENT, TRACK MILES AND RELATIVE VELOCITY

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PLANNING THE CLIMB AND DESCENT

When an aircraft climbs from near sea level to a level near its ceiling the rate of climb, TAS, and fuel flow all vary continuously. Given that the wind velocity and other atmospheric parameters also change as altitude increases, planning a climb is more complex than planning a route segment at cruise altitude. Fortunately, due to the relatively short duration of the climb, we can adopt simplifying assumptions without introducing significant error.

If optimum climb performance is to be achieved, control of speed is critical. All aircraft have an optimum climb RAS/CAS or Mach number, and it is usual to specify the climb profile that is assumed in the calculations. For instance, the B747-300 speed profile is 330/0.84, meaning that the climb is maintained at 330 knots RAS until M0.84 is intercepted, and at constant M0.84 thereafter.

The basic information required to plan the climb is obtained from the aircraft performance manual. From inputs of starting weight, speed profile, atmospheric temperature and vertical extent of the climb we obtain outputs of:-

time to climb	(minutes)
mean TAS	(knots)
fuel used	(kg or pounds)
distance covered	(air nautical miles)

It remains only to combine these data with wind velocity to determine heading to fly and ground distance covered during the climb. The rate of climb decreases steadily as the aircraft nears its operational ceiling and, in the absence of more precise information, it is customary to assume that the upper third of the climb will take about the same time as the lower two thirds. Hence, we assume further that the wind velocity forecast for the two-thirds level in the climb is the mean wind velocity to be used throughout. To calculate the groundspeed, the TAS at the two-thirds level will have to be calculated first.

If the climb is of limited duration, or to a level well below the aircraft's ceiling under the prevailing conditions, it is sometimes acceptable to assume a constant rate of climb. In that case the wind velocity existing at the mid-point of the climb is used as the mean wind.

For heavy jet aircraft, descent planning is similar to climb planning. Again a descent profile is specified and data extracted from the performance manual for the prevailing conditions. However, in this case, the rate of descent is likely to be approximately constant, so the mean wind is determined at the mid-point of the descent.

In a typical exam question you could expect something similar to the following:

Example: An aircraft climbs at a constant 310KIAS from FL150 to FL250 with an average rate of climb between FL150 and FL250 of 1550ft/min. The distance covered over the ground during the climb with a wind component of +50kt and a temperature deviation of ISA -5 is:

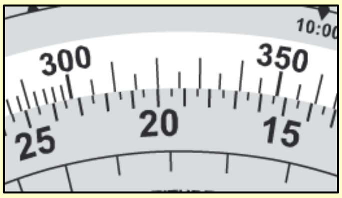
Solution:

Climbing at a constant IAS will result in an increase in both TAS and Mach number. To determine the average TAS, you have to compensate for the fact that climb performance will reduce the higher you climb. The mean TAS will therefore occur at two-thirds of the climb.

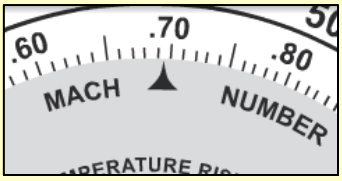
$$\text{Two - thirds altitude} = (\text{Total height change x } \frac{2}{3}) + \text{start height}$$

$$= ((25000 - 15000) \text{ x } \frac{2}{3}) + 15000$$

$$\approx 21700 \text{ ft}$$

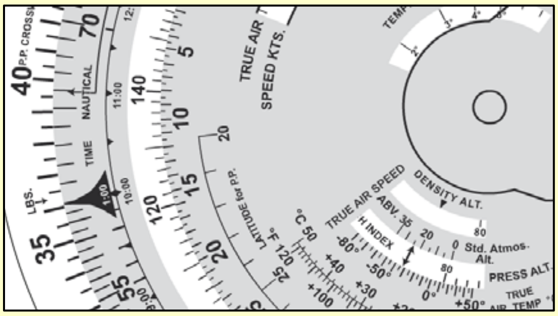


IAS/CAS 310 kts at 21 700 ft gives a Mach number of 0.695



At ISA -5 the temperature at 21 700 ft will be -33°C

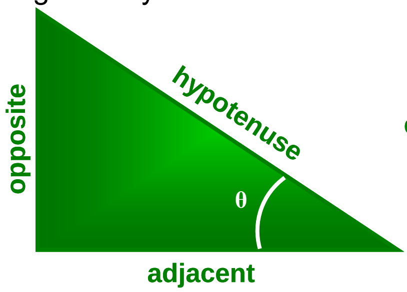
This results in a TAS of 419kt, and factoring in a +50kt wind component, the groundspeed is 469 kt.



