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DOCUMENT TITLE

ATPL NAVIGATION (AUS)

CHAPTER 1 – THE NAVIGATION COMPUTER

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CHAPTER 1 - THE NAVIGATION COMPUTER

At this stage of a typical aviation career, it is assumed that students have achieved proficiency in the use of the navigation computer. Hence, these notes will only cover basic techniques rather briefly and tend to concentrate on the theoretical background and on some more advanced procedures.

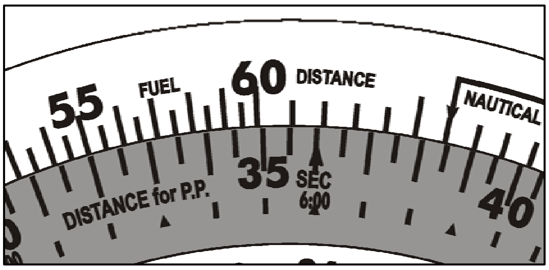
Navigation computers provide a convenient means of solving many navigational problems. Two types are in widespread use; the traditional slide type and the more compact circular type such as the Jeppesen 'CR' series. Special purpose electronic calculators are also available, but will not be discussed further in these notes.

The 'back' of both the slide and circular computer is the wind face, and the 'front' is a circular slide rule providing logarithmic scales for calculation, conversion of units, and special purpose scales for the determination of TAS, density altitude, Mach number, etc, from input data.

THE CALCULATOR SIDE

As the Jeppesen CR-3 is the more common style of navigation computer in use at this school, we will concentrate most of our examples on this type. The CR3 Calculator side can be used for various calculations, some of which include:

- Speed, Distance and Time Calculations
- Fuel Calculations
- Airspeed conversions
- Unit conversions
- 1 in 60 Rule calculations
- Density Altitude calculations
- True Altitude calculations

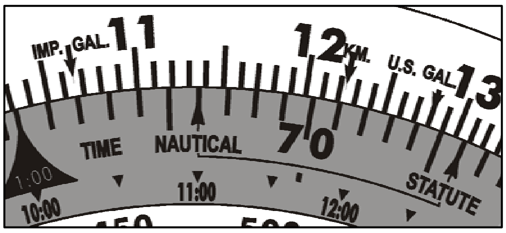


SPEED, DISTANCE, TIME

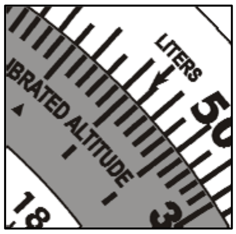
It is customary for aircraft performance manuals to tabulate fuel flow information in units of fuel usage per hour (e.g. kg per hour or pounds per hour). The flow meters in the aircraft itself are calibrated in a similar fashion. This convention is equivalent to that used in speed/distance/time problems, and the calculations are done in an identical fashion. For instance, when we place the '60' time index on, say, '480' on the Jeppesen computer, we are effectively saying that a speed of 480 kts equals 480 nm in 60 minutes, or 8 miles per minute, from which we obtain distance for any given time interval. Similarly, we might have a fuel flow of 480 kg per hour, whence we obtain fuel usage of 8 kg per minute, and fuel used for any given time interval. On the Jeppesen computer, the outer disc is labelled 'Fuel Distance', thus clearly indicating the dual purposes of these scales.

MASS AND VOLUME CONVERSIONS

Units of volume are derived from units of length and, in particular, one litre is the volume of a cube with sides of 0.1 metre; i.e. 1 litre = $(0.1\text{m})^3$ = 0.001 cubic metre.
The gallon is another unit of volume still in common use. This comes in two versions, the US gallon of 231 cubic inches or 3.785411784 litres, and the imperial gallon of 1.20094 US gallons, or 4.546052428 litres.



Note that units of volume (litres or gallons) are commonly used for the measurement of fuel quantities for both light aircraft and cars, but larger aircraft invariably have both fuel quantity and fuel rate indicators calibrated in units of mass, usually pounds or kilograms. This is because the energy content of fuel is a function of its mass which is fixed, while the volume of a given mass of fuel varies with variations in temperature. The variation of temperature, and hence the variation of fuel density will affect the mass for a given volume.



The mass of the fuel can be calculated from the Specific Gravity (SG) of the fuel. The SG value of fuel gives a conversion from a unit of volume to a unit of mass. 1 Litre of water weights 1 kilogram. The density of fuel is however less than that of water, so an SG of 0.70 implies that 1 litre of fuel will only weigh 0.70 kilogram. For conversions into kilogram, it is therefore easiest to convert a given quantity of fuel into litres, and then to multiply that by the SG of the fuel. Should a fuel quantity be required in pounds instead of kilograms, the kilogram quantity can be converted into pounds. Alternatively, it is useful to remember that 1 imperial gallon of water weighs 10 pounds. Any given volume of fuel can therefore be converted into imperial gallons, then multiplied by 10, and multiplied by the SG of the fuel to turn it into a mass in pounds.

MACH NUMBER, LOCAL SPEED OF SOUND CALCULATIONS

The flight characteristics of high performance aircraft depend largely upon the speed of the aircraft through the air mass (i.e. TAS) expressed as a fraction of the local speed of sound (LSS) in the same air mass. This ratio is called the Mach Number (M). Thus, if the TAS equals the LSS, the Mach number is M1.0, and if TAS is half the LSS, Mach number is M0.5, and so on. Since aircraft performance depends upon Mach number, basic navigation still requires TAS, a quick and simple means of converting between the two quantities is needed.

The common factor in this conversion is the local speed of sound in air, which, from physical theory, is known to vary only with variation in the absolute temperature of the air mass. The actual relationship is;

$$LSS = 38.945\sqrt{Temp_{KELVIN}}$$

where LSS is in knots and Temperature is in Kelvin.

