General Navigation

[awesome ATPL formulas]

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This e-book has been written and published as a reference work to assist students enrolled on an approved EASA Air Transport Pilot Licence (ATPL) course to prepare themselves for the EASA ATPL theoretical knowledge examinations. Nothing in the content of this e-book is to be interpreted as constituting instruction or advice relating to practical flying.

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Content

1. Track Angle Error

Description: The track angle error is the angle between the aircraft's actual ground track and the planned track. The formula is used to calculate the angle based on the 1-in-60 rule.

Formula:

$$\textit{Track Error} = \frac{\textit{Distance Off}}{\textit{Distance Gone}} \times 60$$

Explanatory notes:

- Insert distance off track in nautical miles (NM)
- Insert distance gone in nautical miles (NM)
- You will get the track angle error in degrees (°)

Example

The distance between A and B is 90 NM. At a distance of 75 NM from A the aircraft is 7 NM right of course. The track angle error (TKE) is approximately:

[Try to calculate this yourself, the solution is on the next page]

Solution:

1. ***First, we have to realize that we don't need all the information provided in the question for our calculation. So don't be confused with the total distance, we won't use it.***

2. ***Then we substitute the numbers into the equation:***

$$Track\ Error\ =\ \frac{Distance\ Off}{Distance\ Gone}\ x\ 60$$

$$Track\ Error\ =\ \frac{7}{75}\ x\ 60\ =\ 0.0933\ x\ 60\ =\ 5.6^{\circ}$$

3. ***Since the question states that the aircraft is 7 NM <u>right</u> of course, the cross angle error is also to the <u>right</u>.***

Answer: The track angle error (TKE) is approximately **6° right**.

2. Closing Angle

Description: The closing angle is basically a track angle error at your destination point. The formula is used to calculate the correction angle to the heading to reach the planned destination point.

Formula:

$$Closing\ Angle = \frac{Distance\ Off}{Distance\ to\ Go}\ x\ 60$$

Explanatory notes:

- Insert distance off track in nautical miles (NM)
- Insert distance to go in nautical miles (NM)
- You will get the closing angle in degrees (°)

Example

The distance between A and B is 90 NM. At a distance of 15 NM from A the aircraft is 4 NM right of course. To reach destination B, the correction angle on the heading should be:

[Try to calculate this yourself, the solution is on the next page]

Solution:

1 ***The aircraft is flying from point A to point B away from the correct track. So to calculate the answer, we first have to calculate the correction to fly parallel with the correct track and then another correction to intercept the correct track at the destination point.***

$$Correction\ Angle\ =\ Track\ Error\ +\ Closing\ Angle$$

2 ***So, first we calculate the track error as the first part of the solution:***

$$Track\ Error\ =\ \frac{Distance\ Off}{Distance\ Gone}\ x\ 60$$

$$Track\ Error\ =\ \frac{4}{15}\ x\ 60\ =\ 0.2666\ x\ 60\ =\ 16^{\circ}$$

3 ***Now we calculate the closing angle, as the second part of the solution:***

$$Distance\ to\ Go\ =\ 90\ NM - 15\ NM\ = 75\ NM$$

$$Closing\ Angle\ =\ \frac{Distance\ Off}{Distance\ to\ Go}\ x\ 60$$

$$Closing\ Angle\ =\ \frac{4}{75}\ x\ 60\ =\ 0.0533\ x\ 60\ =\ 3.2^{\circ}$$

4 ***Finally we add up both angles to get the heading correction:***

$$Correction\ Angle\ =\ Track\ Error\ +\ Closing\ Angle$$

$$Correction\ Angle\ =\ 16^{\circ}\ +\ 3.2^{\circ}\ =\ 19.2^{\circ}$$

Answer: The correction angle on the heading should be **19° left**.

3. Convergency (Earth)

Description: Let's assume a flight on a great circle from A to B. Convergency is the difference between the great circle tracks measured at meridians at point A and B. The formula is used to calculate the convergency on the earth.

Formula:

$$\boldsymbol{Convergency = Ch\ Long\ x\ Sin\ Mean\ Latitude}$$

Explanatory notes:

- Insert change in longitute (Ch Long) in degrees (°)
- Insert mean latitude in degress (°)
- You will get convergency in degrees (°)

Example

You are flying from A (50°N 10°W) to B (58°N 02°E). What is the Convergence between A and B?