Climbing through 10 000 ft at 1550ft/min, will take 6.45 minutes and in this time the aircraft will cover a distance of 50.4 nm.

DIVERSIONS AND COURSE CORRECTIONS

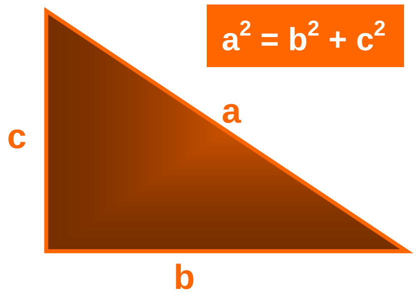
During navigation exercises, it is sometimes required to divert left or right of track due weather or other unforeseen circumstances. These course corrections can be solved on the wind side of the CR-3, through the use of scale diagrams or by applying simple trigonometry or geometry rules.



$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

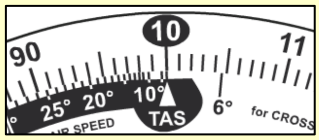
$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

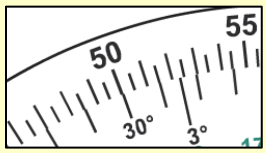


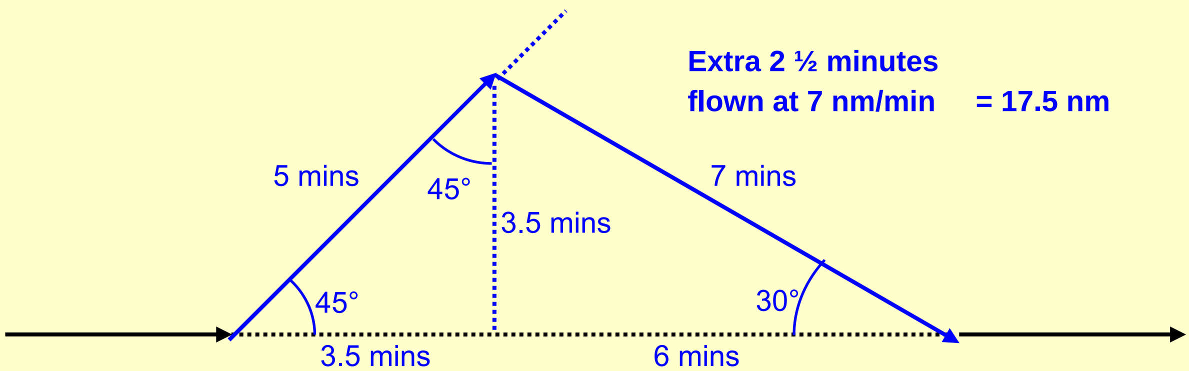
Example: For weather avoidance, you divert 45° left of track for 5 minutes, and then intercept your original track at an angle of 30°. At a groundspeed of 420 kts, what is the extra track distance flown compared to the original track distance?

Solution: Draw either a scale diagram and measure the distances, or make a quick rough drawing and calculate the remaining sides, or angles, using trigonometry and geometry. For most a scale drawing is much simpler to do, so only the calculation of angles and sides are explained below.

1. The aircraft turns 45° left for 5 mins. This results in the aircraft being 3½ minutes left of track, and also 3½ minutes further along the original track.
2. On the navigation computer, set up 1.0 opposite TAS. Opposite 30° on the middle disk read off a value of 0.5. The side opposite to 30° is 3.5 minutes, so the hypotenuse is 7 minutes for a 30° intercept of the track.
3. Using Pythagoras' Theorem, the side adjacent to 30° is 6 minutes.
4. Along the original track the aircraft would travel 9½ minutes, and along the diverted track the aircraft travels 12 minutes.
5. The difference of 2½ minutes at 420 kts, results in an additional distance of 17.5 nm.







AIRCRAFT SEPARATION

Most people are conditioned from childhood to a concept of motion viewed from a 'stationary' point on the surface of the Earth. Thus we develop our ideas of 'fast' and 'slow' as if they were absolute values, little realizing that another observer, using a different point of reference, might obtain a quite different perspective. Experience in aviation soon changes our ideas of relative motion. Aviation places us in an environment in which the Earth's surface is usually remote, and often invisible, so the reference upon which our daily experience was hitherto based is suddenly removed. Hence, we need to re-develop our ability to visualize motion relative to a point that is itself moving.

