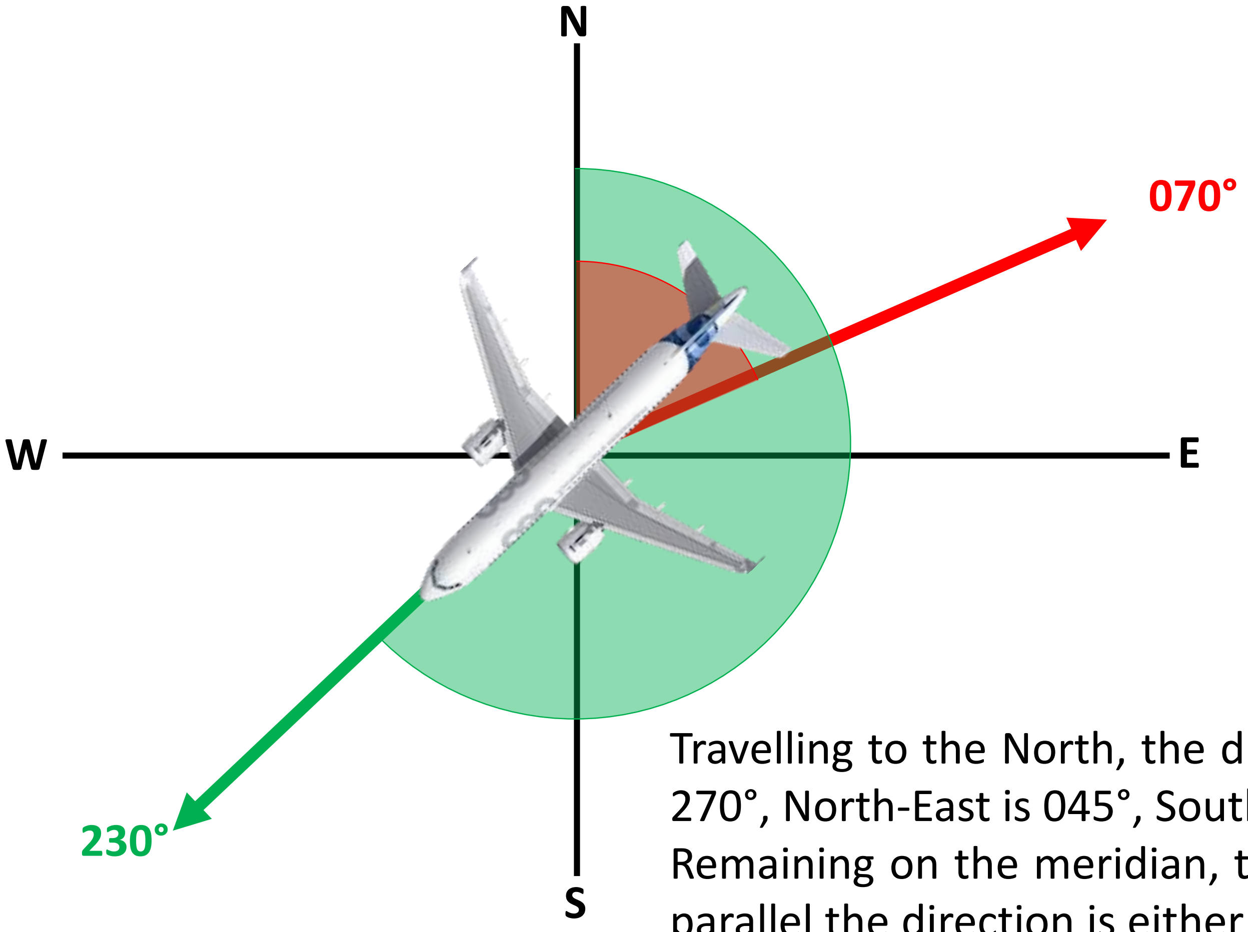
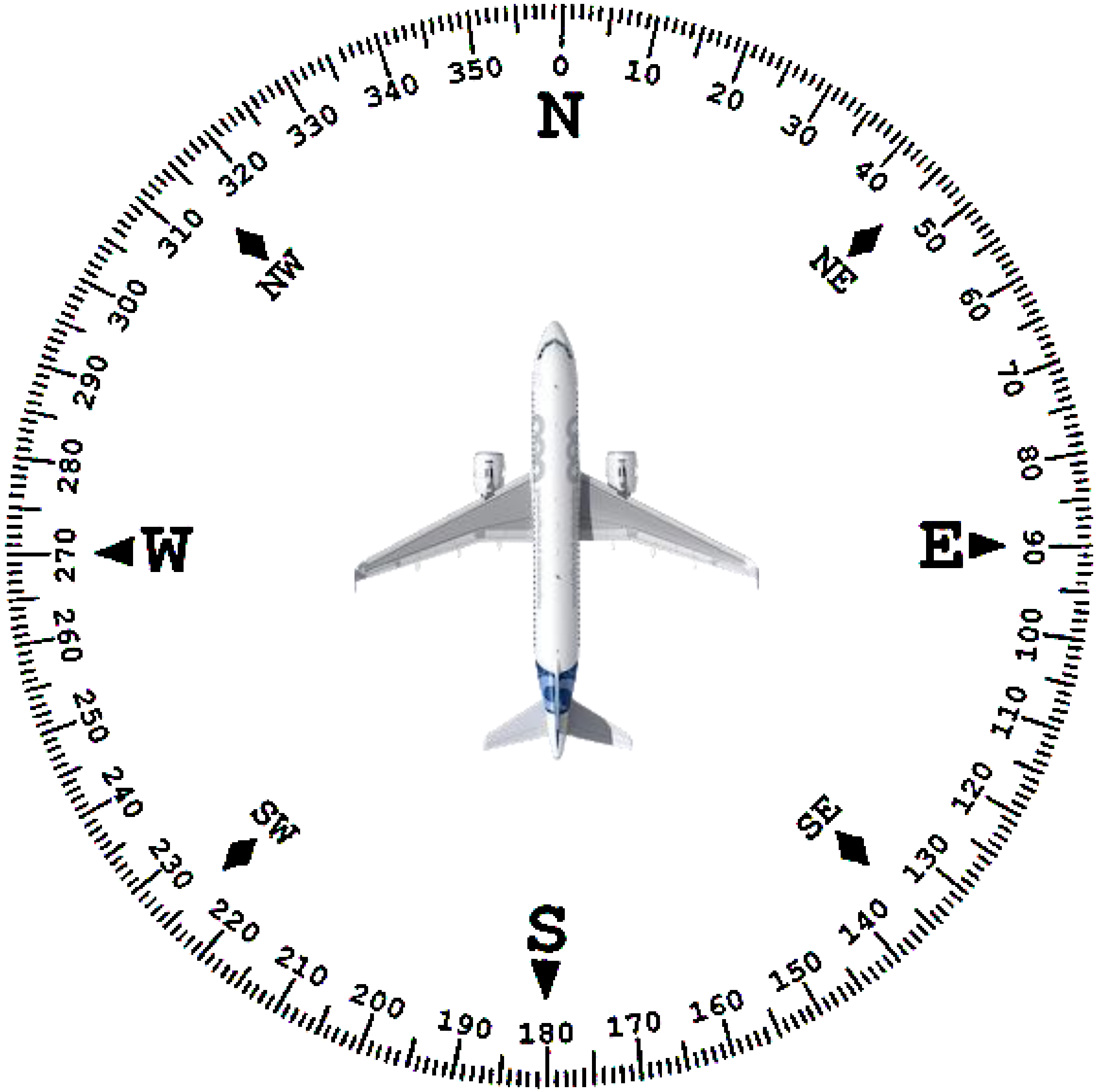
IV
MAGNETISM
& COMPASS

True Reference

It has been seen that the meridians connect the north to the south, and we can speak now about the direction.
A direction is always compared from the direction to the north, in other words, compared from the actual meridian on which you are. A direction is an angle measured clockwise from the North direction, and its value is comprised between 000° and 360°.





Travelling to the North, the direction is 360°, the East is 090°, the South is 180°, the West is 270°, North-East is 045°, South-East is 135°, South-West is 225°, and North-West is 315°
Remaining on the meridian, the direction is either North (360°) or South (180°), and on the parallel the direction is either East (090°) or West (270°).

When the direction are measured from the direction to North Pole (90°N), they are « true » direction.

Indeed the North Pole is the « real » North and the directions are therefore the « real » direction

The North Pole is called the **True North (TN)** or sometimes called **Geographic North**, so when we measure a direction from the direction to the North Pole, we measure True directions or Geographic directions, we speak about:

True Route (TR)*, **True Track (TT)** or **True Course (TC)***
Angle measured clockwise from the True North to flight path over the Earth surface.

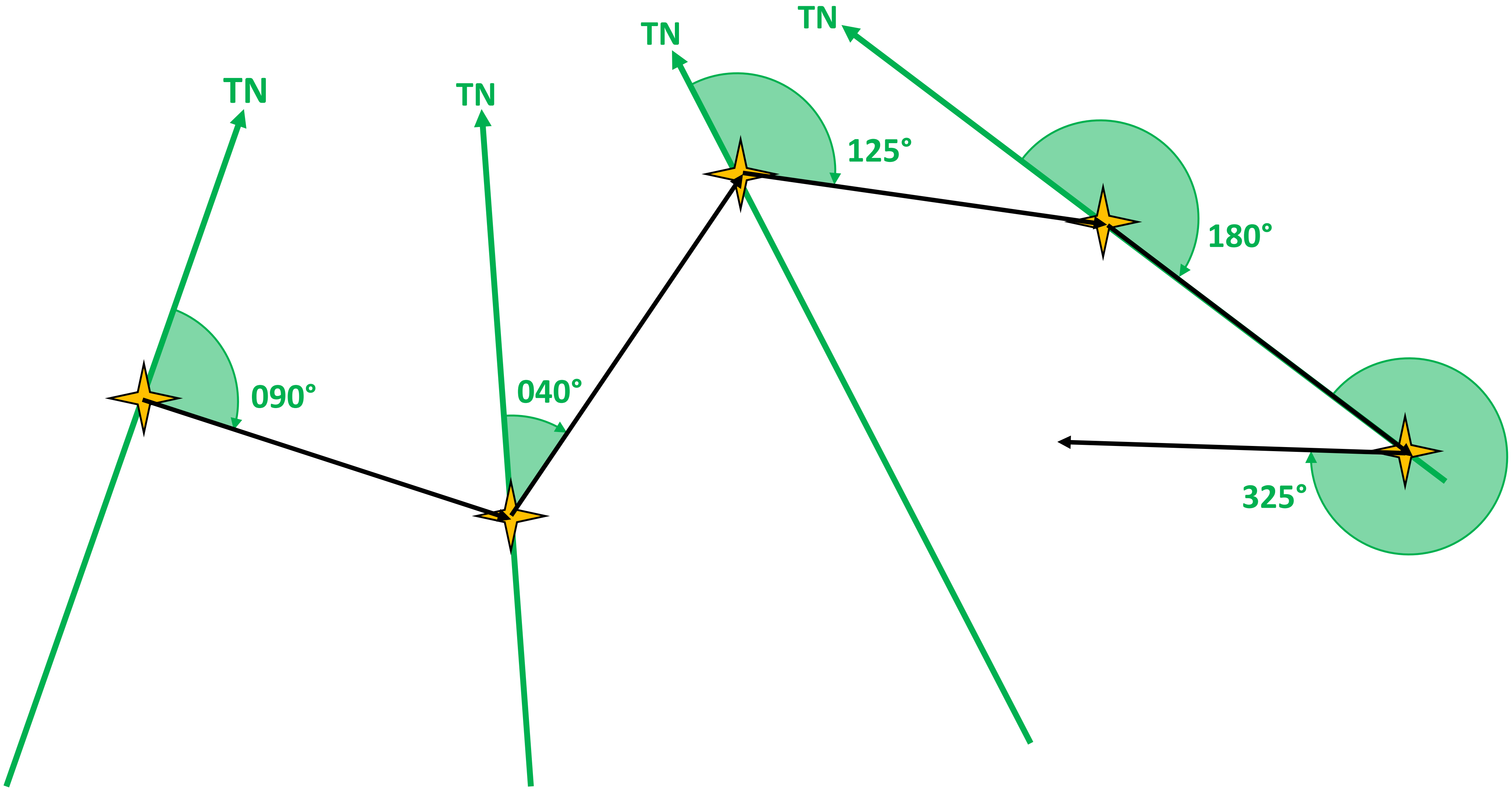
True Heading (TH)
Angle measured clockwise from the True North to the aircraft's longitudinal axis

True Wind
Wind direction expressed in angle measured clockwise from the True North

Etc….

We need to make this precision because later we will see that a direction can be measured from other references

Examples of initial true routes at different points

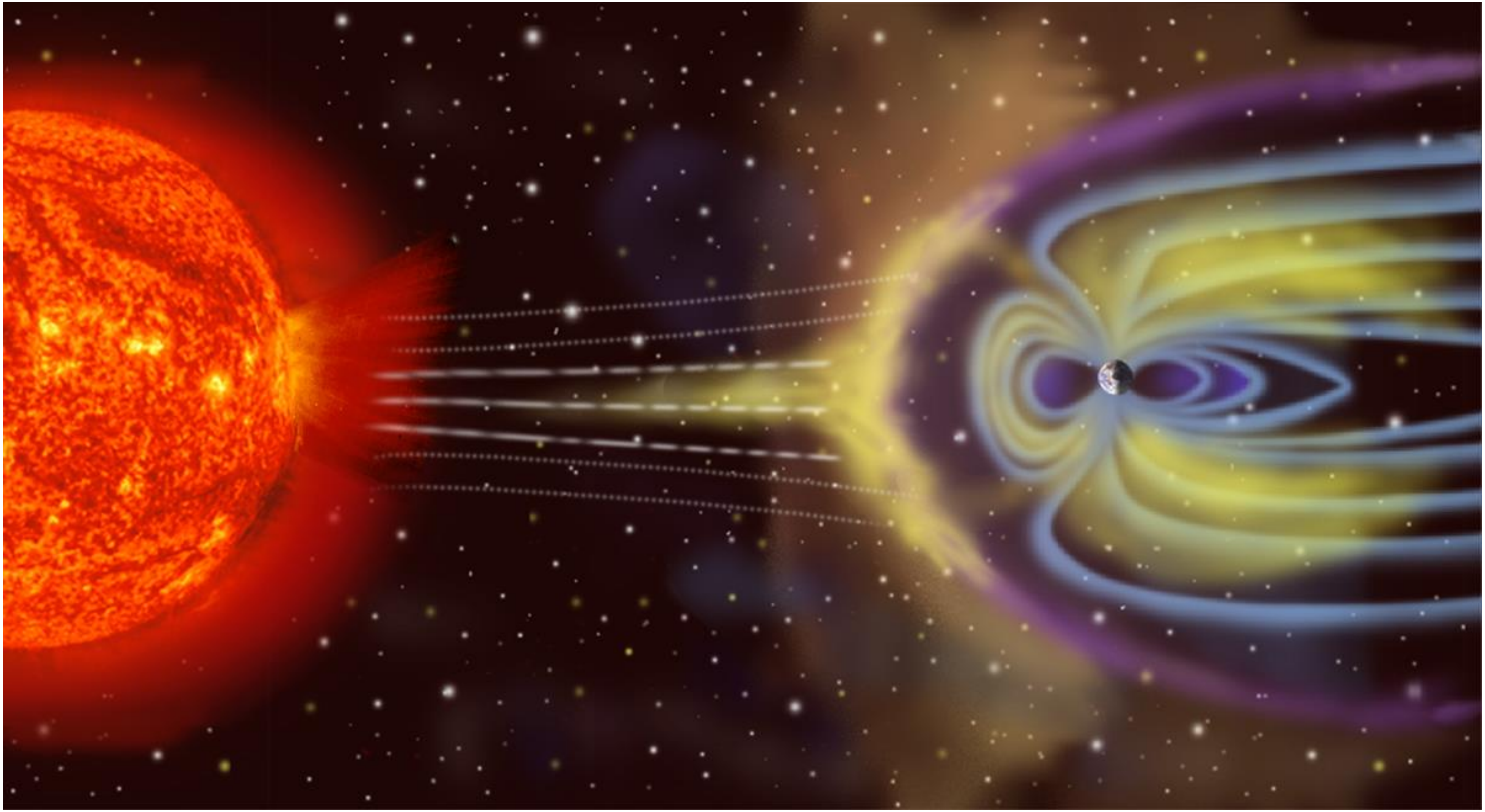


Magnetic Reference

On the map or on the chart, to measure a direction we simply need to find the meridian and plot (measuring the angle clockwise from TN to that direction).