[Try to calculate this yourself, the solution is on the next page]

Solution:

1. ***First, we have to find the change in longitude. Point A is 10° west, point B is 2° east. It's 10° degrees from point A to Greenwich and then a further 2° from Greenwich to point B. So it's a total 12° change in longitude.***

2. ***Then we have to calculate the mean latitude (Note: be careful when crossing the equator, the calculation is different):***

$$Mean\ Latitude = \frac{First\ Latitude + Second\ Latitude}{2}$$

$$Mean\ Latitude = \frac{50 + 58}{2} = \frac{108}{2} = 54^{\circ}$$

3. ***Now we substitute the numbers into the equation:***

$$Convergency = Ch\ Long\ x\ Sin\ Mean\ Latitude$$

$$Convergency = 12\ x\ Sin\ 54^{\circ} = 12\ x\ 0.8090 = 9.7^{\circ}$$

Answer: The convergence between A and B is **9.7**°.

4. Convergency (Lambert's Projection)

Description: Let's assume a flight on a great circle from A to B. Convergency is the difference between the great circle tracks measured at meridians at point A and B. The formula is used to calculate the convergency on the Lambert's / Conic projection.

Formula:

$$\boldsymbol{Convergency = Ch\ Long\ x\ Sin\ Parallel\ of\ Origin}$$

Explanatory notes:

- Insert change in longitute (Ch Long) in degrees (°)
- Insert mean latitude in degress (°)
- You will get convergency in degrees (°)
- Note: „Sin Parallel of Origin" is also called „Constant of the Cone", „Chart Convergency Factor (CCF)" or „n" in ATPL exams, all these variables are dimensionless

Example

Calculate the constant of the cone on a Lambert Chart given chart convergency between 010°E and 030°W as being 30°.

[Try to calculate this yourself, the solution is on the next page]

Solution:

1. ***First, we have to find the change in longitude. It's 10° from 010°E to Greenwich and then further 30° from Greenwich to 030°W. So it's a total 40° change in longitude.***

2. ***As we know, „Constant of the Cone" means „Sin Parallel of Origin", so we adjust our formula and substitute the numbers:***

$$Convergency = Ch\ Long\ x\ Constant\ of\ the\ Cone$$

$$30^\circ = 40^\circ\ x\ Constant\ of\ the\ Cone$$

3. ***Now we basically divide both sides of the equation by 40 to separate the variable:***

$$\frac{30^\circ}{40^\circ} = \frac{40^\circ\ x\ Constant\ of\ the\ Cone}{40^\circ}$$

$$0.75 = Constant\ of\ the\ Cone$$

Answer: The constant of the cone is **0.75**.

5. Conversion Angle

Description: The conversion angle is the angle between the Great Circle (orthodromic) track and the Rhumb Line (loxodromic) track, measured at the common origin. The formula is used to calculate this difference based on convergency.

Formula:

$$\textbf{Conversion Angle} = \frac{\textbf{Convergency}}{2}$$

Explanatory notes:

- Insert convergency in degrees (°)
- You will get the conversion angle in degrees (°)

Example

The angle between the true great circle track and the true rhumb line track joining the following points: A (60°S 165°W) and B (60°S 177°E), at the place of departure A, is:

[Try to calculate this yourself, the solution is on the next page]

Solution:

1. ***There is no convergency provided in the question, so first we have to find this using the formula we already know:***

$$Convergency = Ch\,Long\ x\ Sin\,Mean\,Latitude$$

2. ***To calculate convergency, we have to find the change in longitude. Point A is 165° west, point B is 177° east. The shortest way to fly from point A to point B is via 180° E/W meridian. It's 15° degrees from point A to the 180° meridian and then a further 3° from the meridian to point B. So it's a total 18° change in longitude.***

3. ***Because both A and B are on the same latitude, the mean latitude for our calculation is basically 60°.***

4. ***Now we substitute the numbers into the convergency equation:***

$$Convergency = Ch\,Long\ x\ Sin\,Mean\,Latitude$$

$$Convergency = 18\ x\ Sin\,60^\circ = 18\ x\ 0.8660 = 15.5^\circ$$

5. ***And then we simply divide the convergency by two to get the conversion angle, which is the difference between the great circle and the rhumb line track:***

$$Conversion\ Angle = \frac{Convergency}{2}$$

$$Conversion\ Angle = \frac{15.5^\circ}{2} = 7.7^\circ$$

Answer: The difference between the great circle and the rhumb line track is **7.7**°.