The relative velocity problems covered in this section are of two basic types; those in which the aircraft involved are flying along the same track, and those in which the aircraft are on converging tracks. Sometimes the problem will involve only one aircraft changing speed, e.g. to advance or delay an ETA. In that case the 'relative motion' relates to the difference between the two speeds.

Problems can often be solved by a number of methods, but the two basic rules for successful solution are the same in all cases:

1. Draw a diagram of the situation.

2. If aircraft position, speeds, etc. are specified for different times, adjust as necessary to bring all aircraft to a common start time.

When aircraft are on the same track, relative velocity problems usually involve only simple arithmetic. The principles are illustrated in the following examples.

CLOSING SPEED

> Closing speed exists when two aircraft are flying towards each other or when the faster of the two is approaching from behind the other aircraft. In both cases the distance between the aircraft will reduce at a rate equal to the relative velocity between the aircraft.

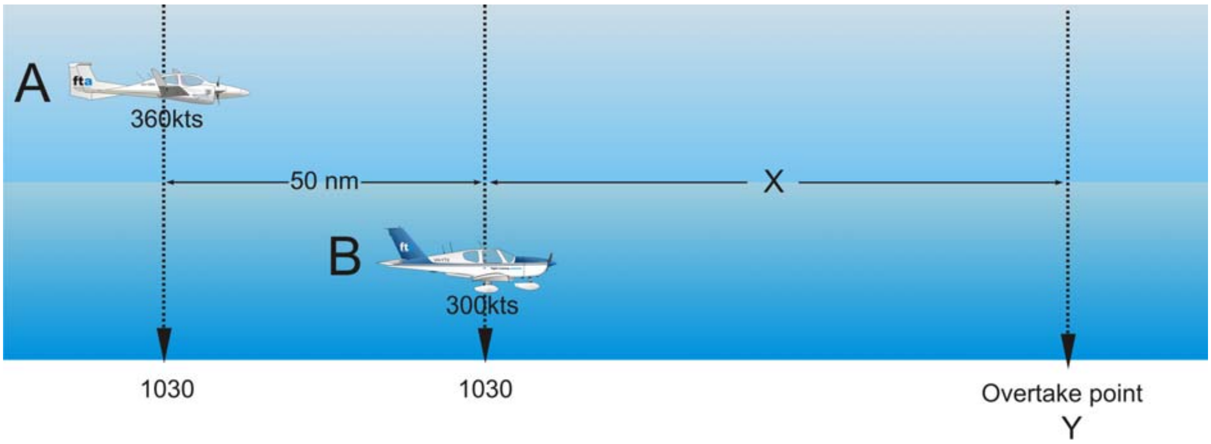
EXAMPLE 1

Two aircraft, A and B, are on the same track, with B ahead of A. B's groundspeed is 300 knots and A's is 360 knots. At time 1030 the aircraft are 50nm apart.

a) If visibility is 10nm, at what time will A be within visual range of B?

b) At what time will A overtake B?

Two methods are available, one algebraic and the other using the relative velocity.



Aircraft A is overtaking aircraft B with a relative velocity (closing speed) of 60 knots.

For the first question, A needs to close the existing 50 nm gap to 10nm, i.e. it has to close 40nm of the initial 50nm separation. This is done at the relative velocity of 60 kts.

40nm at 60 knots will take 40 minutes.

∴ aircraft will be 10nm apart at 1110. 1030 + 00:40 = 1110

For the second question, B will overtake A when the 50nm separation is reduced to zero, i.e. A has to close all 50nm of the initial 50nm separation. This is done at the relative velocity of 60 kts.

50nm at 60 knots will take 50 minutes.

∴ aircraft will overtake at 1120. 1030 + 00:50 = 1120

This scenario can also be solved using algebra. Let the distance between B's initial position and the overtake point Y, be X.

At Y, B will have travelled X nm and, in the same time T, A will have travelled (X + 50)nm.