However while navigating (here in flight), to find the direction (route, heading, wind, etc), we simply need to find the North Pole direction. Unfortunately there's no conventional or basic instrument to « detect » or indicate the TN.

One way to measure a direction is to use the Earth's Magnetic Field. The geological activity and the chemical reactions inside of our Earth generate an electromagnetic field that runs from a positive magnetic pole (+) to a negative magnetic pole. (-)
It's because of this Magnetic Field around our Earth that our atmosphere is still preserved and protected from the Solar Eruptions (that can be seen as Northern or Southern lights)

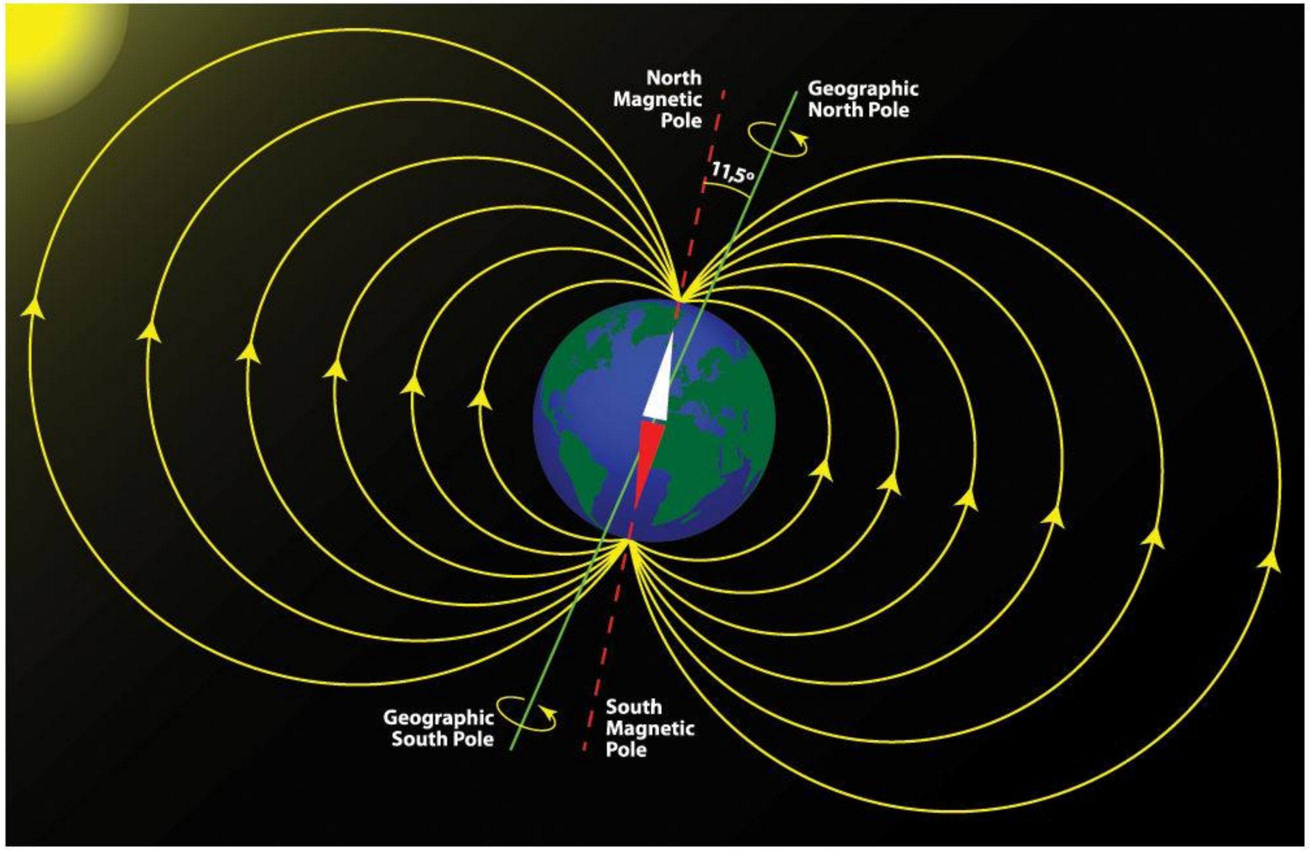


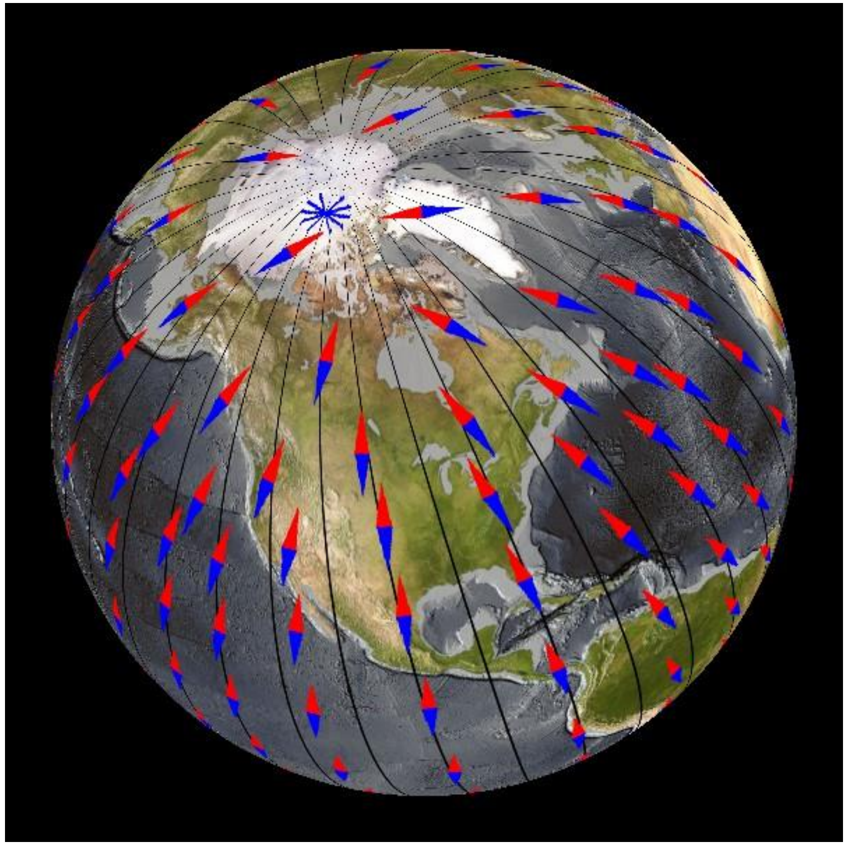
So to detect the Magnetic field, we simply need to suspend a ferrous material and leave it to rotate freely to be aligned by the Earth's Magnetic Field.

This instrument is called a **magnetic compass** or **Direct Reading Compass (DRC)**, which consists of a 360° rose graduated and a magnetic needle suspended and rotating freely in a swirl liquid which damps out the oscilliations.

However, the Earth's Magnetic Field **doesn't run** from the Earth's South Pole to the Earth's North Pole.

Indeed, the axis of the « magnet » isn't aligned with the Earth's polar axis. This means that magnetic compass won't show the direction of the TN, **but shows the direction of the Magnetic North (MN)** *[It's actually showing the direction of the Magnetic negative pole (-) however by conveniency and since it's « close » to the True North, the negative magnetic pole (-) is labelled magnetic North and the positive magnetic pole (+) labelled magnetic South]*

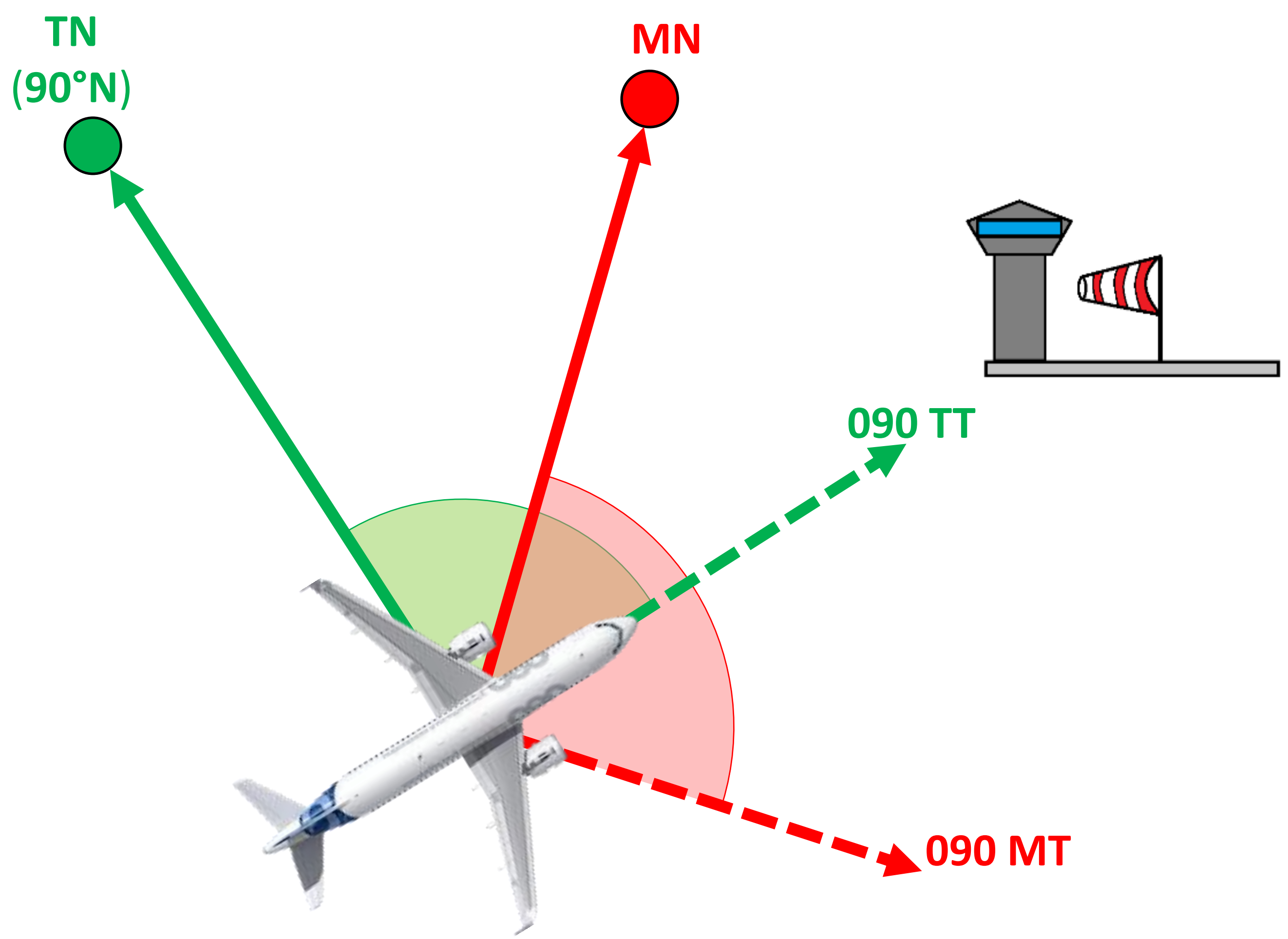




So since the DRC uses as reference the **Magnetic North (MN)**, so if the pilot desires to fly a True Track (TT) of 090°, by maintaining an angle of 090° according to the magnetic compass, the pilot won’t fly on the disered track and eventually will be lost.

He in this case, the True Track is 090°TT, it’s the REAL track. The 090° that the pilot reads on the magnetic compass is 090° Magnetic Track (090°MT).