6. Departure

Description: Departure in navigation can be defined as the East/West distance along a parallel of latitude. So, the formula can be used to calculate a distance between meridians (change of longitude) along any latitude.

Formula:

$$\textbf{Departure} = \textbf{Ch Long x Cos Latitude}$$

Explanatory notes:

- Insert change in longitute in minutes ('), one degree is 60 minutes
- Insert latitude in degrees (°)
- You will get departure in nautical miles (NM)

Example

What is the time required to travel along the parallel of latitude 60°N between meridians 010°E and 030°W at a groundspeed of 480 kts?

[Try to calculate this yourself, the solution is on the next page]

Solution:

1. ***To use the formula, we have to find the change in longitude. The first meridian is 010° east, the second one is 030° west. It's 10° degrees from the first meridian to Greenwich and then a further 30° from Greenwich to the second meridian. So it's a total 40° change in longitude.***

2. ***Now we have to convert the difference in longitude to minutes:***

$$Latitude\ (Minutes)\ =\ 60\ x\ Longitude\ (Degrees)$$

$$Latitude\ (Minutes)\ =\ 60\ x\ 40\ =\ 2400'$$

3. ***Then we substitute the numbers into the equation:***

$$Departure\ =\ Ch\ Long\ x\ Cos\ Latitude$$

$$Departure\ =\ 2400'\ x\ Cos\ 60^{\circ}\ =\ 2400'\ x\ 0.5\ =\ 1200\ NM$$

4. ***To calculate time, we simply divide the distance by speed:***

$$Time\ =\ \frac{Distance}{Speed}$$

$$Time\ =\ \frac{1200\ NM}{480\ kts}\ =\ 2.5\ hrs$$

Answer: The time required to travel is **2.5 hrs**.

7. Departure: Change with Latitude (Mercator)

Description: Departure in navigation can be defined as the East/West distance along a parallel of latitude. The formula can be used to calculate a change in distance represented by a given length on a direct Mercator chart with change in latitude on the chart. It also works in reverse to calculate the change in latitude on the chart with a known change in distance.

Formula:

$$\frac{Departure_A}{Departure_B} = \frac{Cos\ Latitude_A}{Cos\ Latitude_B}$$

Explanatory notes:

- Insert departure in nautical miles (NM)
- Insert latitude in degrees (°), it does not matter, if the latitude is north or south
- You will get new departure in nautical miles (NM) or new latitude in degress (°)

Example

On a direct Mercator chart at latitude 15°S, a certain length represents a distance of 120 NM on the Earth. The same length on the chart will represent on the Earth, at latitude 10°N, a distance of:

[Try to calculate this yourself, the solution is on the next page]

Solution:

1. ***For our calculation, we assume 120 NM = $Departure_A$ and 15°S = $Latitude_A$. If you perform the same calculation and substitute the numbers as $Departure_B$ and $Latitude_B$, you will get the same result.***

2. ***We substitute the numbers into the equation:***

$$\frac{Departure_A}{Departure_B} = \frac{Cos\ Latitude_A}{Cos\ Latitude_B}$$

$$\frac{120}{Departure_B} = \frac{Cos\ 15^\circ}{Cos\ 10^\circ}$$

$$\frac{120}{Departure_B} = \frac{0.9659}{0.9848}$$

$$\frac{120}{Departure_B} = 0.9808$$

3. ***Now we basically multiply both sides of the equation by $Departure_B$ to separate the variable:***

$$120 = 0.9808\ x\ Departure_B$$

$$Departure_B = 122.34\ NM$$

Answer: The same length will represent **122.34 NM**.

8. Scale: Representative Fraction

Description: Scale is the relationship between the distance on a chart and the same distance on the corresponding surface of the Earth. The formula is used to calculate the scale of any chart knowing the distances.