$$\text{Then T (minutes)} = \frac{\text{Distance (nm)}}{\text{Speed (nm per minute)}}$$

$$\therefore\ T = \frac{X + 50}{6} = \frac{X}{5}$$

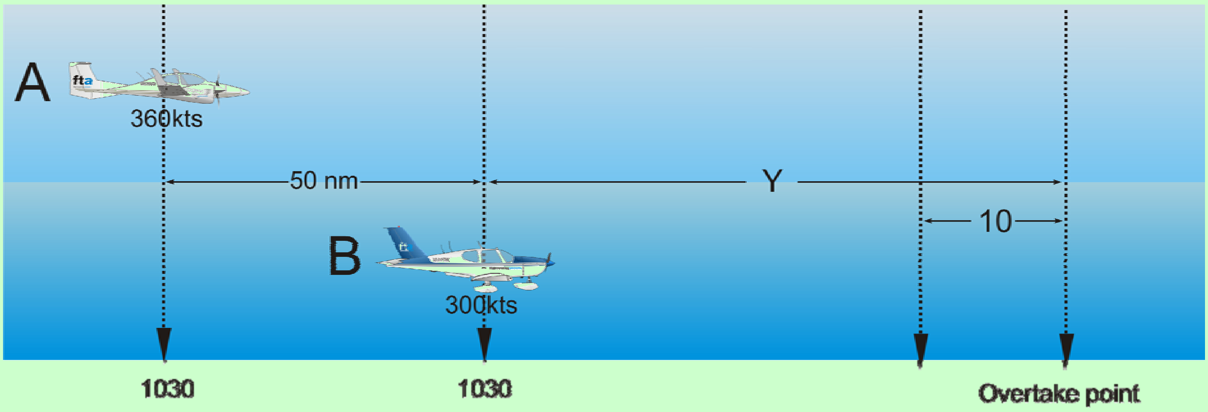
$$\therefore\ 6X = 5X + 250$$

$\therefore$ X = 250nm

At B's speed of 300 knots, 250nm will take 50 minutes

$\therefore$ aircraft will overtake at 1120

To find when the aircraft will be 10nm apart we adjust the diagram as follows:



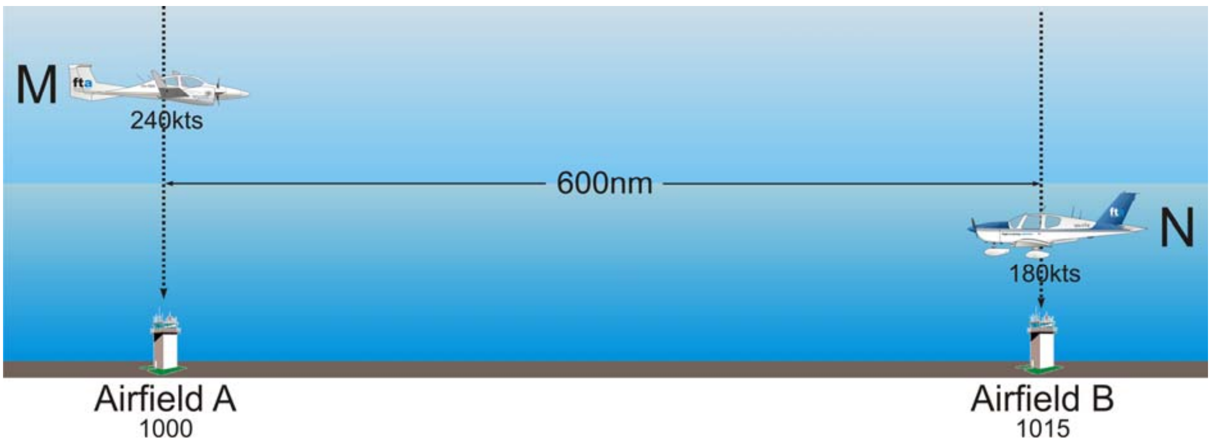
$$\frac{Y}{5} = \frac{(Y - 10) + 50}{6}$$
$$\therefore 6Y = 5Y + 200$$
$$\therefore Y = 200$$

At B's speed of 300 knots, 200nm will take 40 minutes.

$\therefore$ aircraft will be 10nm apart at 1110.