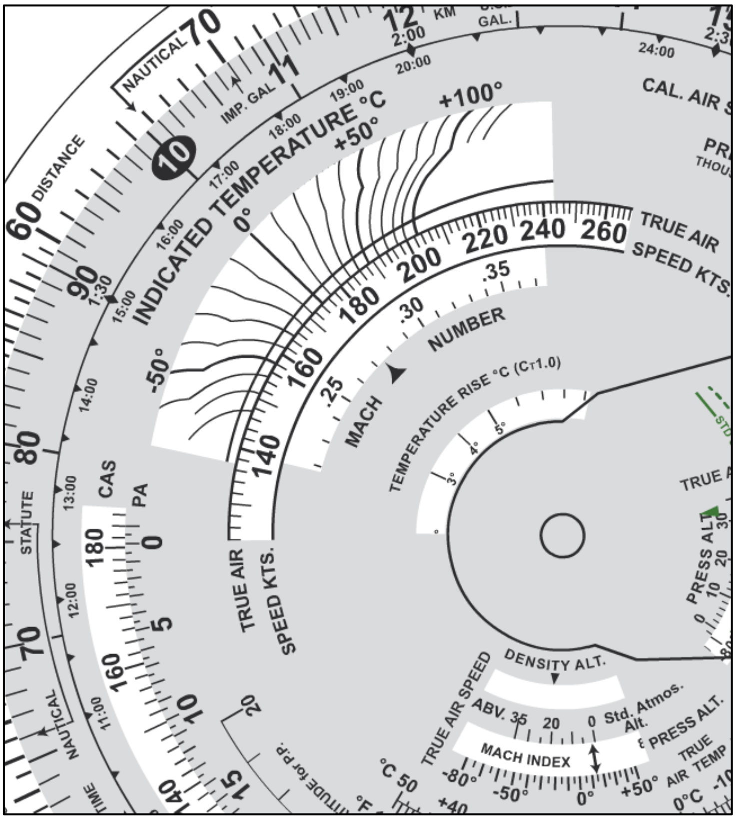
For instance, the LSS in ISA sea level conditions is:

$$LSS = 38.945\sqrt{15+273}$$

$$\approx 661 \text{ knots,}$$

and at the ISA tropopause, $LSS = 38.945\sqrt{-56.5+273}$

$$\approx 573 \text{ knots}$$



The calculation can also be effected using the Jeppesen computer by setting the air temperature against the 'Mach Index', and reading the LSS on the outer scale against 10 (i.e. M1.0) on the inner scale. Check both the above results on the computer. More generally, if we know the Mach number (either from the aircraft manual during flight planning or from the machmeter in flight), we set the outside air temperature as described, and read the TAS on the outer scale against the Mach number on the inner scale and vice versa.

In effect, we are simply multiplying the LSS by the Mach number, reflecting the fact that,

$$M\ No = \frac{TAS}{LSS},$$

$$\text{so } TAS = M\ No \times LSS$$

For example, at ISA sea level, M1.2 = 1.2 x 661

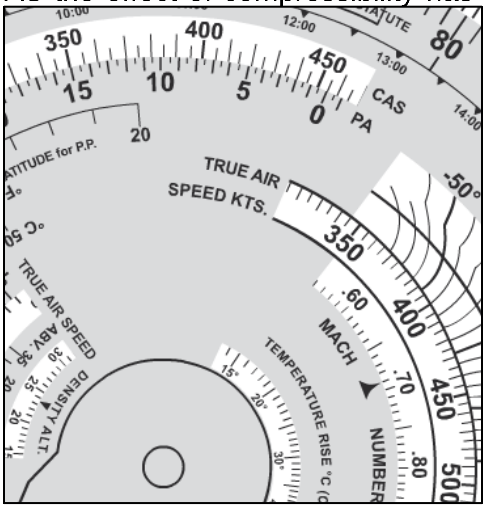
= 793 kts TAS

To attain a TAS of 793 kts at the ISA tropopause we would require a Mach number of about M1.38 (793 ≈ 1.38 x 573).

These examples illustrate the important fact that Mach number is not a unit of speed, but is merely a ratio between two speeds that can both vary independently.

CALCULATING TAS GIVEN OAT

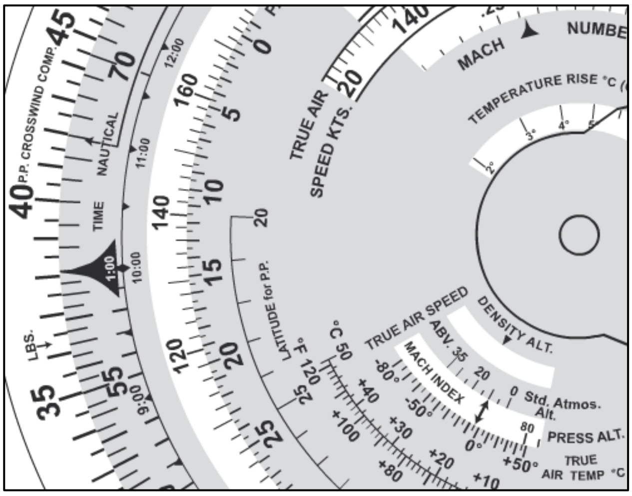
In earlier studies you might have concentrated on using the True Airspeed window on the CR-3 to calculate TAS by setting up an OAT and a Pressure Altitude, and finding TAS on the outside disk from CAS on the inside disk. This method however does not take compressibility into account. To calculate the correct TAS the effect of compressibility has to be considered. Compressibility is an over reading of the CAS displayed on the ASI, and it is dependant on both altitude and airspeed. For a given altitude, compressibility error will increase with an increase in airspeed.



To allow for compressibility, the TAS is calculated from Mach Number which is free of compressibility error.

Given a CAS of 350 kt, Pressure Altitude of 15,000 ft and Outside Air Temperature of -5°C, the calculation is made as follows:

- In the CAS/PA window, SET CAS opposite PRESS ALT
- READ OFF the MACH NUMBER in the MACH NUMBER window
- In the TRUE AIRSPEED window, SET the double headed MACH INDEX arrow opposite the OAT.
- On the OUTSIDE DISK, READ OFF the TAS from MACH NUMBER on the INSIDE.



ANSWER: M0.69, TAS 439 kts

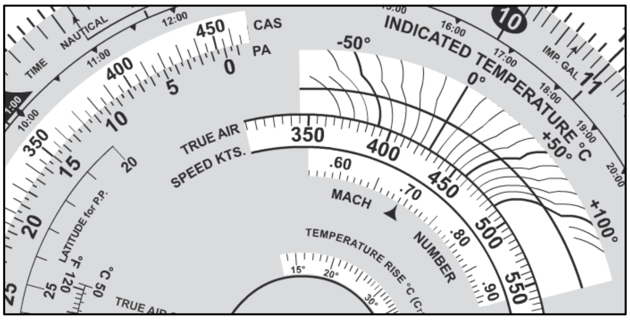
NOTE: For other calculations, refer to the Jeppesen CR-3 operating handbook. In Flight Instruments and Flight Planning the relationship between CAS, TAS and Mach Number is also discussed in more detail. Ensure you are familiar with the various calculations and conversions between the different airspeeds as well as the general use of the calculator side on the CR-3.