So the pilot must do something in order to maintain 090°TT (which is not the same as 090°MT)



L	R
W	E
-	+

Declination or Variation (V)

Angle between the TN and the MN

When MN is East or "right" of TN, **V** is said **East** or **Positive (+)**

When MN is West or "left" of TN, **V** is said **West** or **Negative (-)**

The angle of **V** can vary **between 0° and 180°**

Magnetic declination varies both from place to place and with the passage of time. **The magnetic declination** in a given area may (most likely will) **change slowly over time**, possibly as little as **2–2.5 degrees every hundred years** or so, depending upon how far from the magnetic poles it is. For a location closer to the pole like Ivujivik (Canada), the declination may change by 1 degree every three years

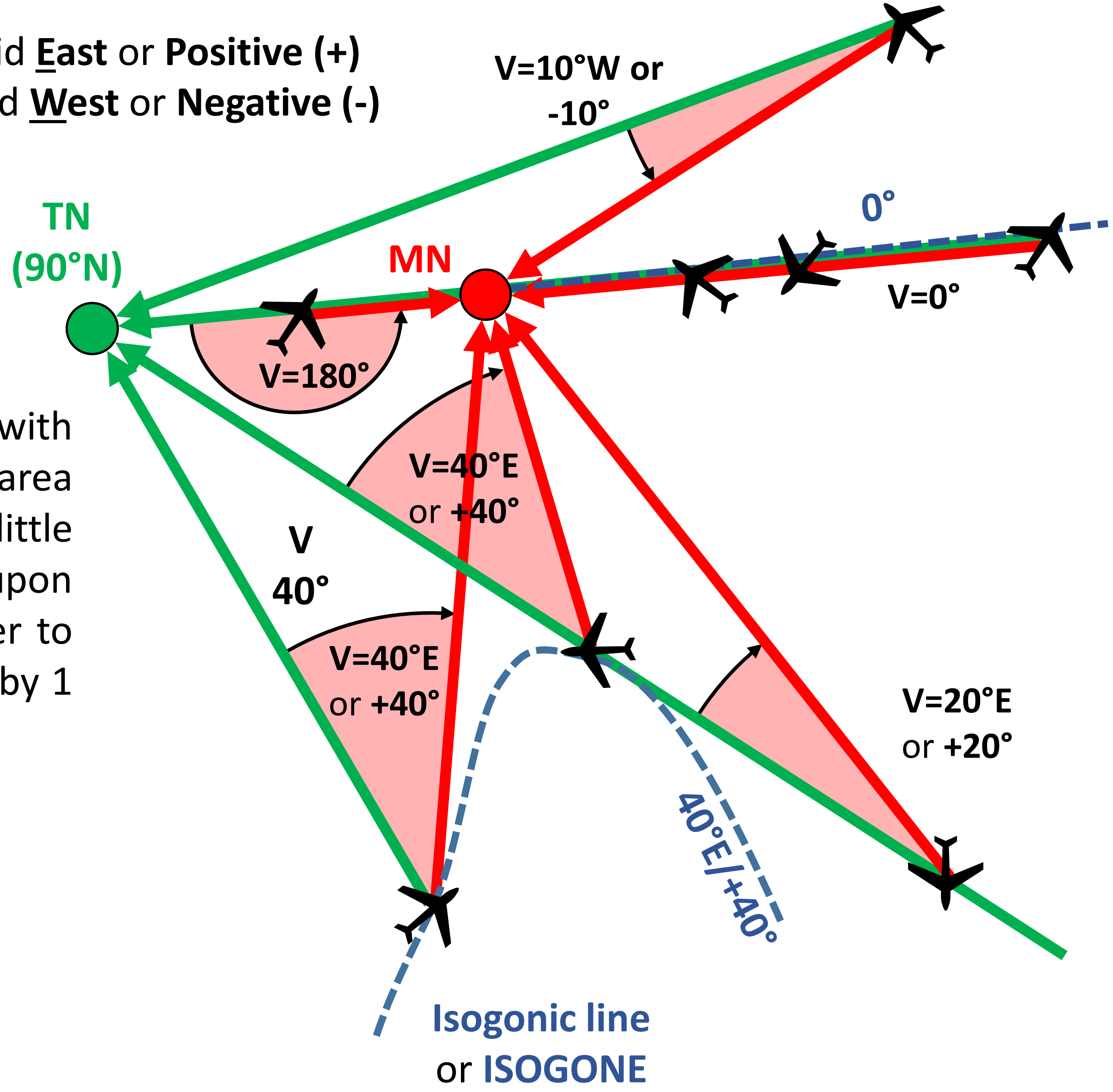
Isogonic line or **ISOGONE**

Line connecting area of equal or same V

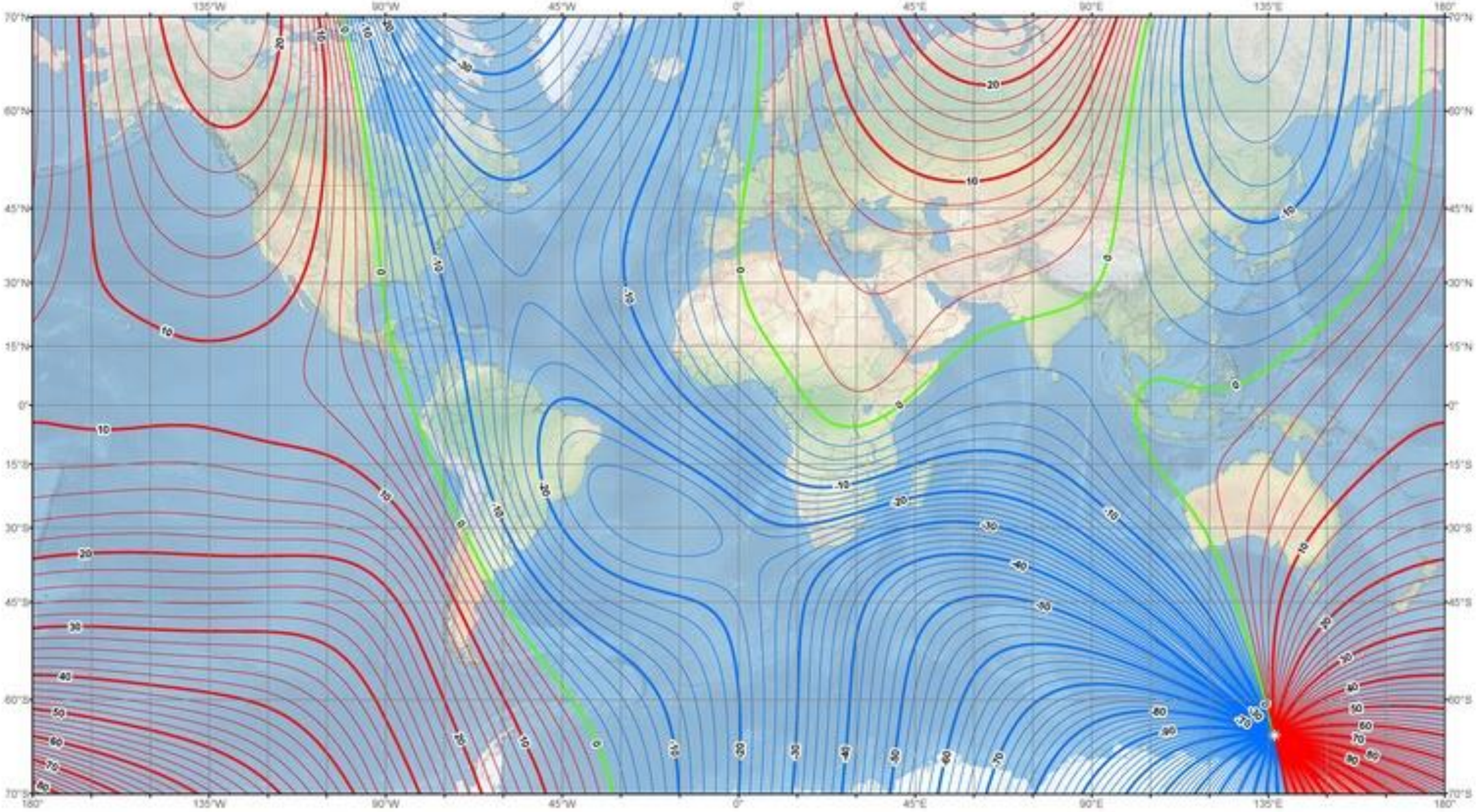
Agone

Isogone of zero degree Variation (or Declination)

Isogone of V=0°



US/UK World Magnetic Model - Epoch 2015.0
Main Field Declination (D)

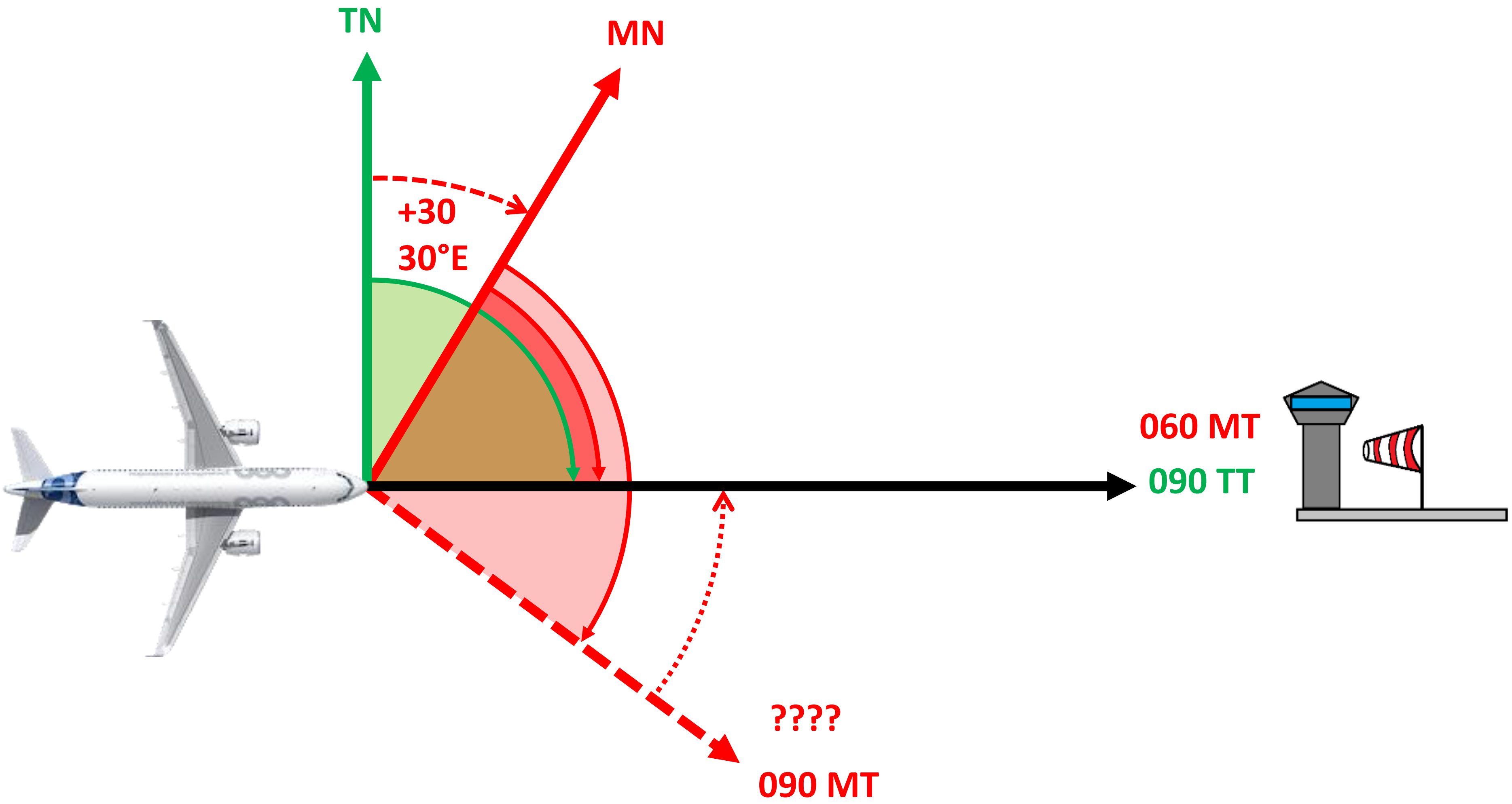


Main field declination (D)
Contour interval: 2 degrees, red contours positive (east); blue negative (west); green (agonic) zero line.
Mercator Projection.
: Position of dip poles

Map developed by NOAA/NGDC & CIRES
http://ngdc.noaa.gov/geomag/WMM
Map reviewed by NGA and BGS
Published December 2014