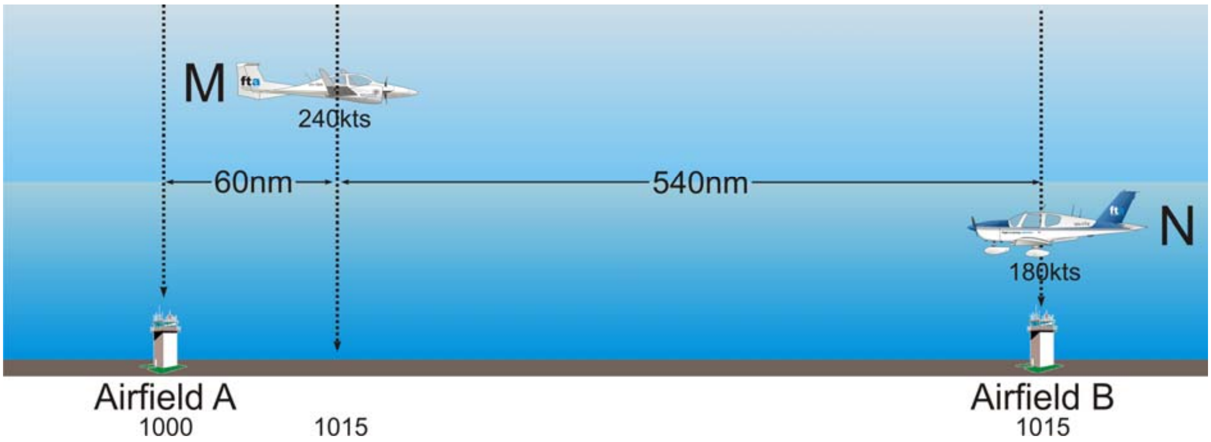
EXAMPLE 2

Two airfields A and B are 600nm apart. Aircraft M departs A for B at 1000, groundspeed 240 knots. Aircraft N departs B for A at 1015, groundspeed 180 knots.



At what time and position will they pass?

First, establish a common start time. By 1015, aircraft M has travelled 60nm from A. Therefore, at 1015 the aircraft are both airborne and are 540nm apart.



The closing speed of the aircraft at 1015 is 420kts.

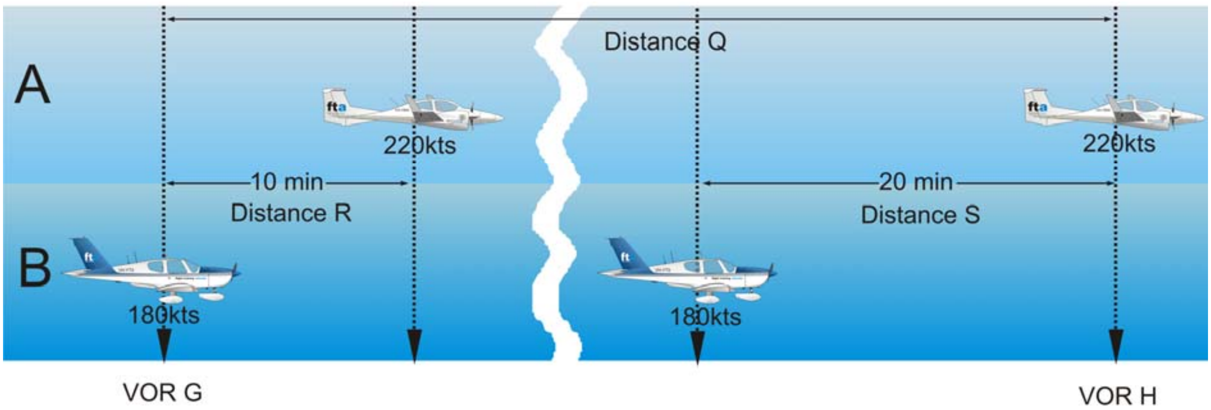
The time required to close 540nm at 420kts is $1^{hr}17^{min}$. The aircraft will pass one another at 1132.

In the $1^{hr}17^{min}$ aircraft N will have covered 231nm. The aircraft pass one another about 231nm from airfield B, or 369nm from airfield B.

OPENING SPEED

EXAMPLE 3

Aircraft A, groundspeed 220 knots passes overhead VOR G 10 minutes ahead of aircraft B, groundspeed 180 kts. Both aircraft are following the same route to VOR H. Aircraft A passes overhead VOR H 20 minutes ahead of aircraft B. What is the distance between VOR G and VOR H



At the time when aircraft B arrives overhead VOR G, aircraft A is already 10 minutes away, flown at 220kts.

Distance R = 10^{min} @ 220kts = 36.67nm

At the other end of the leg aircraft B is 20 minutes behind aircraft A.

Distance S = 20^{min} @ 180kts = 60nm

Therefore aircraft A increased the initial 36.67nm gap between the aircraft by 23.33nm to 60nm. The gap was increased at a rate equal to the difference between the aircraft speeds, i.e. 40kts.