CALCULATING TAS GIVEN TAT/RAT (IOAT)

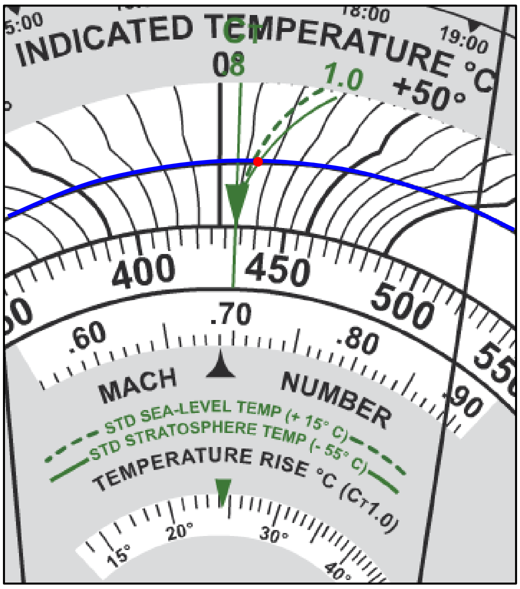
In the above example you were given the OAT, CAS and Press Alt/Flight Level. In flight you will more commonly have access to IOAT (Indicated Outside Air Temperature), which includes a percentage of Ram Rise dependent on the Recovery Factor (C_T) of the air temperature probe. For examination purposes, the question will specify the C_T of the probe. The most common will be a C_T of 0.8 or a C_T of 1.0.

Given a CAS of 350 kt, FL150 and Indicated Outside Air Temperature of +15°C (C_T 1.0) the calculation is made as follows:

- In the CAS/PA window, SET CAS opposite PRESS ALT.
- READ OFF the MACH NUMBER in the MACH NUMBER window. If Mach Number was provided, this can be set without the need for using CAS/P Alt.



- In the INDICATED TEMPERATURE WINDOW, locate **+15°C** on the **long spiral** and through this **point** move the green index cursor for **C_T 1.0** (no need to interpolate between sea-level and stratosphere temperature).
- Follow this green line inwards to find TAS 433tks.
- Move further in and fine a temperature rise of 24°. This temperature rise is for a C_T 1.0 probe



ANSWER: M0.69, TAS 433 kts, temperature rise 24°, OAT -9°C

When given RAT the same steps are followed as described above. The first difference will be to use the C_T 0.8 index cursor to find TAS. By moving further inward, the temperature rise can be found, but this is only valid for C_T 1.0. To find the temperature rise for C_T 0.8, the temperature rise has to be multiplied by 0.8 and then the static air temperature (SAT), or OAT calculated as described above.

THE WIND SIDE AND THE TRIANGLE OF VELOCITIES

The circular slide rules all employ the same basic principles, but differ widely in detail between different brands and types of computer. These notes will concentrate attention on the wind faces of the slide and circular computers.

The slide computer requires little explanation as it simply mechanises the triangle of velocities. The entire triangle is usually not displayed but there is always sufficient to allow ready comprehension of all the factors that affect the result. A typical display is shown in Figure 1 (overleaf), together with the actual triangle of velocities that it represents.

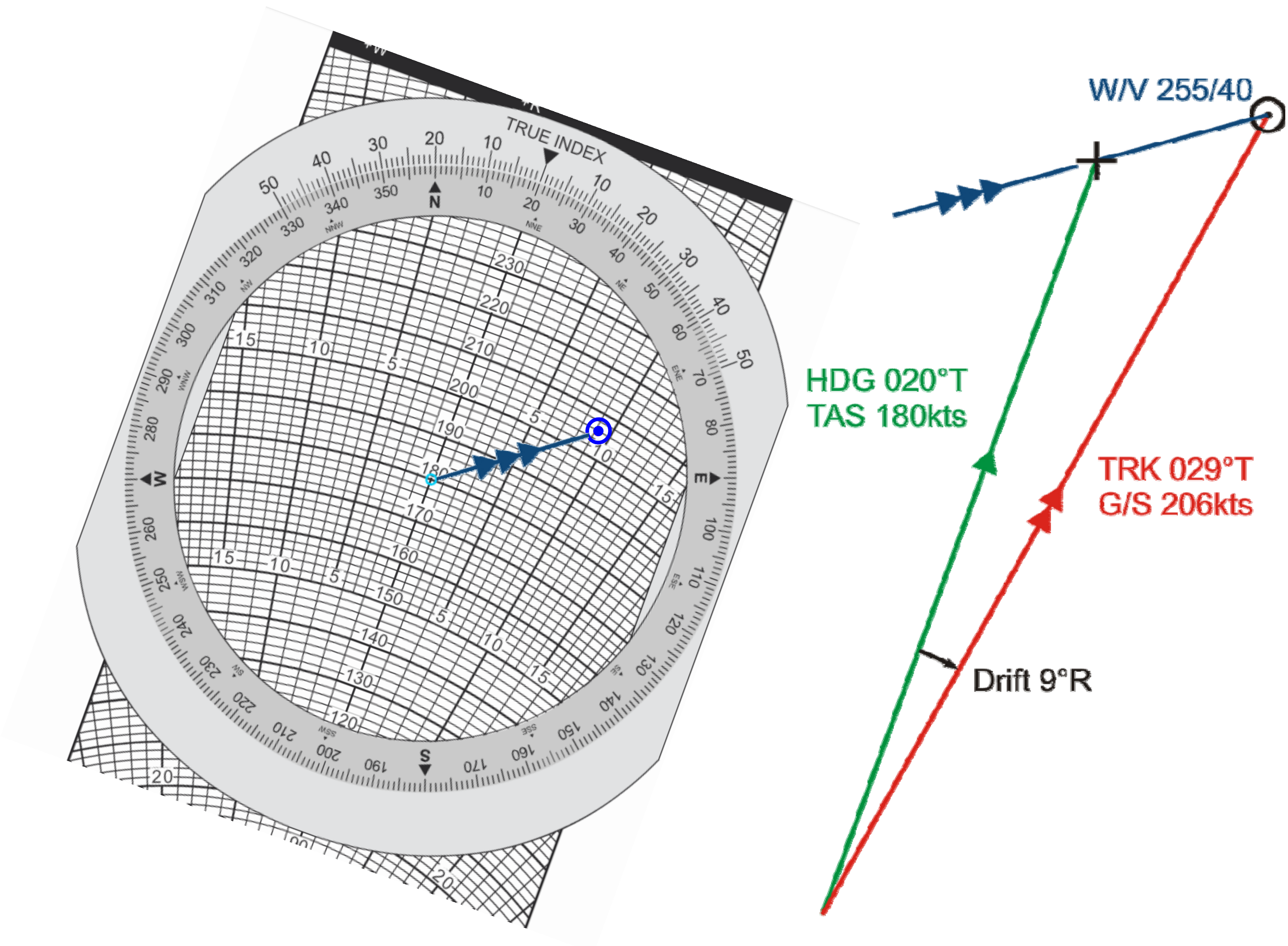


Figure 1

The small size of the circular computer prevents the display of the entire triangle, so we utilise only a very small portion as illustrated in Figure 2.