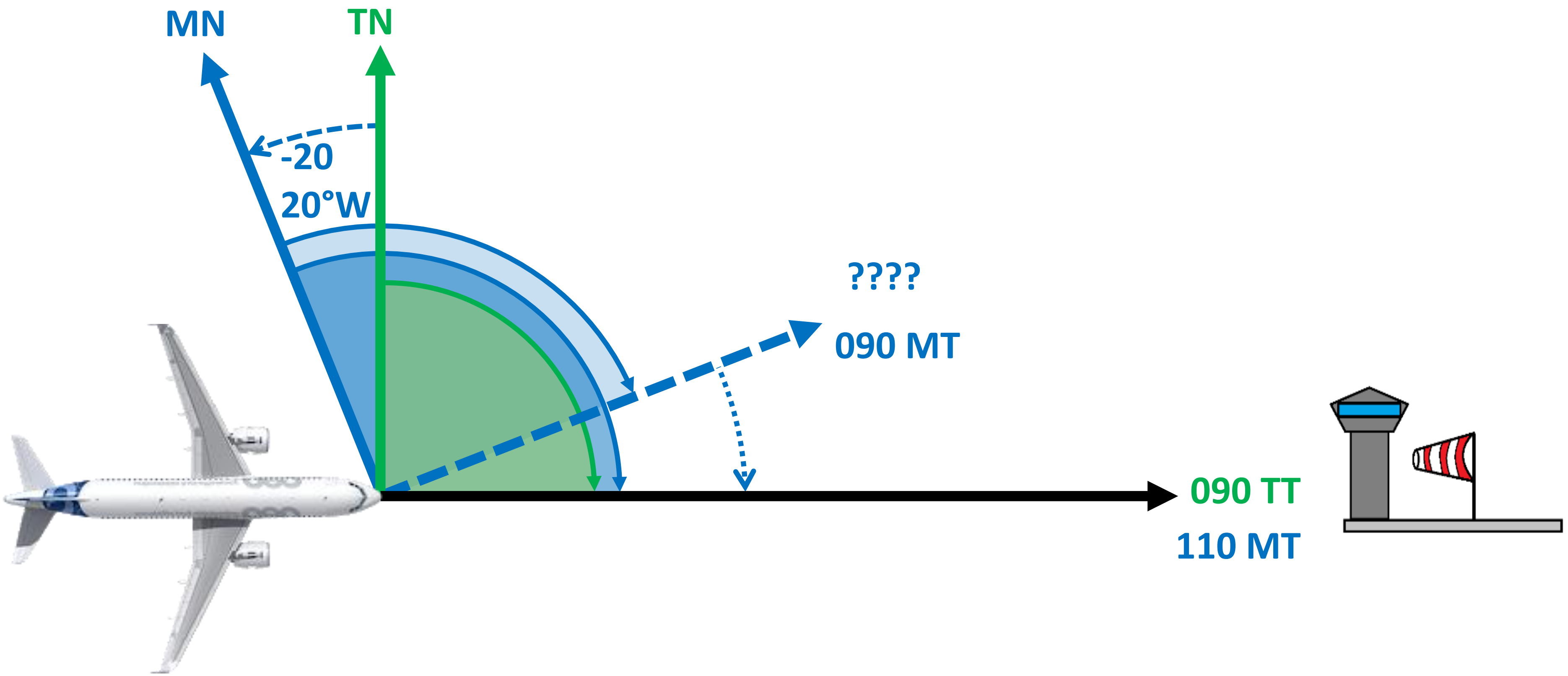
TT - V = MT

090 - (+30) = 060



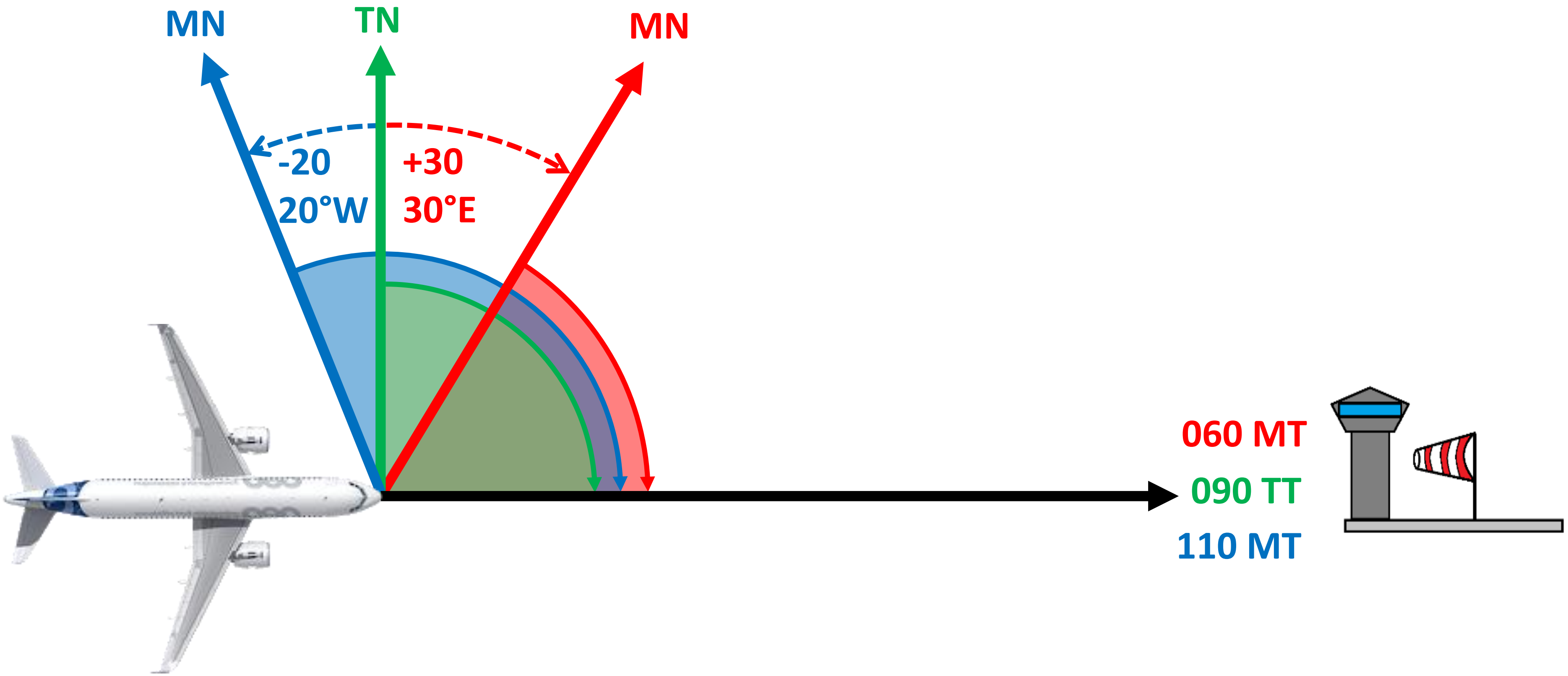
TT - V = MT

090 - (-20) = 110



TT - V = MT
090 - (+30) = 060

TT - V = MT
090 - (-20) = 110



M = T – V

T = M + V

V = T - M

REVIEW

Declination or Variation (V)
Angle between the TN and the MN

When MN is East or “right” of TN, **V** is said **East** or **Positive (+)**

When MN is West or “left” of TN, **V** is said **West** or **Negative (-)**

The angle of **V** can vary **between 0° and 180°**

Magnetic declination varies both from place to place and with the passage of time.

Isogonic line or **ISOGONE**
Line connecting area of equal or same V

Agone
Isogone of zero degree Variation (or Declination)
Isogone of V=0°

M = T – V

Q) What is the MT if TT is 320° and the local variation is 18°W?

A) MT = TT – V = 320 – (-18) = **338°**

T = M + V

Q) What is the TT if MT is 355° and the local variation is (+33°)?

A) TT = MT + V = 355 + (+33) = **388°**
→ **028°**

V = T – M

Q) What is the local variation if TT is 138° and the MT is 153°?

A) V = TT – MT = 138 – 153 = **-15°**
→ **15°W**

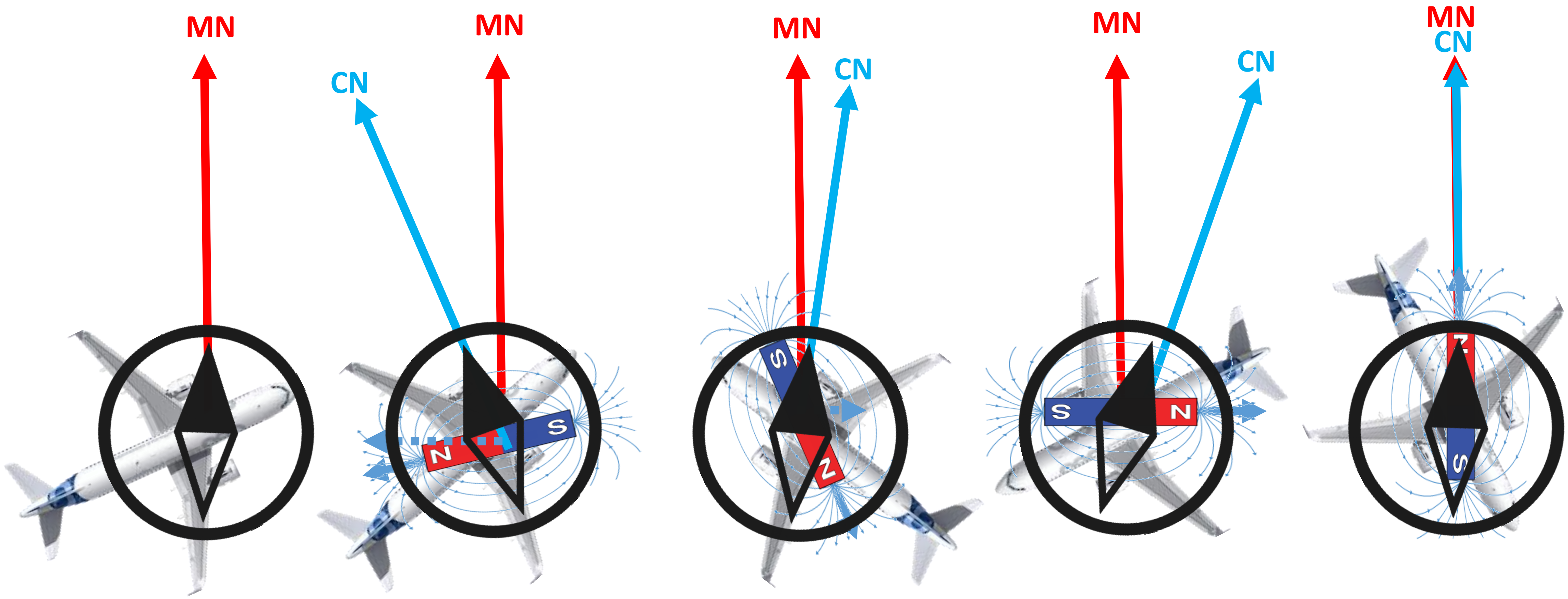
Compass Reference

Normally the red pointer of the DRC should point toward the MN

However the aircraft equipment (radio instruments, electrical equipment, etc) are generating their own electromagnetic field acting in one direction, relative to the aircraft longitudinal axis.

Based on the aircraft orientation in space (heading), this local electromagnetic field will be exerted on the DRC, making it **deviating** from showing the MN, by an amount which depends on the component perpendicular to the Earth's magnetic field.

The DRC will therefore show something else than the MN, it will show its own North, called the **Compass North (CN)**



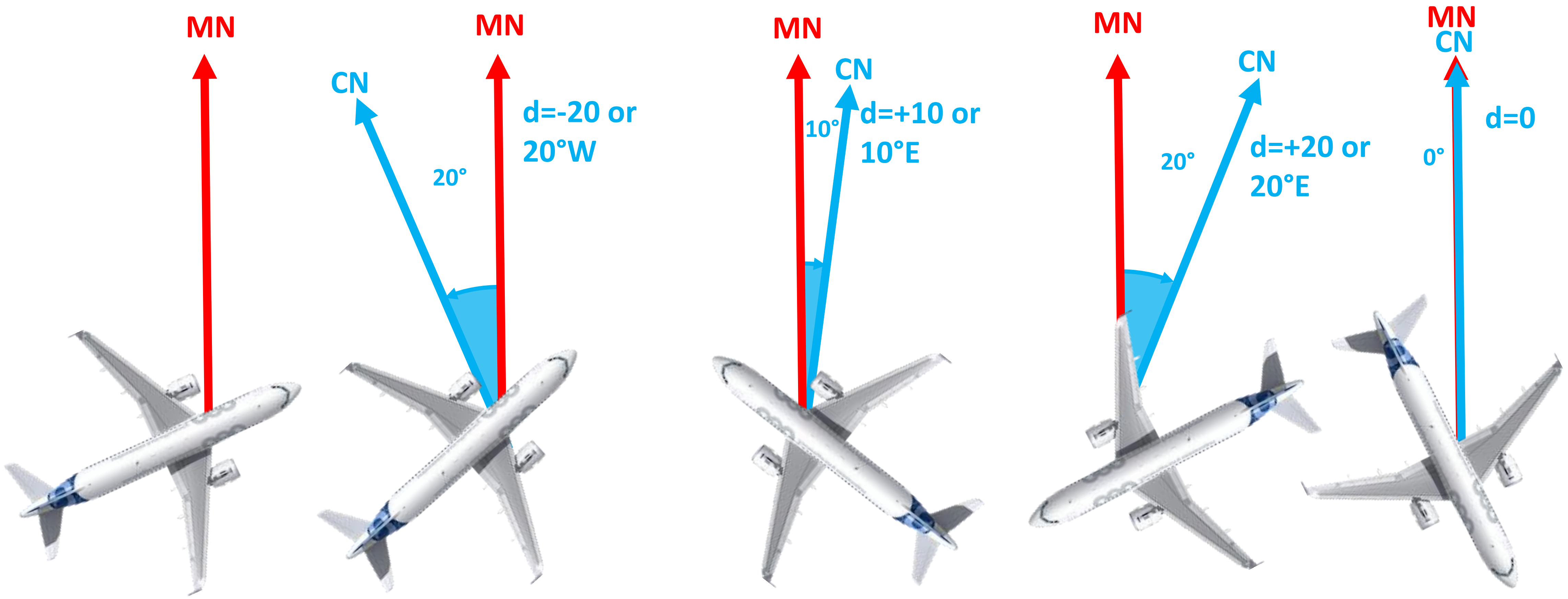
L	R
W	E
-	+

Deviation (d)

Angle between the MN and the CN

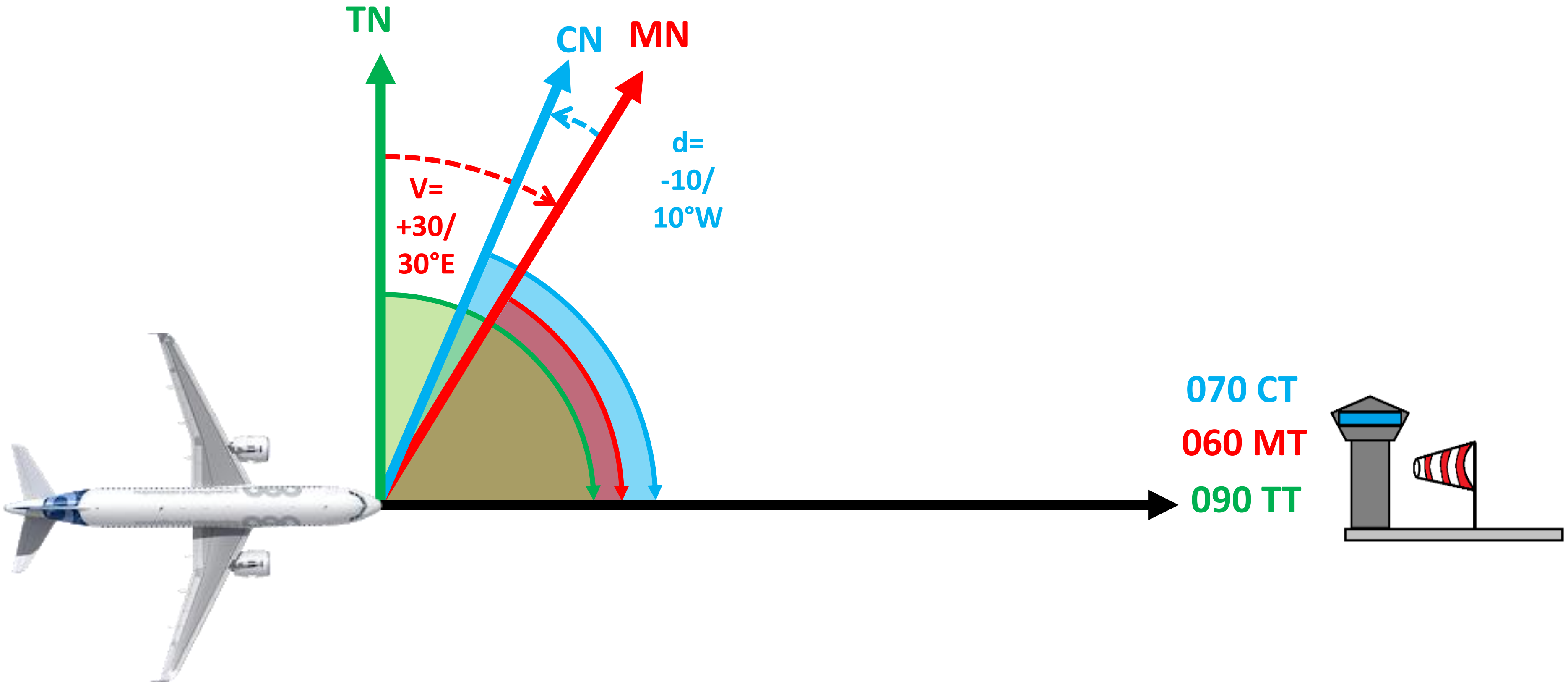
When CN is East or "right" of MN, **d** is said **E**ast or **Positive (+)**