23.33nm @ 40kts = 35^{min}

Distance travel by aircraft A in 35^{min} is:

35^{min} @ 220kts = 128.33nm

Distance between VOR G and VOR H is then:

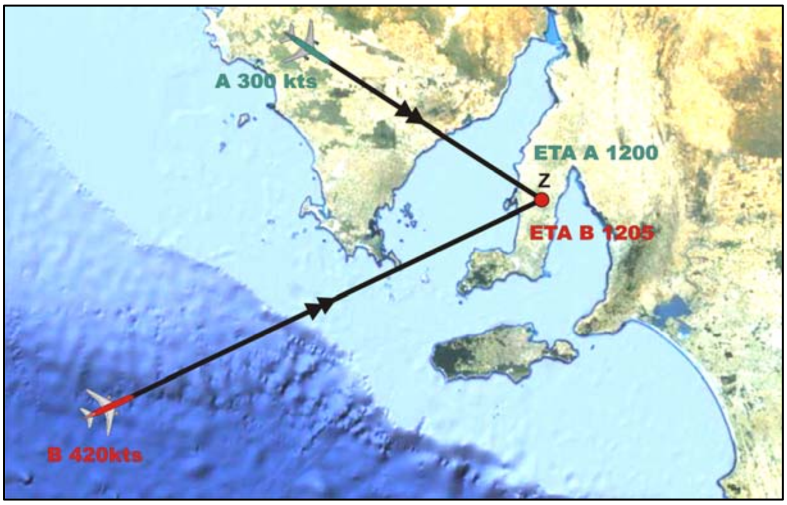
128.33nm + 36.67nm = 165nm

In the examination you can be expected to do calculations similar to this, but will not be given the distance between aircraft. You will be given positions on an ERC, and from that have to calculate the distance between aircraft. At the same time you could also expect not to be given ground speeds, but rather a TAS/Mach No, OAT/TAT, Flight Level and W/V. Once you have the ground speeds and distances, the same principle applies.

DELAYS

EXAMPLE 4

Aircraft A, groundspeed 300 knots, and aircraft B groundspeed 420 knots, are on converging tracks, both heading for point Z. A estimates Z at 1200 and B estimates Z at 1205. ATC requires B to delay his ETA until 1210.



a) If aircraft B reduces speed at 1130, what speed must be maintained to satisfy the requirement?

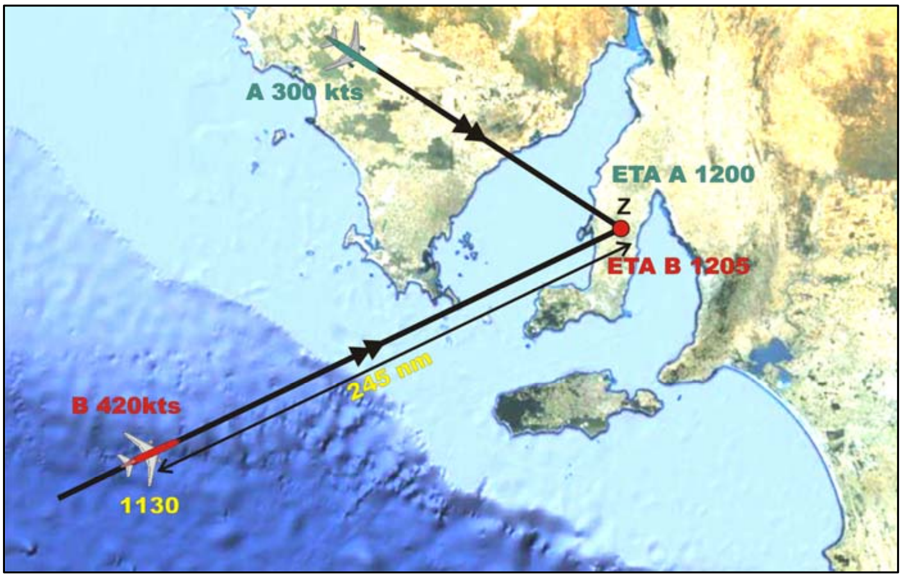
Despite the scenario involving two aircraft and 'converging tracks', this problem is really about a single aircraft changing speed, in this case aircraft B.

First assume aircraft at 1130 before changing speed. At 1130 aircraft B estimate Z at 1205, which is 35 minutes of flying time at a speed of 420kts. Therefore the distance of aircraft B from Z can be calculated:

420 kts = 7nm/min

7nm/min x 35min = 245nm

After the speed change at 1130, the 245nm should now be covered in 40 min to accommodate the ATC's request. The new speed for aircraft B can therefore be calculated:



$$\frac{245\text{nm}}{40\,\text{min}} = 6.125\text{nm}/\text{min}$$

6.125nm/min = 367.5kts

Aircraft B will have to reduce speed to 367.5kts at 1130 to delay its ETA at Z by 5 minutes