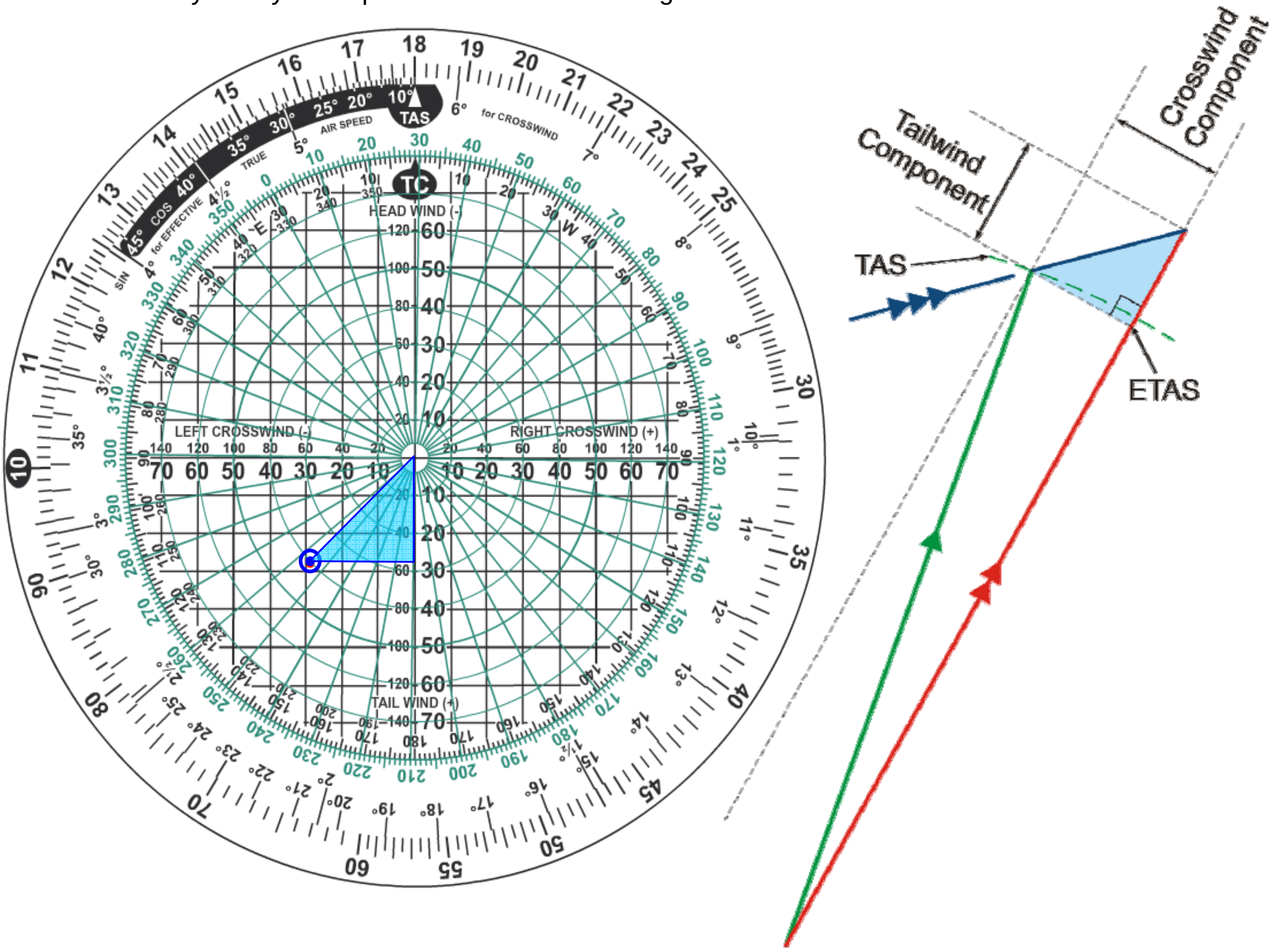


Figure 2

These diagrams illustrate the major differences between the two displays. Firstly, the centre of the wind face on the slide computer is the end of the TAS/Heading vector, but on the circular computer it is the end of the Groundspeed/Track vector.

Secondly, the slide computer uses arcs of circles centred on a zero speed origin to display TAS and groundspeed, and radial lines to indicate drift, while the circular computer uses a square grid to give head/tailwind component and crosswind component. The reason for this is that the circular computer has no slide to 'scale' the drift correctly to the TAS, so this scaling process must be done off the wind face using separate inputs of crosswind component and TAS.

Thirdly, and less obviously, the circular computer resolves both the wind velocity and the TAS about the track, while the slide computer resolves the wind velocity about the heading. This does not affect the solution in either case, but it does have important implications whenever the problem involves the calculation of along-track wind components.

The circular computer achieves its compact design by elimination of the slide and, in general terms, this leads to additional complexity of calculation. Headings and groundspeeds that are read directly from the wind face of the slide computer must be calculated indirectly after obtaining drift and head/tailwind component on the circular computer. Likewise, the calculation of inflight wind velocity, either from drift/groundspeed information obtained from other sensors, or by the multi-drift technique, is effected easily on the slide computer by marking the wind face at the observed values. On the circular computer, drift and heading must first be converted to track, and the crosswind component calculated. If drift exceeds 10 degrees, a head or tailwind component can only be calculated after ETAS has been obtained from TAS, and compared with the observed groundspeed. This is then combined with the crosswind component to give the wind velocity.

The circular computer does, however, offer advantages in any process that requires the calculation of wind components, e.g. ETP, PSR, wind components for take-off and landing etc. The resolution of both TAS and wind velocity about the track results in wind components directly related to the track direction, and a resolved component of TAS (ETAS). Since we usually require the aircraft to maintain a particular track and adjust the heading accordingly, the presentation of wind components referenced to track is more readily utilised than a slide computer solution that is referenced to heading.

The principles underlying the detailed workings of the wind face of the circular computer are somewhat complex, and are beyond the scope of the ATPL syllabus. They are, however, presented below for information. The explanation examines the normal flight planning problem of determining heading and groundspeed, given track, TAS and forecast wind velocity. This explanation should provide an adequate understanding of all the important operational features of the wind face.

HEADING AND GROUNDSPEED CALCULATIONS

A major aim in the design of the Jeppesen circular computer was to produce an instrument small enough to fit ‘in the shirt pocket’. This was achieved by eliminating the slide from the traditional DR computer, and by adjusting the method of computation to utilise the reduced portion of the triangle of velocities now available.

The wind face consists of three discs:

- The outer or TAS/crosswind disc
- The middle or drift disc
- The inner or W/V/True Course disc.

The method of use depends to some extent on the type of calculation to be performed. The present analysis will deal only with the calculation of heading and groundspeed given W/V, desired track and TAS, but this is sufficient to illustrate the use of all features of the wind face.

We will consider the heading and groundspeed solution in general terms, and use a particular example for illustration:

Desired track	100°T	
W/V	328/52	
TAS	150kt	Determine the heading to fly and the groundspeed.