When CN is West or "left" of MN, **d** is said **W**est or **Negative (-)**



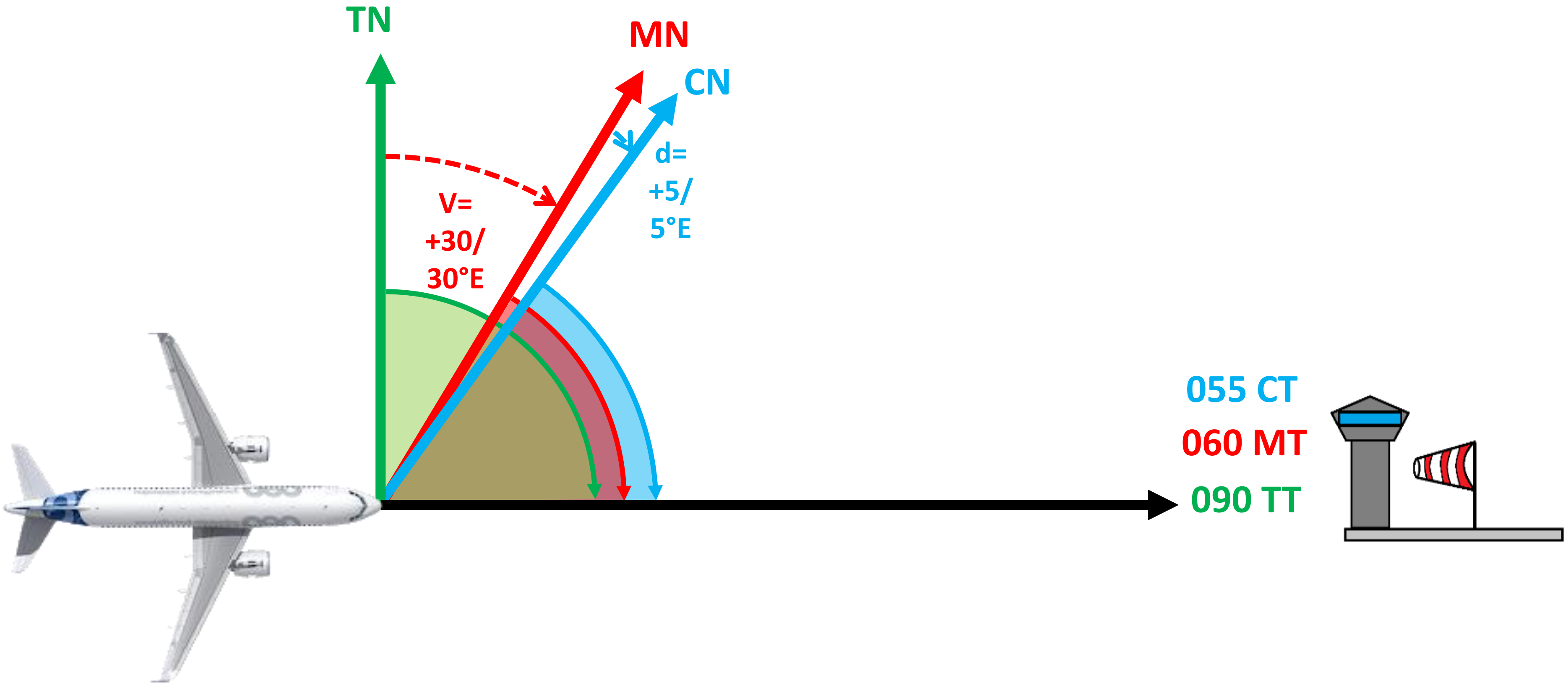
MT - d = CT

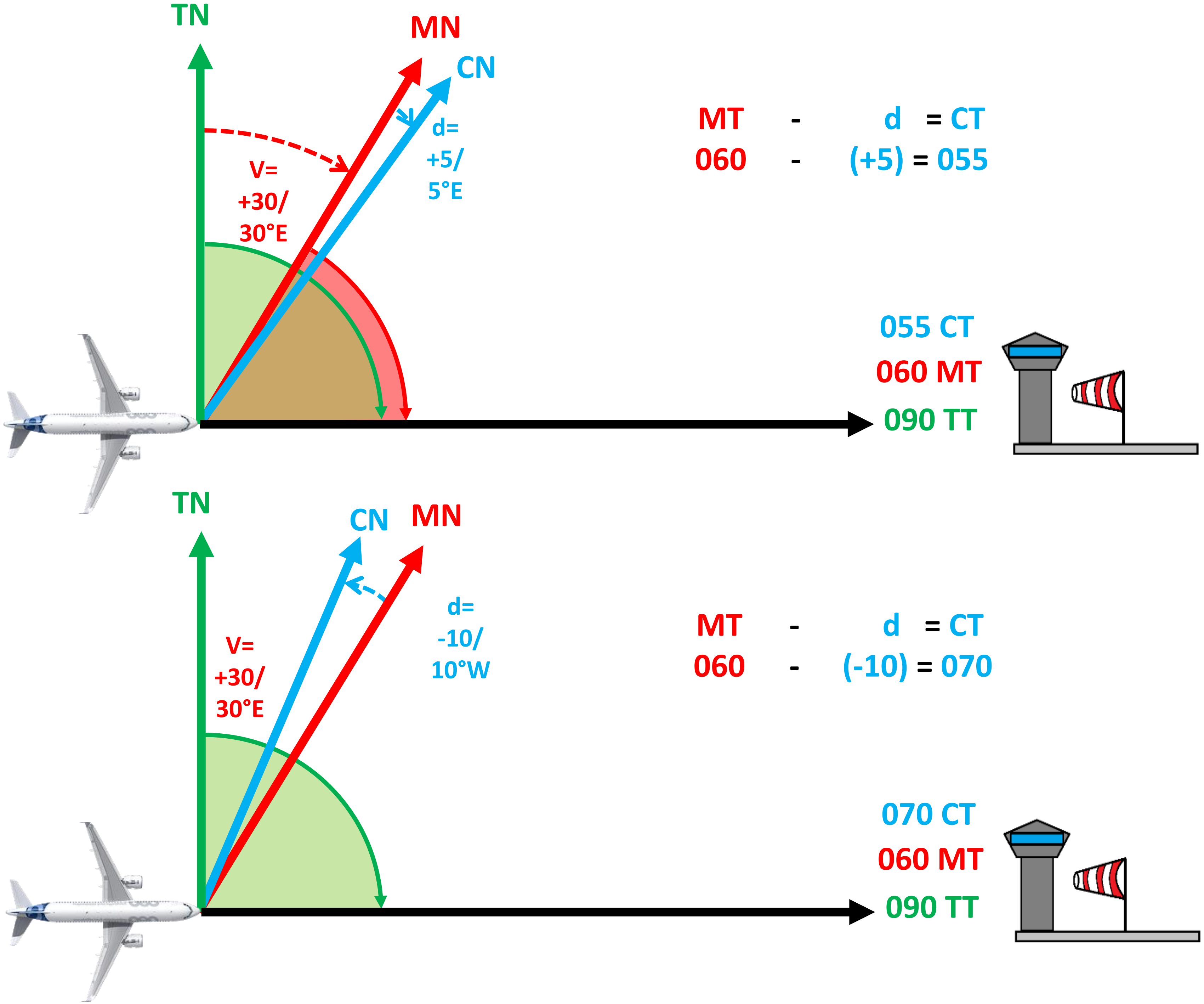
060 - (-10) = 070



MT - d = CT

060 - (+5) = 055




TN
MN
CN
d=
+5/
5°E
V=
+30/
30°E
MT - d = CT
060 - (+5) = 055
055 CT
060 MT
090 TT
TN
CN
MN
d=
-10/
10°W
V=
+30/
30°E
MT - d = CT
060 - (-10) = 070
070 CT
060 MT
090 TT

$$C = M - d$$

$$M = C + d$$

$$d = M - C$$

Exercise

→	-	→	-	→
T	V	M	d	C
←	+	←	+	←
065	-13			075
248		236	-2	
	+15	358		002/362

TT = 065 MT=?
V= 13°W d=?
CT= 075

TT = 248 CT=?
MT = 236 V=?
d= -2°

MT= 358 TT=?
V= +15° d=?
CT= 002

The correction is in the next pages…

Exercise ***(corrected)***

→	-	→	-	→
T	V	M	d	C
←	+	←	+	←
065	-13	078	+3	075
248	+12	236	-2	238
373/013	+15	358	-4	002/362

TT = 065 MT= 078
V= 13°W d= 3°E
CT= 075

TT = 248 CT= 238
MT = 236 V= 12°E
d= -2°

MT= 358 TT= 013
V= +15° d= 4°W
CT= 002

Compass Swing

Aim of compass swing

a) To observe and determine the deviation between the MN and CN on a series of heading (any heading)
b) To correct and remove as much deviation as possible
c) To correct the residual deviation which is left after the compass has been adjusted

MAXIMUM DEVIATION +/- 5° FOR PRIMARY COMPASS OR +/- 10° SECONDARY COMPASS (eg. If the magnetic heading is 043, the compass shall not show less than 033 or more than 053, otherwise the flight is not allowed to be conducted.)

Compass swing shall be conducted

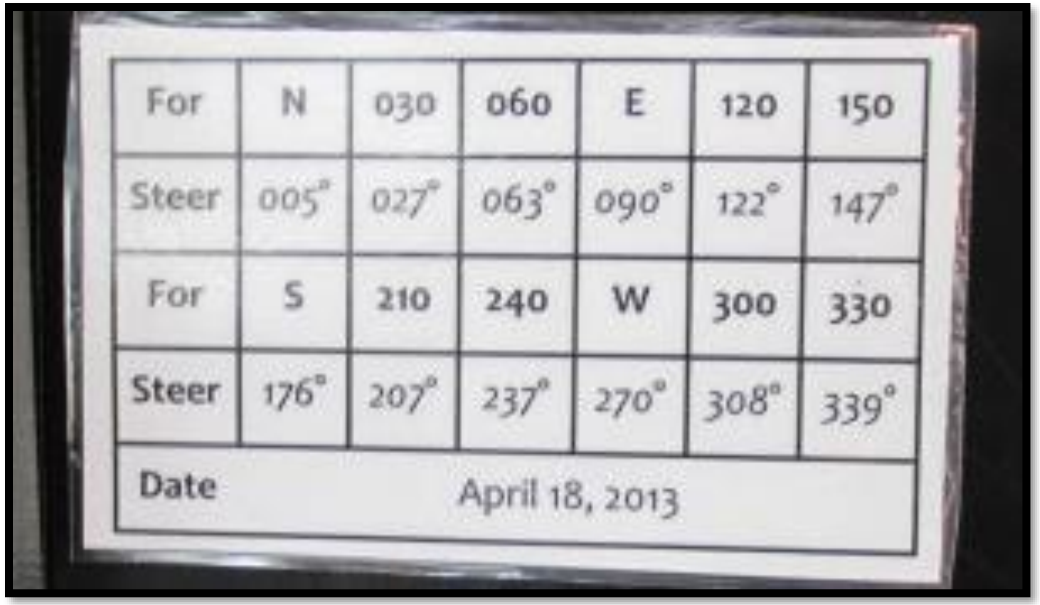
1) When the compass components are installed or replaced
2) Whenever accuracy of the compass is in doubt
3) After a maintenance inspection, if required
4) After significant aircraft modification, repair or replacement involving magnetic material
5) When carrying unusual ferromagnetic payload
6) When the compass has been subjected to significant shocks (HAMMERING)
7) After the aircraft has been given a new location to operate if the move involves a large change of magnetic latitude
8) If the aircraft has been parked in long term storage on a single heading
9) In the event of lightning strike
10) After a significant modification to the aircraft radio and electrical system

Compass Deviation Card

The deviations are tabulated in compass deviation card, a table which is usually in the vicinity of the compass

For	N	30	60	E	120	150
Steer	-1	+1	0	-1	+1	-1
For	S	210	240	W	300	330
Steer	-1	+1	-1	W	-1	+1

Date ... AIRPATH

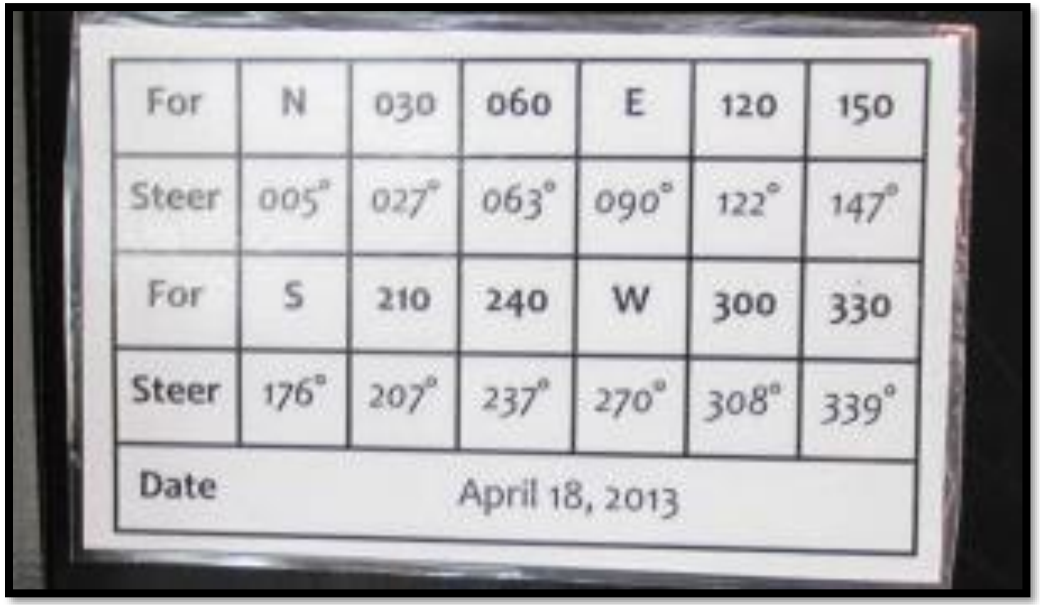


For	N	030	060	E	120	150
Steer	005°	027°	063°	090°	122°	147°
For	S	210	240	W	300	330
Steer	176°	207°	237°	270°	308°	339°
Date	April 18, 2013					

Compass Deviation Card

For	N	30	60	E	120	150
Steer	-1	+1	0	-1	+1	-1
For	S	210	240	W	300	330
Steer	-1	+1	-1	W	-1	+1

Date AIRPATH



For	N	030	060	E	120	150
Steer	005°	027°	063°	090°	122°	147°
For	S	210	240	W	300	330
Steer	176°	207°	237°	270°	308°	339°
Date	April 18, 2013					

In this table, it says how much to correct the MH to obtain CH.
Eg: In order to fly MH=0120, the pilot shall apply (+1) to obtain a CH=121

Remark: the deviation is -1/1°W

For other MH which are not written, the pilot can make interpolation or apply the correction to the closest one

Eg. For MH=135, by interpolation between 120 and 150, (steer -1°/Heading +15) **CH=135**

Eg. For MH=125, by choosing the closest STEER which is +1, **CH=126**

For	120	135	150
Steer	+1	0	-1

In this table, it says where to correct from the MH to obtain CH.
Eg: In order to fly MH=060, the pilot shall directly fly 063, so CH=063

Remark: the deviation is -3/3°W

For other MH which are not written, the pilot can make interpolation or apply the correction to the closest one

Eg. For MH=035, by interpolation between 030 and 060, (steer +1°/Heading +5) **CH=034**

Eg. For MH=032, by choosing the closest STEER which is -3, **CH=029**

For	030	35	060
Steer	027	34	063

Compass Error

Direct Reading Compass (DRC)

The benefit of **the DRC**, is that it **doesn’t require any power supply from the aircraft**, indeed it is aligned thanks to Earth’s Magnetic Field (and if the Earth’s Magnetic Field disappears, do not worry about the DRC, it will be the latest of your problems)