Formula:

$$Scale = \frac{Earth\ Distance}{Chart\ Length}$$

Explanatory notes:

- Insert earth distance in centimeters (cm)
- Insert chart length in centimeters (cm)
- You will get scale in representative fraction (dimensionless)

Example

On a direct Mercator projection, the distance measured between two meridians spaced 5° apart at latitude 60°N is 8 cm. The scale of this chart at latitude 60°N is approximately:

[Try to calculate this yourself, the solution is on the next page]

Solution:

1. ***We know that the distance between two meridians spaced 5° apart at latitude 60°N is 8 cm. So using the departure formula we can calculate the Earth distance in nautical miles:***

$$Departure = Ch\ Long\ x\ Cos\ Latitude$$

$$Departure = 300'\ x\ Cos\ 60^\circ = 300'\ x\ 0.5 = 150\ NM$$

2. ***Then we have to convert the nautical miles to centimetres:***

$$1\ NM = 1.852\ km$$

$$150\ NM = 150\ x\ 1.852 = 277.8\ km$$

$$1\ km = 100\ 000\ cm$$

$$277.8\ km = 277.8\ x\ 100\ 000 = 27\ 780\ 000\ cm$$

3. ***And we substitute the numbers into the equation:***

$$Scale = \frac{Earth\ Distance}{Chart\ Length}$$

$$Scale = \frac{27\ 780\ 000}{8} = 3\ 472\ 500\ (approx.\ 3\ 500\ 000)$$

Answer: The approximate scale of the chart is **1:3 500 000**.

9. Scale: Change with Latitude (Mercator)

Description: Scale is the relationship between the distance on a chart and the same distance on the corresponding surface of the Earth. The formula can be used to calculate a change in scale represented by a given length on a direct Mercator chart with change in latitude on the chart. It also works in reverse to calculate the change in latitude on the chart with a known change in scale.

Formula:

$$\frac{Scale_A}{Scale_B} = \frac{Cos\ Latitude_A}{Cos\ Latitude_B}$$

Explanatory notes:

- Insert the right side of the representative fraction of the scale (dimensionless)
- Insert latitude in degress (°)
- You will get a right side of the representative fraction of the new scale (dimensionless) or a new latitude in degress (°)

Example

On a direct Mercator projection, the distance between position A (17°N, 035°E) and position B (17°N, 040°E) is 5 cm. The scale at 57°N is approximately:

[Try to calculate this yourself, the solution is on the next page]

Solution:

1 ***There is no scale provided in the question, but we know the distance between position A (17°N, 035°E) and position B (17°N, 040°E) is 5 cm. So first we have to calculate the scale at given co-ordinates to calculate its change with latitude later on. To do this, we start with the departure formula to calculate the Earth distance:***

$$Departure \;=\; Ch\,Long \;\; x \;\; Cos\ Latitude$$

$$Departure \;=\; 300' \; x \;\; Cos\ 17^{\circ} \;=\; 300' \; x \;\; 0.9563 \;\;=\; 287\ NM$$

2 ***Then we have to convert the nautical miles to centimetres:***

$$287\ NM \;=\; 287 \;\; x \;\; 1.852 \;\; x \;\; 100\ 000 \;=\; 53\ 150\ 000\ cm$$

3 ***And we substitute the numbers into the equation to calculate the first scale:***

$$Scale \;=\; \frac{Earth\ Distance}{Chart\ Length}$$

$$Scale \;=\; \frac{53\ 150\ 000}{5} \;=\; 10\ 630\ 000$$

4 ***Now we have all the numbers to calculate the change in scale with latitude:***

$$\frac{Scale_{\,A}}{Scale_{\,B}} = \frac{Cos\ Latitude_{\,A}}{Cos\ Latitude_{\,B}}$$

$$\frac{10\ 630\ 000}{Scale_{\,B}} = \frac{Cos\ 17^{\circ}}{Cos\ 57^{\circ}}$$

$$\frac{10\ 630\ 000}{Scale_{\,B}} = \frac{0.9563}{0.5446}$$

$$\frac{10\ 630\ 000}{Scale_{\,B}} = 1.75$$

5 ***Now we basically multiply both sides of the equation by $Scale_B$ to separate the variable:***

$$10\,630\,000 = 1.75\ x\ Scale_B$$

$$Scale_B = 6\,074\,285$$

Answer: The scale at 57°N is approximately **1:6 074 285**.

10. Rate of Descent

Description: The rate of descent is an aircraft's vertical speed, which is a negative rate of altitude change with respect to time. It is usually expressed in feet per minutes.