The geometry of the situation as portrayed on the Jeppesen computer is shown in Figure 3.

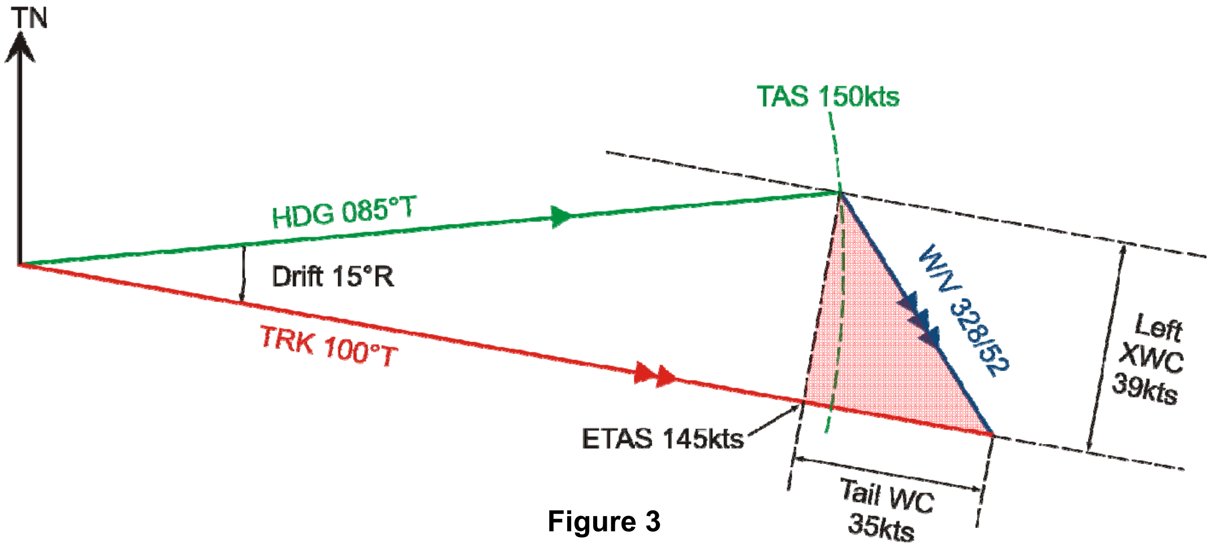


Figure 3

Note that only the small shaded triangle is actually displayed on the wind face.

After plotting the W/V as a 'wind dot' upwind from the centre of the inner disc, the first step is to resolve the W/V into two components about the track direction. These are:

Headwind component (HWC)
or
Tailwind component (TWC)
= wind speed x cosine θ

and

Crosswind component (XWC) = wind speed x sine θ

θ is the smaller angle between the track and the wind direction.

This is done by turning the inner disc to display the desired track under the TC (True Course) index, in this case 100°. The effect is to set the angle θ between track and wind direction, 328° - 100° = 228° - 180° = 048°.

Now read the values of HWC and XWC from the square grid inscribed under the inner disc:

HWC = 52 cos 48 = 34.8 kts, and

XWC = 52 sin 48 = 38.6 kts left crosswind

Again from Figure 3, we see that the required values of heading and groundspeed are fixed by the two wind components, XWC and HWC or TWC. The common factor in these calculations is the drift angle.

HEADING

From Figure 3: $\text{Sin (drift angle)} = \dfrac{\text{XWC}}{\text{TAS}}$

so, $\text{drift angle} = \sin^{-1}\left(\dfrac{\text{XWC}}{\text{TAS}}\right)$, and $\text{Heading} = \text{Track} \pm \text{Drift}$

GROUNDSPEED

If the drift angle is small, the HWC or TWC is applied directly to TAS to give groundspeed. However, the Jeppesen computer resolves the wind vector about the track, so if the drift angle is large, the TAS vector must also be resolved about the track before the wind component is added to obtain groundspeed. We see from Figure 3 that the component of TAS that acts along track, the Effective TAS or 'ETAS' - is given by:

ETAS = TAS x cosine (drift angle)

If the drift is small, then cos (drift angle) $\approx$ 1, and ETAS $\approx$ TAS, but this approximation becomes more and more inaccurate as drift increases. Noting that:

$$\cos^{-1}(0.99) = 8.11°,$$

it then becomes clear that to maintain the accuracy of computations within 1% we should calculate ETAS whenever the drift exceeds 8°. Jeppesen sets the cut-off at 10°, and recommends that ETAS be calculated for all drift angles of 10° or more.

If drift is 10°, cos 10° = 0.985, so failure to convert from TAS to ETAS results in a 1.5% overestimate of groundspeed, the error increasing as drift increases above 10°.