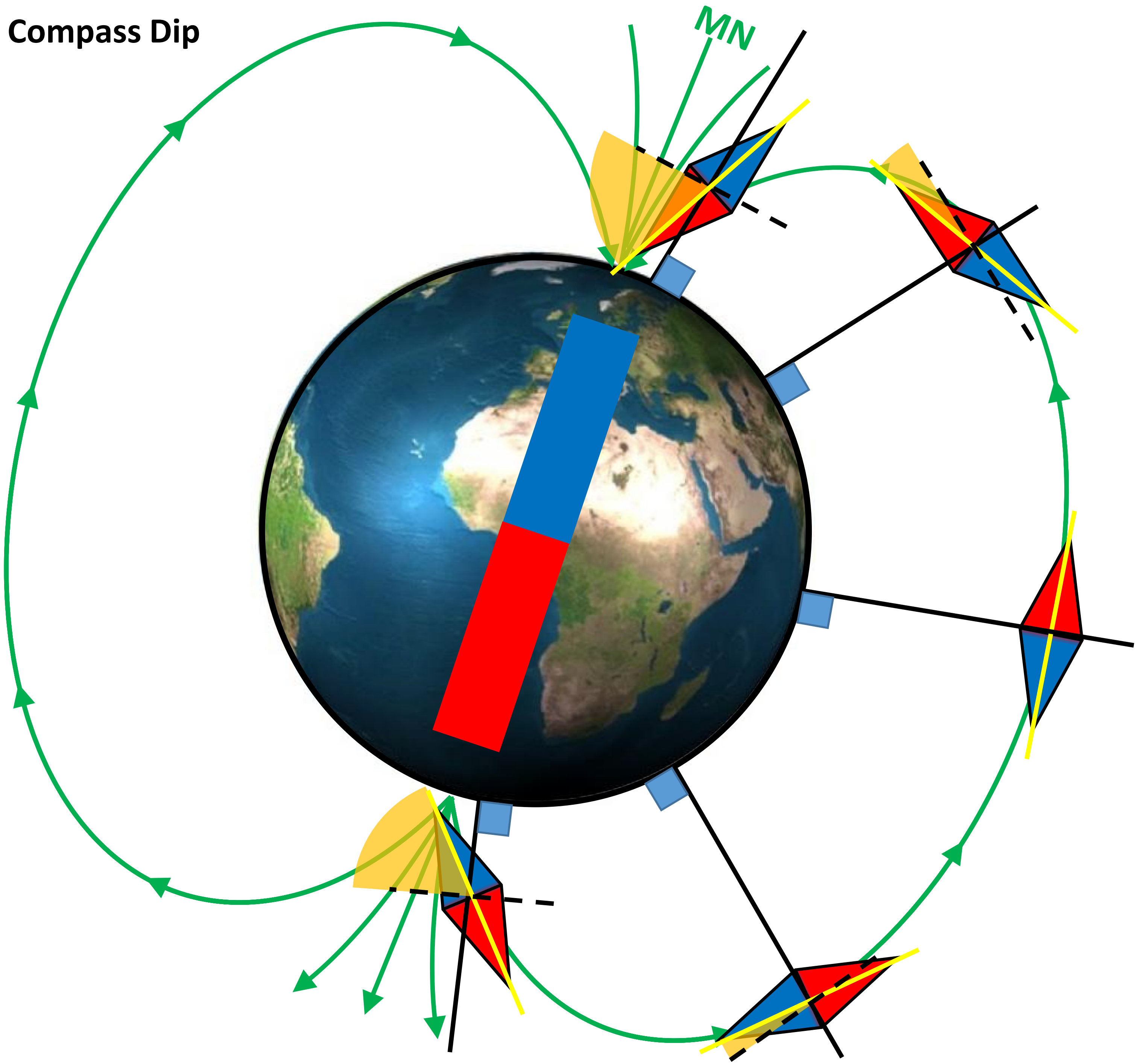
The fluid within which the magnets are immersed will tend to dampen any oscillation of the magnet assembly.

The compass fluid must completely fill the compass bowl in order to prevent liquid swirl during turns, as this would deflect the magnet assembly.

To ensure that the bowl is always completely full despite change in temperature, an expansion bellows (sylphon tube) is fitted which acts as a fluid reservoir.

However the DRC is subjects to many errors, that makes its accuracy unreadable during some maneuvers or locations in flight

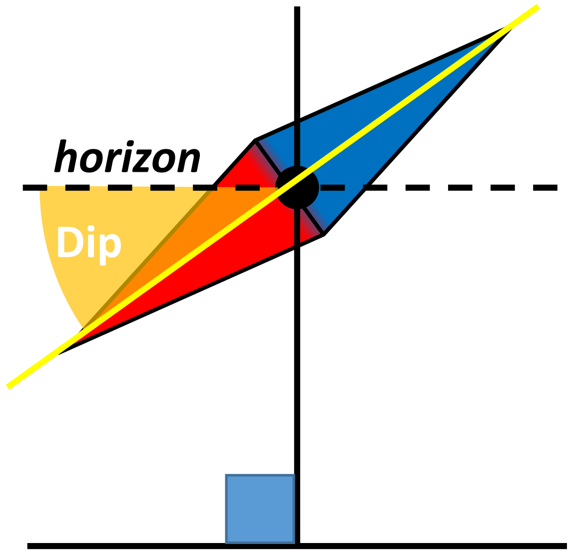
Compass Dip



The DRC will align itself with the Earth's Magnetic Field.

It means that the DRC will not be aligned with the horizon and it will dip.

The angle between the horizon and where the DRC is pointing, is called the **Dip Angle**

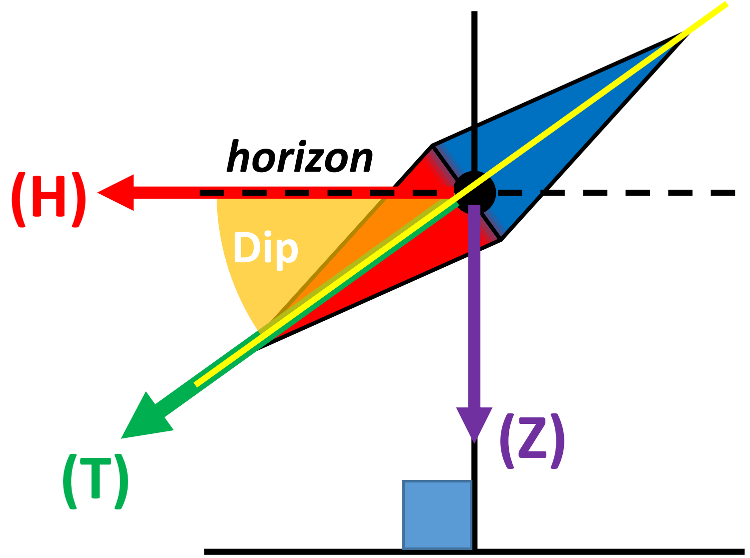


The DRC is aligned with the Earth's Magnetic Field (T)

Two component of the Earth's Magnetic Field (T) can be observed:

- **The Horizontal Component (H)**, that will align the DRC with the horizon (North). Also called **the Directive Force**

- **The Vertical Component (Z)**, that will make the DRC to dip



→ The angle of Dip will increase with high magnetic latitudes

→ The horizontal component provides the directive force

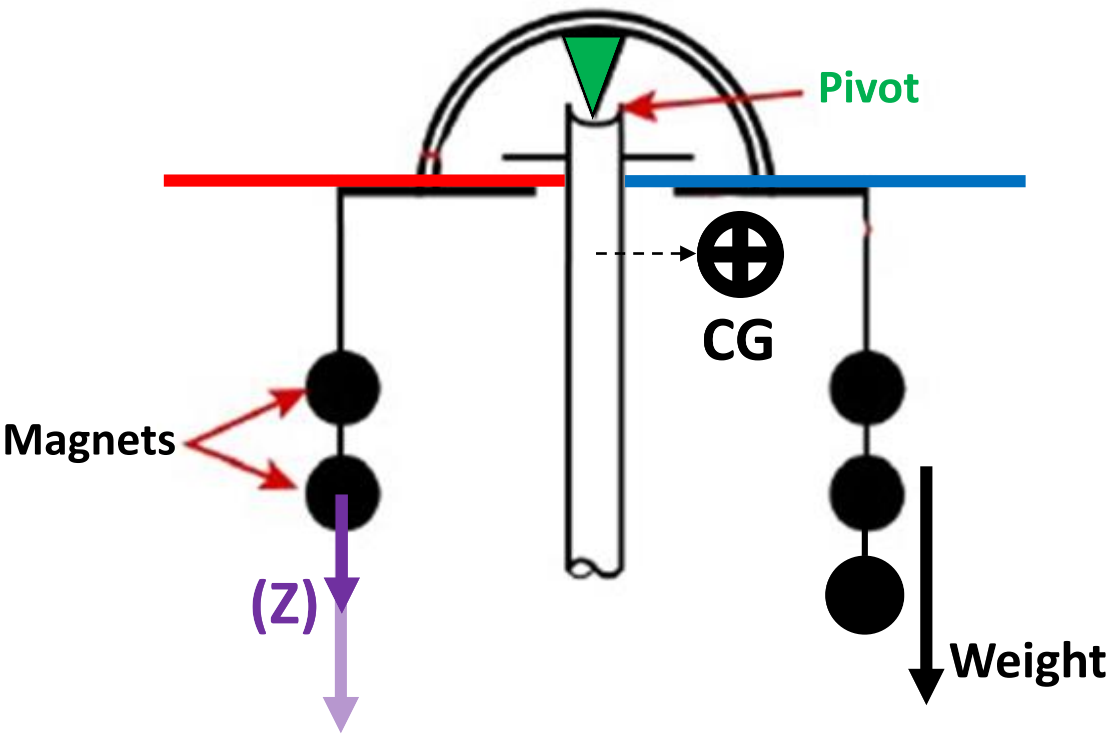
→ At high magnetic latitudes, the (H) is weak and (V) is strong

→ At low magnetic latitudes, the (H) is strong and (V) is weak

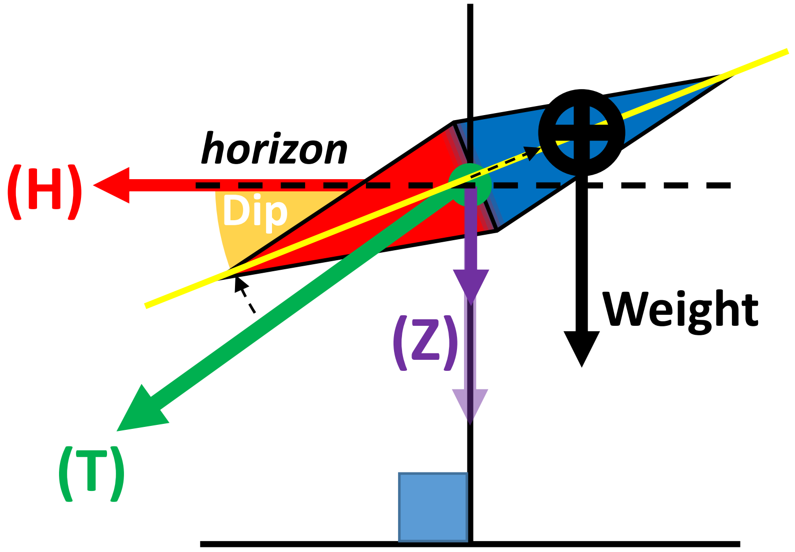
Locations where the Dip Angle is the same, are connected by a line called **ISOCLINICAL LINE**

It is important the DRC is aligned as close as possible with the horizon to show the direction to the North

To overcome this problem, a system of pendulous suspension is employed



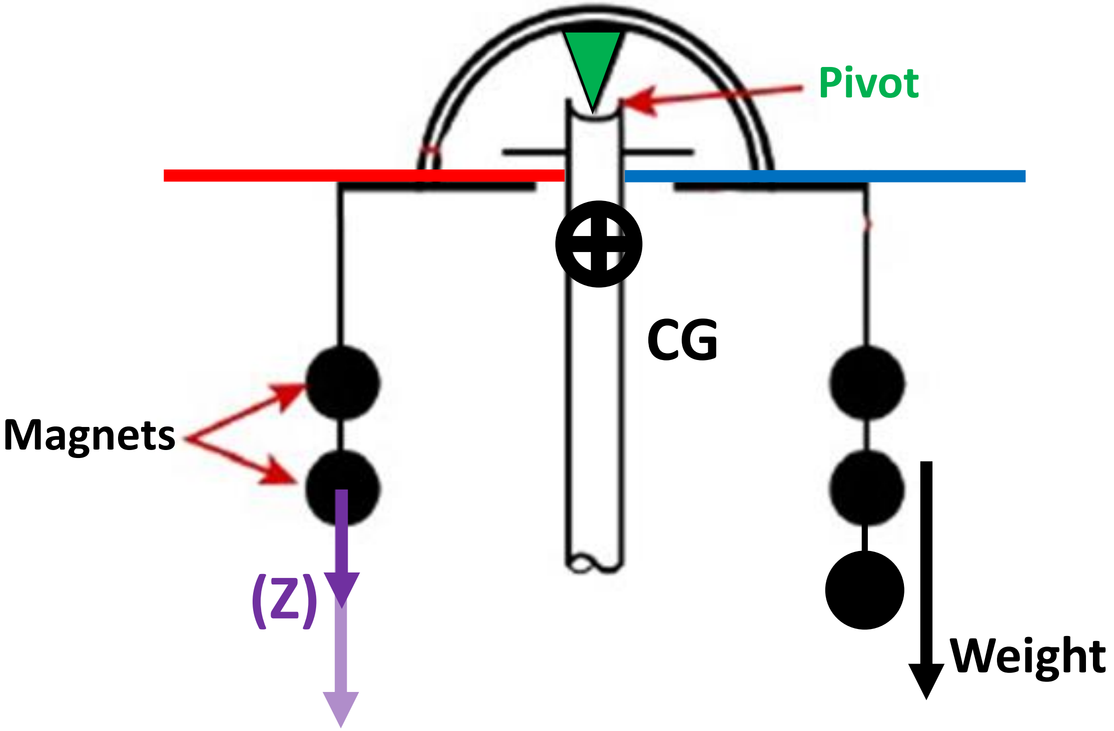
This is done by shifting the **CG** on the magnets, the additional weight will act against the **vertical component (Z).**



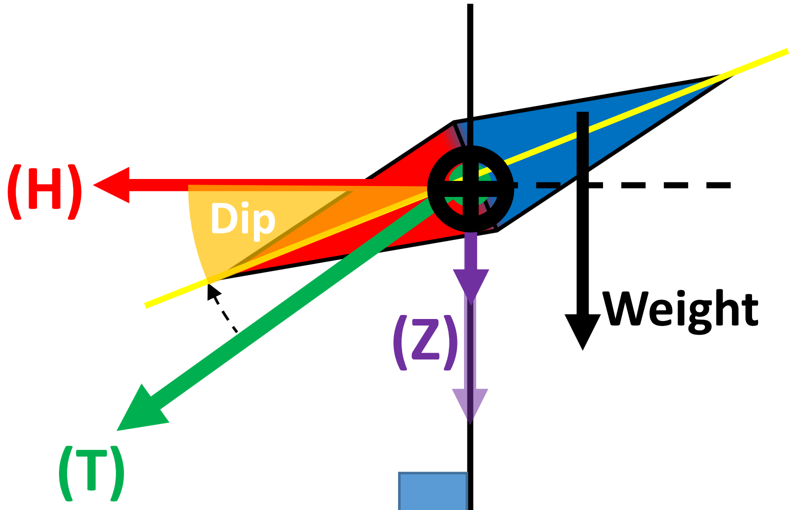
Since the Dip is different with latitudes, each area will produce its own DRC corrected for Dip. The DRC onboard is the one designed for the area where the aircraft is based.