Formula:

$$Rate\ of\ Descent\ =\ Gradient\ x\ GS$$

Explanatory notes:

- Insert gradient (slope) in percentage (%)
- Insert ground speed in knots (kts)
- You will get the rate of descent in feet per minutes (ft/min.)

Example

An aircraft is descending down a 6% slope whilst maintaining a GS of 300 kts. The rate of descent of the aircraft is approximately:

[Try to calculate this yourself, the solution is on the next page]

Solution:

1 ***We just substitute the numbers into the equation:***

$$Rate\ of\ Descent = Gradient\ x\ GS$$

$$Rate\ of\ Descent = 6\ x\ 300 = 1800\ ft/min.$$

Answer: The rate of descent of the aircraft is approximately **1800 ft/min**.

11. Climb / Descent Gradient

Description: The gradient is defined as the ratio of the increase or decrease of altitude to the horizontal air distance. The formula is used to calculate the gradient in percentage.

Formula:

$$Gradient = \frac{Altitude\ Difference\ x\ 100}{Ground\ Difference}$$

$$Gradient = \frac{Angle\ x\ 100}{60}$$

Explanatory notes:

- Insert altitude difference in feet (ft)
- Insert ground difference in feet (ft), assume 1 NM = 6080 ft
- Insert angle in degrees (°)
- You will get the gradient in percentage (%)

Example

An aircraft is maintaining a 5.2% gradient at 7 NM from the runway, on a flat terrain its height is approximately:

[Try to calculate this yourself, the solution is on the next page]

Solution:

1. ***First, we have to convert nautical miles to feet:***

$$1\ NM = 6\,080\ ft$$

$$7\ NM = 7\ x\ 6\,080 = 42\,560\ ft$$

2. ***Then we substitute the numbers into the equation:***

$$Gradient = \frac{Altitude\ Difference\ x\ 100}{Ground\ Difference}$$

$$5.2 = \frac{Altitude\ Difference\ x\ 100}{42\,560}$$

$$5.2 = \frac{Altitude\ Difference}{425.6}$$

3. ***To separate the variable, we multiply both sides of the equation by the denominator on the right side:***

$$5.2 = \frac{Altitude\ Difference}{425.6}$$

$$5.2\ x\ 425.6 = Altitude\ Difference$$

$$Altitude\ Difference = 2\,213.12\ ft$$

Answer: The aircraft height is approximately **2 213 ft**.

12. Crosswind

Description: Crosswind is the perpendicular component of the wind direction. The formula is used to calculate the crosswind relative to a runway / aircraft direction.

Formula:

$$\boldsymbol{Crosswind = Sin\,(Wind\ Angle)\ x\ Wind\ Speed}$$

Explanatory notes:

- Insert wing angle in degrees (°)
- Insert wind speed in knots (kts)
- You will get crosswind vaule in knots (kts)

Example

Given:

Runway direction: *305° (M)*
Surface W/V: *260° (M) / 30 kts*

Calculate the crosswind component.

[Try to calculate this yourself, the solution is on the next page]

Solution:

1 ***First, we have to calculate the wing angle:***

$$Wind\ Angle = Runway\ Direction - Wind\ Direction$$

$$Wind\ Angle = 305^\circ - 260^\circ = 45^\circ$$

2 ***Then we substitute the numbers into the equation:***

$$Crosswind = Sin\ (Wind\ Angle)\ x\ Wind\ Speed$$

$$Crosswind = Sin\ 45^\circ\ x\ 30 = 0.7071\ x\ 30 = 21.21\ kts$$

Answer: The crosswind component is **21 kts**.

13. Drift

Description: The angle between heading and track is called drift. It's always measured from heading to track. The formula is used to calculate the drift based on crosswind and true airspeed.

Formula:

$$Drift = \frac{Crosswind \ x \ 60}{TAS}$$

Explanatory notes:

- Insert crosswind component in knots (kts)
- Insert true airspeed in knots (kts)
- You will get drift angle in degrees (°)

Example

Given:

TAS: 230 kts
HDG: 250° (T)
W/V: 205° (T) / 10 kts

Calculate drift.