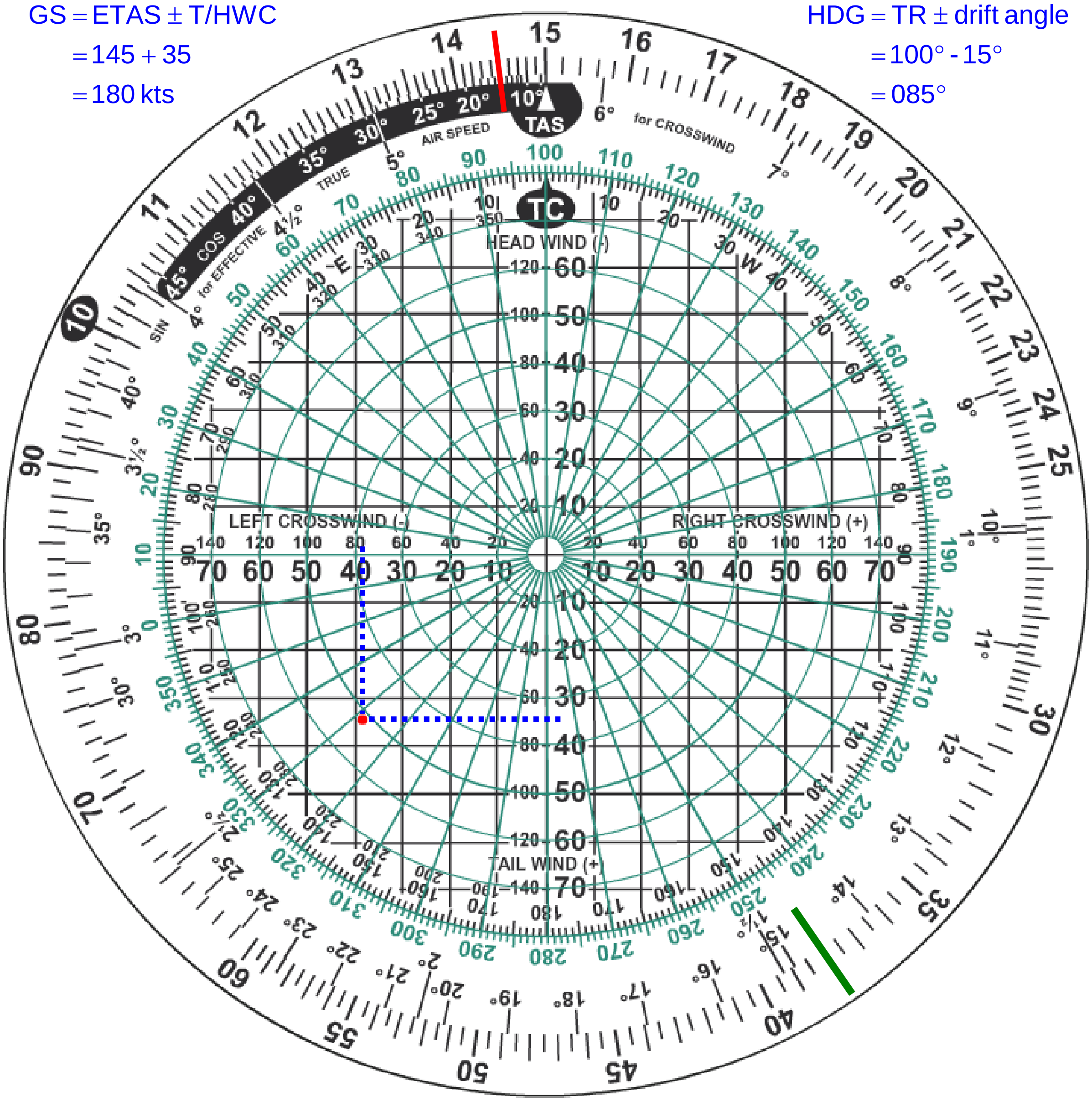
One important thing to remember from the above is that at higher airspeeds, a 1% error in the calculation of groundspeed from TAS, instead of ETAS, can still result in a significant error. For greater accuracy therefore, it is recommended that **ETAS be used** for groundspeed calculations whenever the **drift angle ≥ 5°**.

PRACTICAL HEADING AND GROUNDSPEED CALCULATION

Desired track	100°T	
W/V	328/52	
TAS	150kt	Determine the heading to fly and the groundspeed.

We begin by marking in a wind dot, and then setting up the TAS and Track.

From the wind dot, draw a line horizontally and vertically to determine crosswind (XWC) and head- or tailwind component (HWC / TWC). In this case a XWC of 43 kts and HWC of 25 kts. On the outside disk, locate 43 kts left XWC and on the middle disk read off drift angle, 15°R. As the drift exceeds 5°, find ETAS (145kts) on the black cosine scale to the left of the TAS marker.



WIND COMPONENTS FOR TAKE-OFF AND LANDING

The circular computer is ideal for finding runway wind components. Mark the wind face with the forecast or observed wind velocity in the usual way, then rotate the inner disc to set the runway direction under the TC index. Read the head/tailwind and crosswind components directly from the wind face. (Take care to ensure that the wind direction and runway direction are both expressed in degrees true or degrees magnetic).

On the slide computer the process is similar but must be performed on the square grid section of the slide rather than on the normal navigational section.

GROUNDSPEED 'OUT' AND GROUNDSPEED 'HOME'

In the calculation of equi-time point (ETP) and point of no return (PNR) we need to know both the groundspeed 'out' and the groundspeed 'home' along a given track line. These, of course, are easily calculated using standard techniques on both types of computer, but a complication arises with the slide computer if large drift angles are involved.

Consider the following example:	Track (OUT),	090°T
	Track (HOME),	270°T
	TAS,	150 knots
	Wind velocity,	030/50

The slide computer yields the following results:

- Heading (OUT) 073°T, Drift 17°R, Groundspeed (OUT) 119 knots, and
- Heading (HOME) 287°T, Drift 17°L, Groundspeed (HOME) 169 knots

Hence, the wind components would appear to be:

119 – 150 = –31 knots (OUT)   and 168 – 150 = +18 knots (HOME)

The reason for this apparent anomaly is that we are comparing groundspeed which, obviously, acts along track, with TAS which, equally obviously, acts along heading. In this case there is a large difference of 17° between track and heading, and so the two quantities are not directly comparable.

The circular computer avoids this problem because the head/tailwind component is calculated from groundspeed and ETAS, both of which act along track. Using the same example we find:

- On the track of 090°T, left XWC is 43 knots, and on 270°T, right XWC is 43 knots.
- With TAS of 150 knots, these crosswinds produce drift angles of 17°R and 17°L respectively.
- A drift angle of 17° with TAS 150 knots produces an ETAS of 144 knots.

- The headwind component on 090°T is 25 knots and the tailwind component on 270°T is also 25 knots. Referenced to the ETAS of 144 knots, this produces groundspeed 'OUT' of 119 and 'HOME' of 169 knots, as before.

Note that the groundspeeds are the same as those calculated on the slide computer, but the wind components are equal and opposite, as one would expect, because they are correctly referenced to track. Hence, if a slide computer is used, it does not follow that a TWC of 30 knots outbound will produce a HWC of 30 knots home. Indeed, that assumption would be correct only if the wind direction were aligned with track, i.e. if drift was zero. If there is significant drift, the HWC and TWC must be calculated separately. Either:

- Calculate ETAS = TAS x cosine (drift angle), and reference the out and home groundspeeds to that value to obtain HWC and TWC,

or,

- Observe that ETAS is the mean value of the groundspeeds OUT and HOME. In the example above, the mean groundspeed is:

$$\frac{169 + 119}{2} = 144 = \text{ETAS}$$

Then: Wind component (OUT) = 119 - 144 = -25 knots, and

Wind component (HOME) = 169 - 144 = +25 knots.

These points are illustrated in Figure 5.