It is important the DRC is aligned as close as possible with the horizon to show the direction to the North

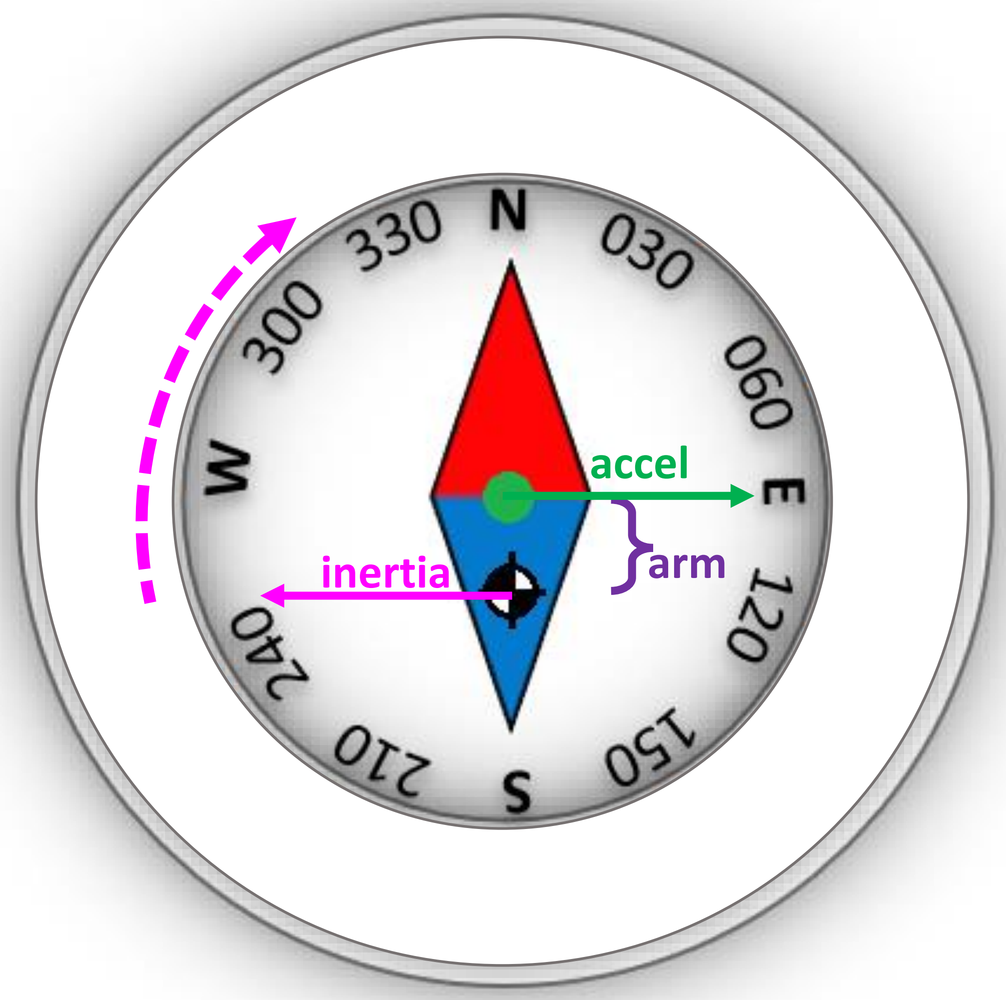
To overcome this problem, a system of pendulous suspension is employed



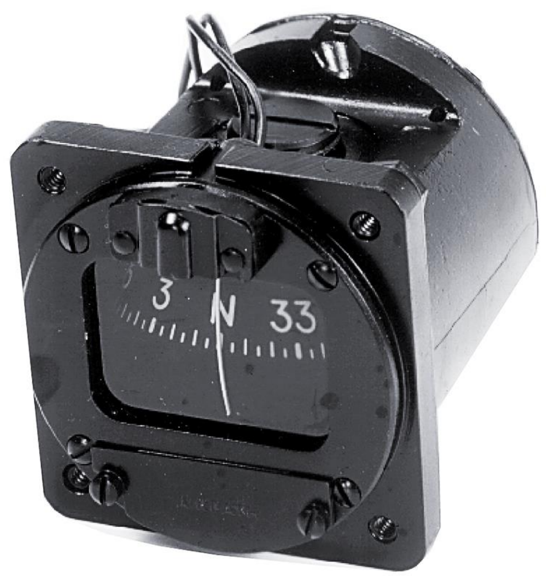
This is done by shifting the **CG** on the magnets, the additional weight will act against the **vertical component (Z).**



Since the Dip is different with latitudes, each area will produce its own DRC corrected for Dip. The DRC onboard is the one designed for the area where the aircraft is based.



You have probably notices the headings on the DRC label are written in opposite direction to the 360° rose



Let’s first understand why it is made like this, in order to understand the errors later.

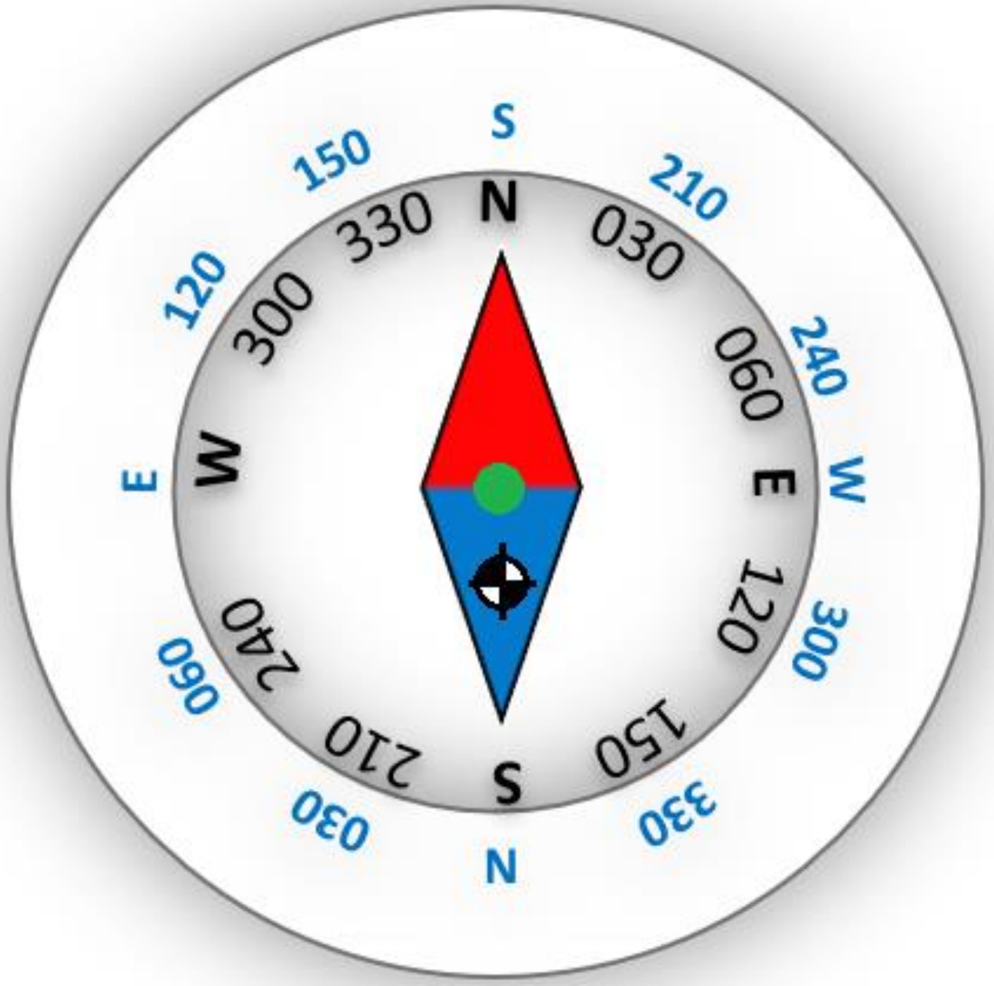
After correcting for the Dip, the **CG** and the **pivot point (attached to the aircraft)** are not on the same position.
So there will be an **arm** that, when the **aircraft** undergoes an **acceleration**, the **CG** is displaced under the **inertia**, the pilot will face reading errors in some cases.
Note: *The arm will be longer at higher magnetic latitudes, since the DRC is corrected for bigger Dip*

The DRC is usually mounted above the pilot's head, and it must be held flat aligned with the horizon

We label the direction that we are heading to on the side of the compass (N when heading North, 030 when heading 030.

This why the heading are reversed on the DRC label

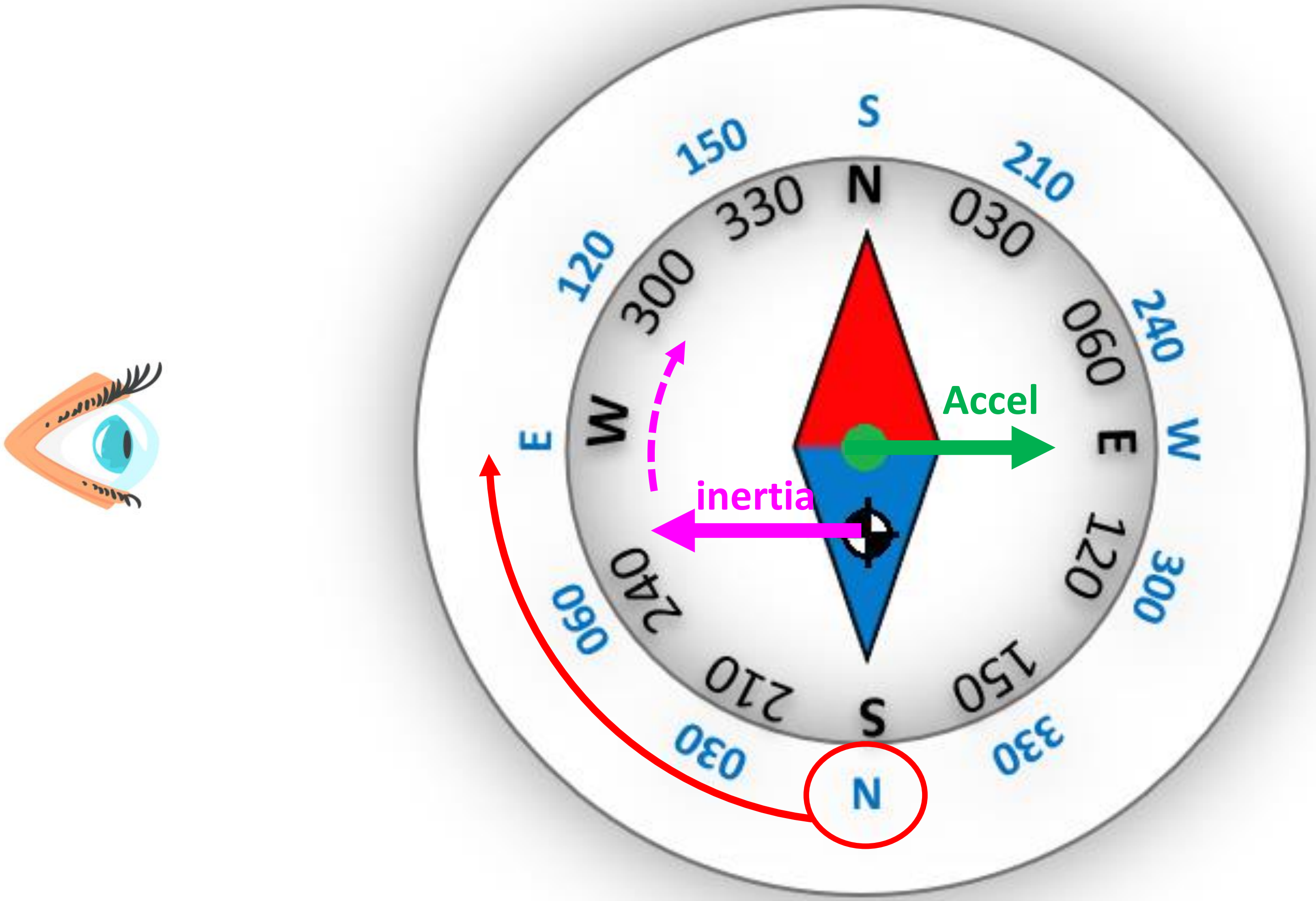
For demonstration, we will observe at the DRC with the outer label flat



***Note**: DRC designed in the Southern Hemisphere, will have the CG in the other side (red). So all the error will be reversed (explained later)*