[Try to calculate this yourself, the solution is on the next page]

Solution:

1. ***There is no crosswind provided in the question, so first we have to calculate this. We start with the wing angle calculation:***

$$Wind\ Angle\ =\ Heading\ -\ Wind\ Direction$$

$$Wind\ Angle\ =\ 250^{\circ}\ -\ 205^{\circ}\ =\ 45^{\circ}$$

2. ***Then we calculate the crosswind component:***

$$Crosswind\ =\ Sin\ (Wind\ Angle)\ \ x\ \ Wind\ Speed$$

$$Crosswind\ =\ Sin\ 45^{\circ}\ \ x\ \ 10\ =\ 0.7071\ \ x\ \ 10\ =\ 7.071\ kts$$

3. ***Now we have all the numbers to proceed with the drift calculation:***

$$Drift\ =\ \frac{Crosswind\ \ x\ \ 60}{TAS}$$

$$Drift\ =\ \frac{7.071\ \ x\ \ 60}{230}\ =\ \frac{424.26}{230}\ =\ 1.84^{\circ}$$

4. ***To find out whether the drift is left or right, we have to realize that question states the heading, not the track. The heading is always into the wind, to keep the desired track. In our case the wind is from the left side (draw a picture), so the heading is to the left of the track. But drift is always measured from the heading to the track, so we have right (R) drift here.***

Answer: The drift is **1.84° R**.

14. Headwind

Description: Headwind is the head component of the wind direction. The formula is used to calculate the headwind relative to a runway / aircraft direction.

Formula:

$$\boldsymbol{Headwind = Cos\ (Wind\ Angle)\ \ x\ \ Wind\ Speed}$$

Explanatory notes:

- Insert wind angle in knots (kts)
- Insert wind speed in knots (kts)
- You will get headwind in knots (kts)
- Negative result (-) means tailwind

Example

Given:

Runway direction: 083° (M)
Surface W/V: 035/35 kts

Calculate the effective headwind component.

[Try to calculate this yourself, the solution is on the next page]

Solution:

1. ***First, we have to calculate the wing angle:***

$$Wind\ Angle\ =\ Runway\ Direction\ -\ Wind\ Direction$$

$$Wind\ Angle\ =\ 083^{\circ}\ -\ 035^{\circ}\ =\ 48^{\circ}$$

2. ***Then we substitute the numbers into the equation:***

$$Headwind\ =\ Cos\ (Wind\ Angle)\ \ x\ \ Wind\ Speed$$

$$Headwind\ =\ Cos\ 48^{\circ}\ x\ 35\ =\ 0.6691\ x\ 35\ =\ 23.41\ kts$$

Answer: The headwind component is **23.5 kts**.

General Navigation: Cheat Sheet

1. Track Angle Error

$$Track\ Error\ =\ \frac{Distance\ Off}{Distance\ Gone}\ x\ 60$$

2. Closing Angle

$$Closing\ Angle\ =\ \frac{Distance\ Off}{Distance\ to\ Go}\ x\ 60$$

3. Convergency (Earth)

$$Convergency\ =\ Ch\ Long\ \ x\ \ Sin\ Mean\ Latitude$$

4. Convergency (Lambert's Projection)

$$Convergency\ =\ Ch\ Long\ \ x\ \ Sin\ Parallel\ of\ Origin$$

5. Conversion Angle

$$Conversion\ Angle\ =\ \frac{Convergency}{2}$$

General Navigation: Cheat Sheet

6. Departure

$$Departure = Ch\ Long\ x\ Cos\ Latitude$$

7. Departure: Change with Latitude (Mercator)

$$\frac{Departure_A}{Departure_B} = \frac{Cos\ Latitude_A}{Cos\ Latitude_B}$$

8. Scale: Representative Fraction

$$Scale = \frac{Earth\ Distance}{Chart\ Length}$$

9. Scale: Change with Latitude (Mercator)

$$\frac{Scale_A}{Scale_B} = \frac{Cos\ Latitude_A}{Cos\ Latitude_B}$$

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$$Rate\ of\ Descent = Gradient\ x\ GS$$

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$$Gradient = \frac{Altitude\ Difference\ x\ 100}{Ground\ Difference}$$

$$Gradient = \frac{Angle\ x\ 100}{60}$$

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$$Crosswind = Sin\ (Wind\ Angle)\ x\ Wind\ Speed$$

13. Drift

$$Drift = \frac{Crosswind\ x\ 60}{TAS}$$

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