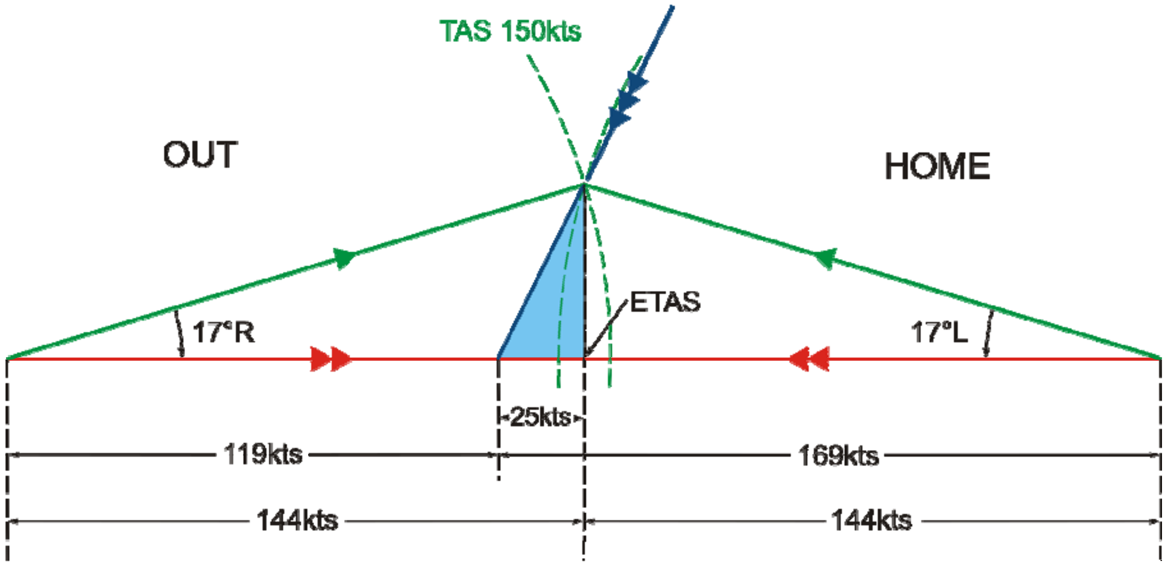


Figure 5

Figure 5 demonstrates clearly why it is not valid to assume that HWC and TWC is the simple difference between TAS and groundspeed.

WIND AND TEMPERATURE FORECASTS

In a CASA examination, as in real life, you could be expected to calculate typical flight planning type problems. You will either be given a track, or have to find the track between two places on a map. You will have to find both distances and tracks from an ERC and then compensate for the wind influence to determine what heading will have to be flown, what groundspeed will result, and what will be the elapsed time for the leg or flight. We follow the method described previously to determine heading and groundspeed.

To determine the heading and groundspeed requires a W/V which might not always be given directly, and most often will be in the form of a Route Sector Wind and Temperature (RSWT) forecast. RSWT forecasts are provided for various sectors of frequently used air routes. The forecasts are normally prepared six flight levels equating to specific atmospheric pressures. In the examination there will not always be a forecast for your actual level. In such a case it is not required to interpolate, simply use the forecast for a level closest to your level. The typical period of validity is six hours with four periods in 24 hours.

RSWT forecasts are given in the following format:

- ISA temperatures in °C are indicated next to each flight level, making it easy to calculate ISA deviation.
- The first two digits indicate the wind direction in °T to the nearest 10°.
- The next three digits indicate the wind speed to the nearest knot, therefore making provision for wind speeds in excess of 100 kts.
- The last two digits indicate the mean temperature in °C without a preceding negative sign.

ROUTE SECTOR WINDS AND TEMPERATURES FORECAST
PROVIDED BY AUSTRALIAN BUREAU OF METEOROLOGY

BASED ON 201200Z DATA FROM WAFC LONDON
VALID 210000Z ISSUED 201702Z

FL	-ISA	YMML/YSSY	YSSY/YBBN	YMML/YPAD	YMML/YMHB	YPAD/YPOD/YMHB	
450	-56	2703858	2603759	2605259	2904454	2505558	2804654
390	-56	2604762	2404060	2606660	2905758	2506959	2805756
340	-52	2804454	2503553	2506854	3106453	2507555	2906152
300	-44	2804244	2403043	2606545	3006745	2507145	2906745
240	-33	2703928	2402726	2505628	3006729	2406428	2906430
180	-21	2803415	2302013	2604915	3006417	2505015	2906118

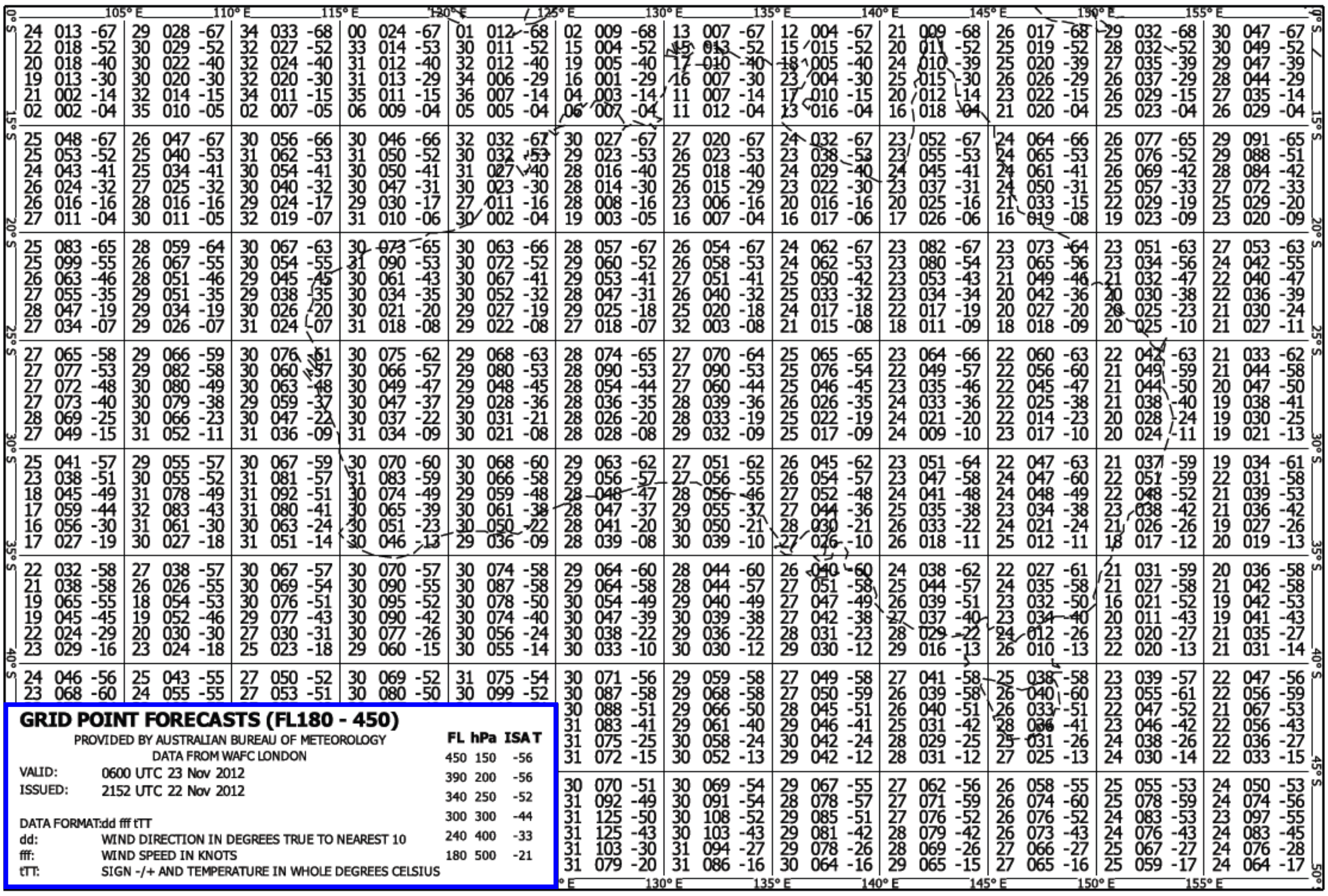
FL	-ISA	YMML/YMDG/YBBN		YMML/YGTH/YWLG		YSSY/YMCO/YMHB		YSSY/YGTH/YPAD	
450	-56	2704058	2504160	2704458	2504660	2803358	3003955	2703859	2605360
390	-56	2604861	2404560	2605461	2405660	2703962	2905460	2504362	2506561
340	-52	2704454	2503653	2705054	2504454	2803754	3105855	2703854	2505254
300	-44	2704344	2503042	2705045	2603643	2803344	3105645	2703644	2504945
240	-33	2704028	2402626	2704928	2603027	2702827	3105429	2603227	2504427
180	-21	2703515	2302013	2804615	2502314	2702315	3105117	2602415	2604114

In the above table if we look at the sector between YMML and YSSY, we can see some interesting facts. We can see the ISA temperature at the various levels, and comparing it to the last two digits we can establish the ISA deviation. At FL390, the temperature is -62°C, increasing to -58°C at FL 450, indicating a temperature inversion. The winds are also mainly westerly, as can be expected at mid latitudes.

The wind could also be given in a Grid Point Wind and Temperature (GPWT) forecast. The use of such a forecast is similar to the RSWT, but a legend is also provided on the chart to explain the values shown in each block on the chart.

GPWT forecasts are given in the following format:

- ISA temperatures in °C and pressures in hPa are indicated next to each flight level in the legend, making it easy to calculate ISA deviation.
- The values depicted in each block show the winds and temperatures for the given flight levels.
- The first two digits indicate the wind direction in °T to the nearest 10°.
- The next three digits indicate the wind speed to the nearest knot.
- The last two digits indicate the temperature in °C with a preceding negative sign.

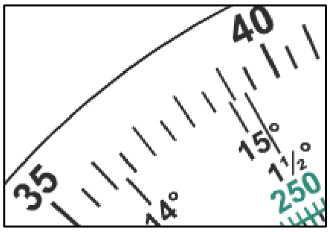


CALCULATING WIND VELOCITY

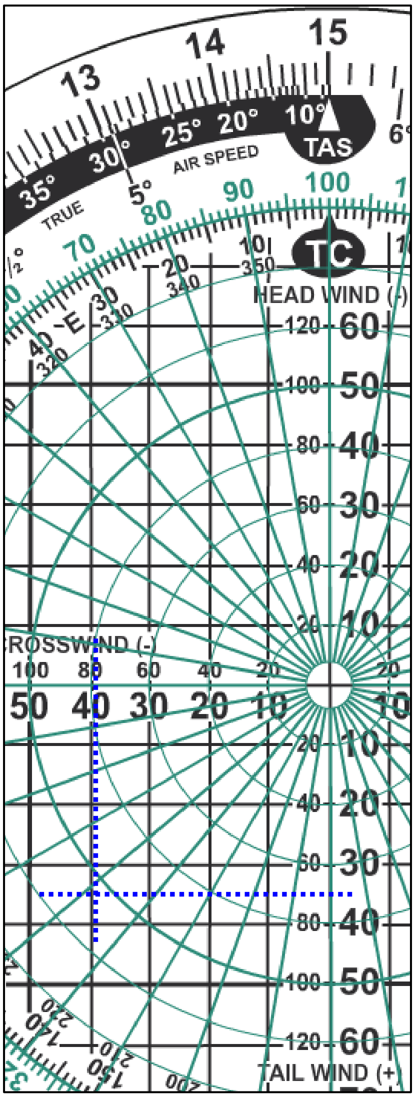
Consider the following example: The aircraft is tracking on the 100° radial from a VOR. Heading to maintain track is 085°M and TAS 150 knots. At time 1010 the range from a DME co-located with the VOR was 60nm, and at 1016 has increased to 78nm. What is the Wind Velocity?

From the above information we observe that true track is 100°M, drift is 15°R, with a groundspeed of 180 knots. On a slide style it is a very simple calculation.

The procedure is more complicated with a circular type computer:



At 150kt TAS, 15° of drift is equivalent to 39 knots crosswind component.



- SET the ‘TC’ index to 100°M and MARK in 39 knots left crosswind (left XWC results in right drift).
- With TAS SET, and drift 15°R determine ETAS as 145 kts.
- Comparing ETAS of 145 kts and GS of 180 knots gives a tailwind component of 35 kts. MARK in a 35 kt TWC.
  (GS = ETAS ± WC).
- MARK the intersection of the above line with the crosswind line.
- READ OFF the wind velocity of 328M/53 by rotating the intersection point onto the TC marker line.

The graphical explanation of this solution is illustrated in Figure 4 below.

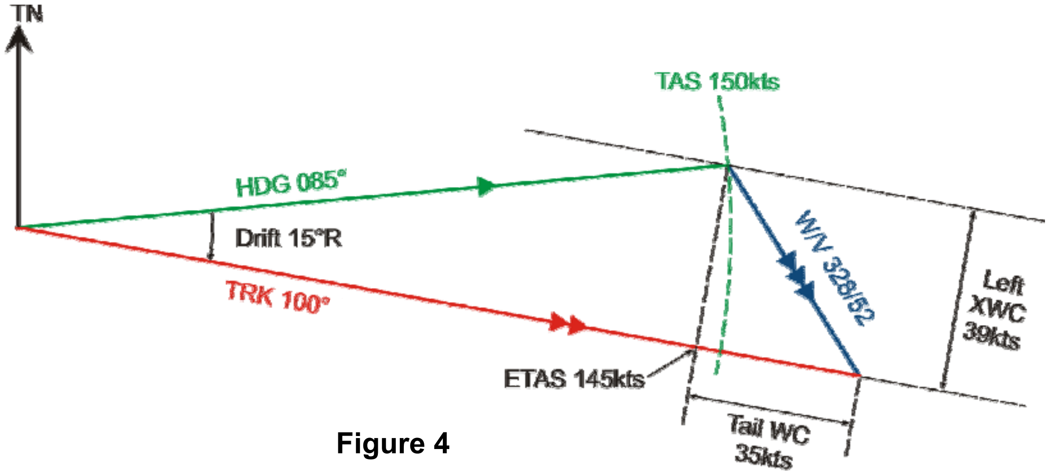


Figure 4