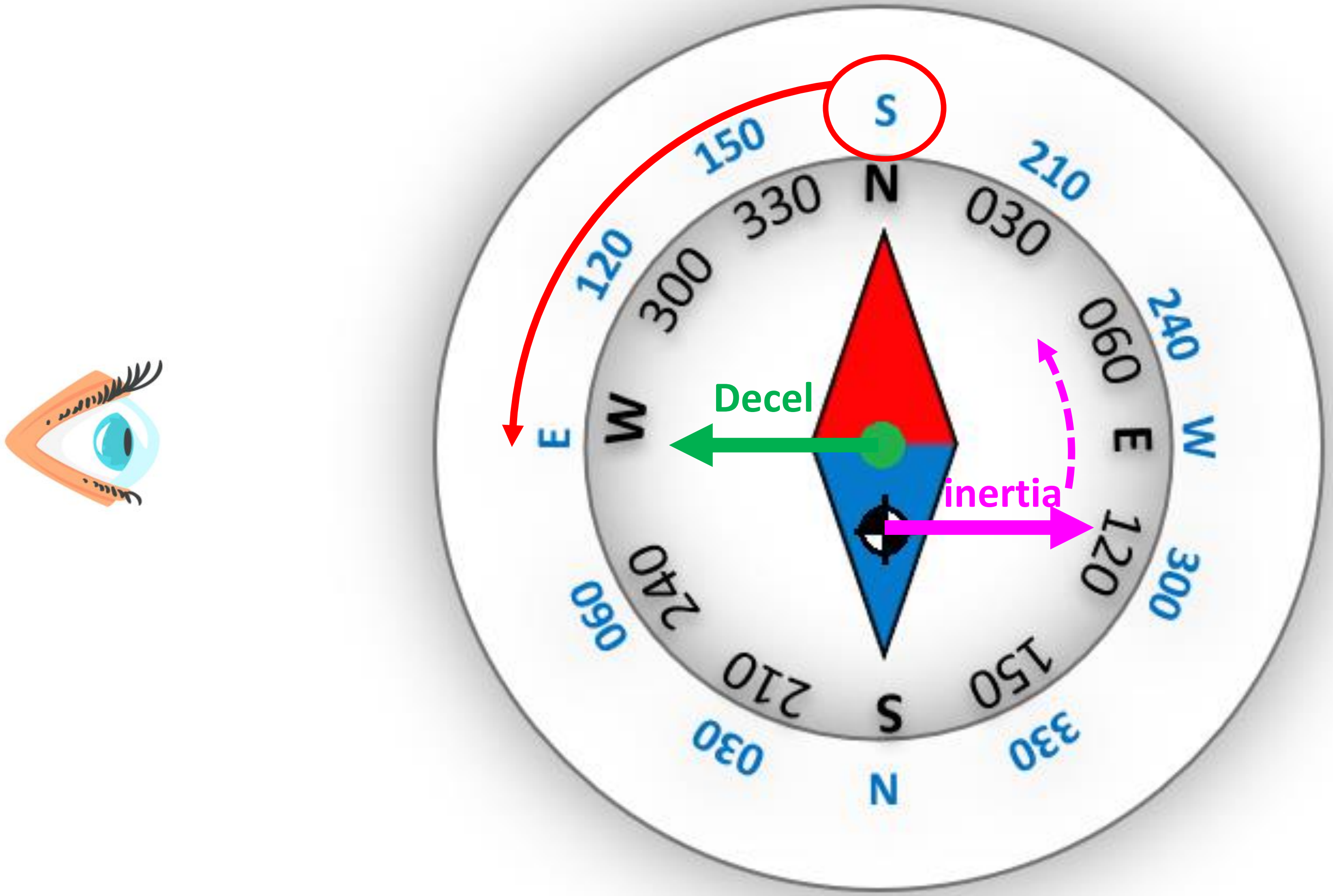
Acceleration Error

In the **Northern Hemisphere**, if we accelerate toward **WEST**



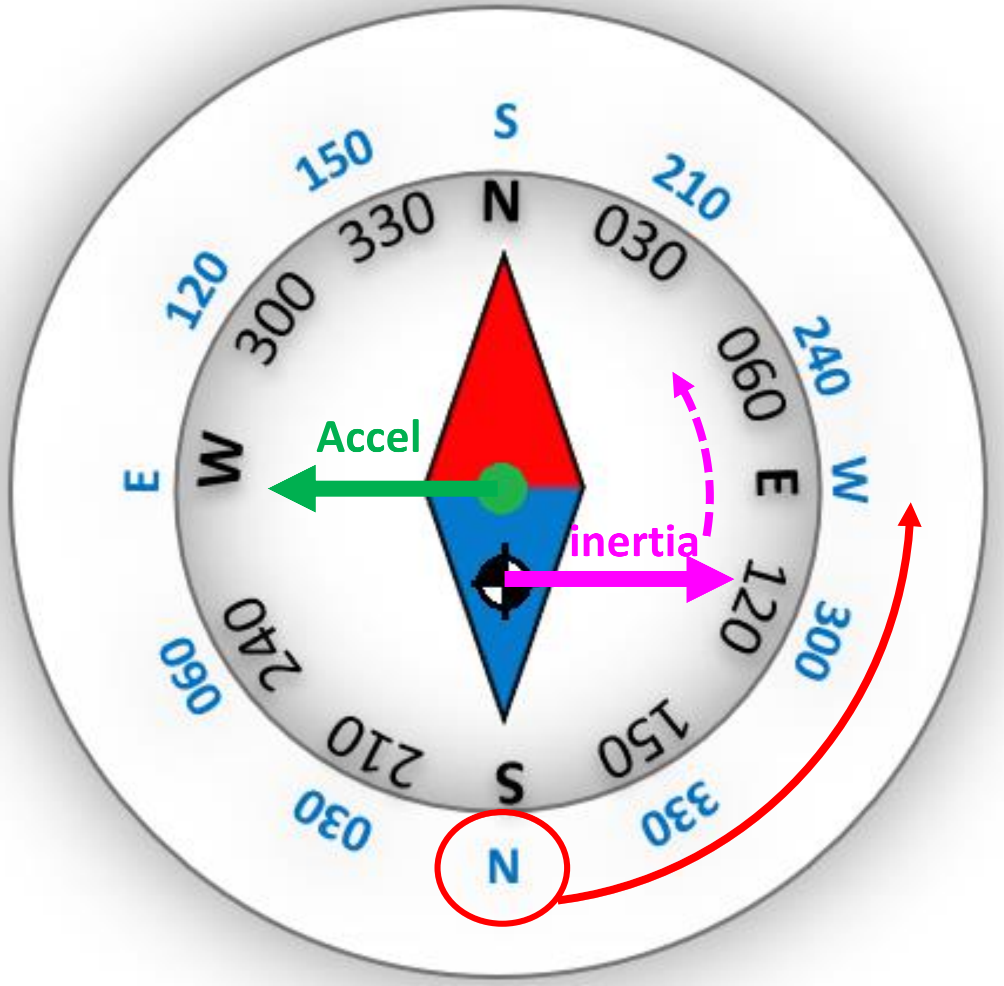
Shows apparent turn to the **North** and DRC turns **Clockwise**

In the **Northern Hemisphere**, if we **decelerate** toward **EAST**



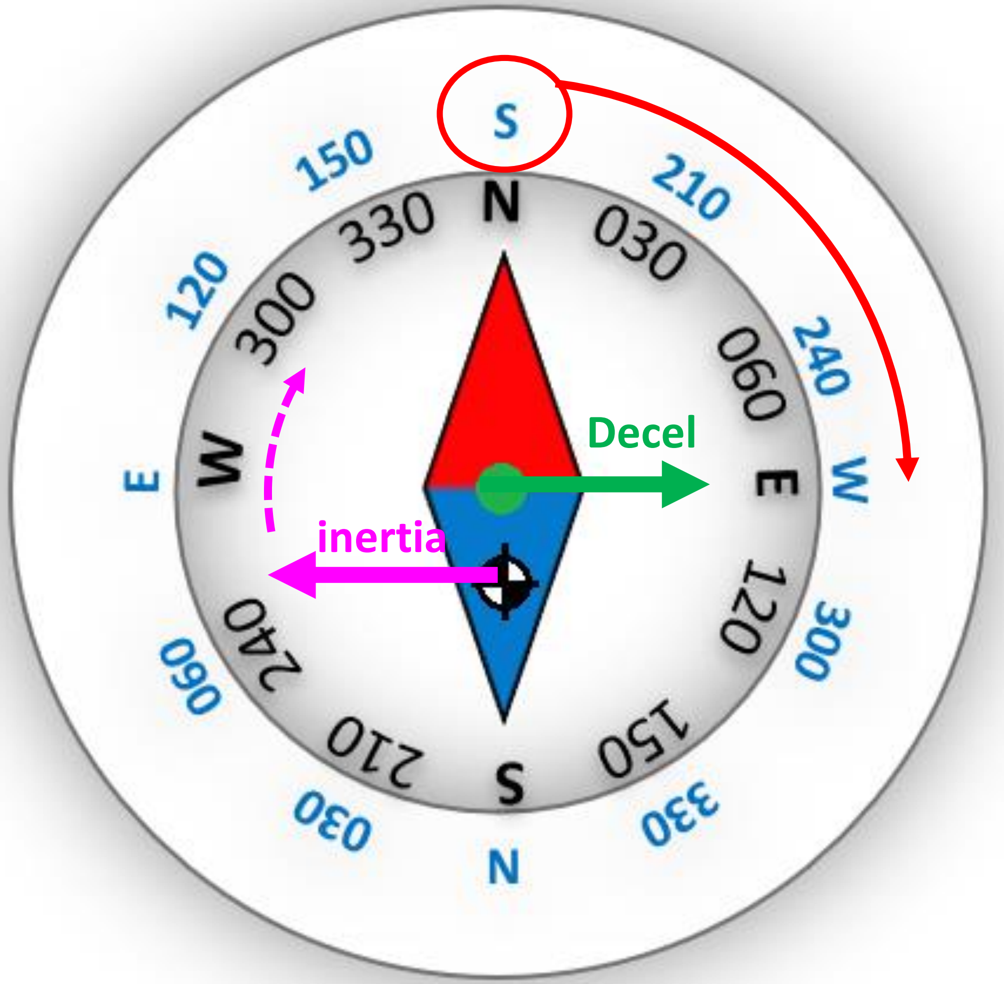
Shows apparent turn to the **South** and DRC turns **Counter-clockwise**

In the **Northern Hemisphere**, if we accelerate toward **WEST**



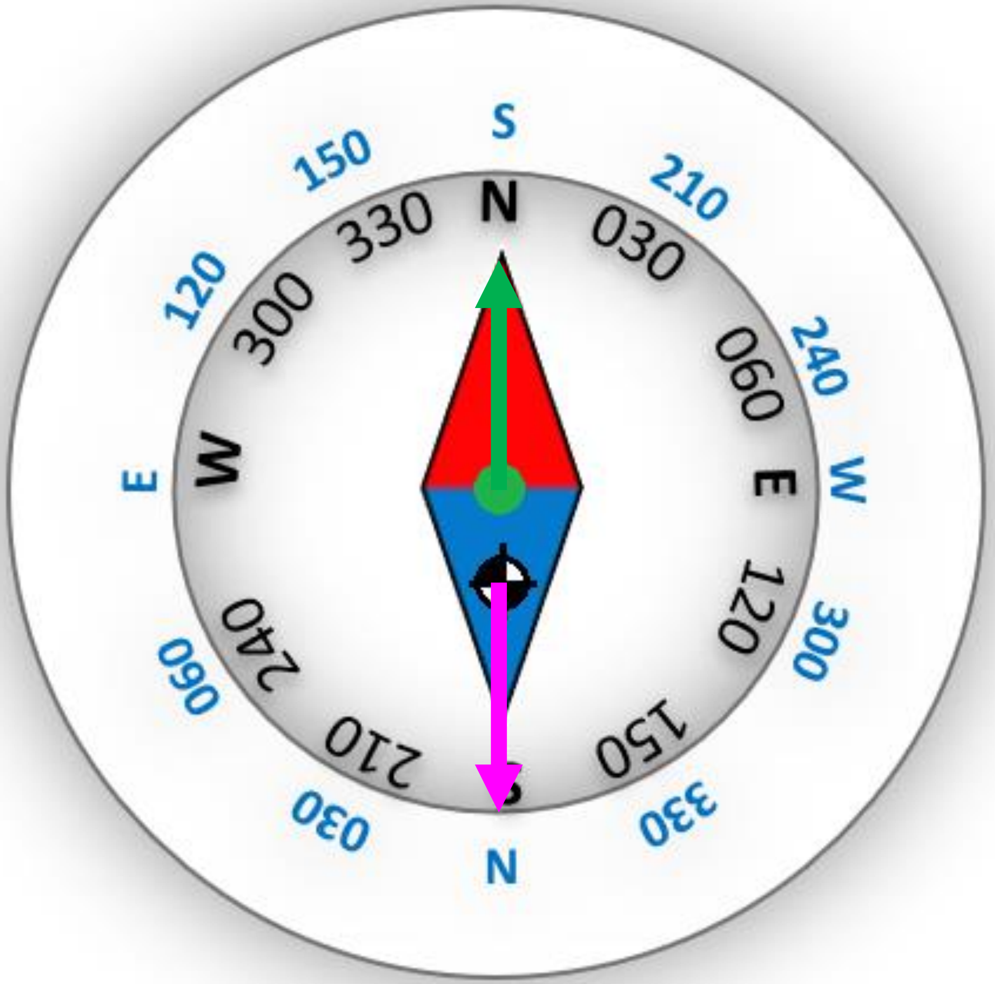
Shows apparent turn to the **North** and DRC turns **Counter-clockwise**

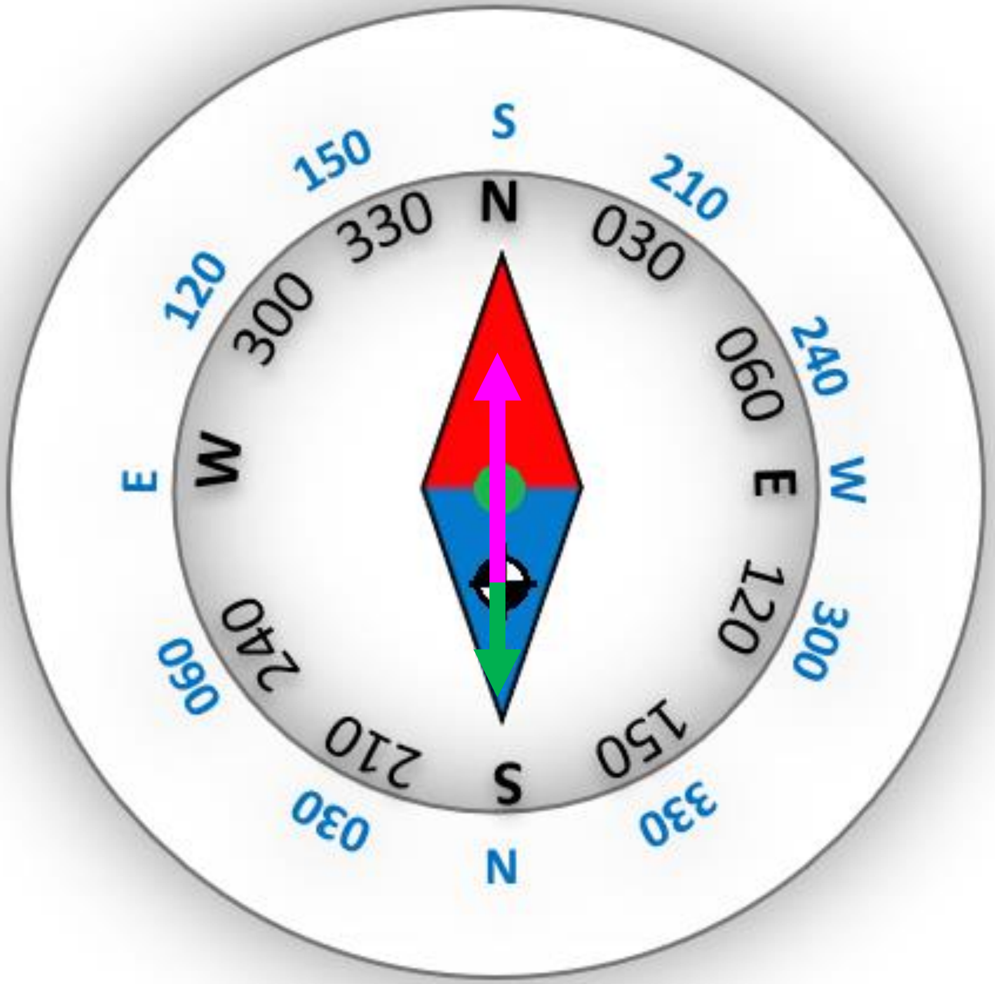
In the **Northern Hemisphere**, if we **decelerate** toward **WEST**



Apparent turn to the **South** and DRC turns **Clockwise**

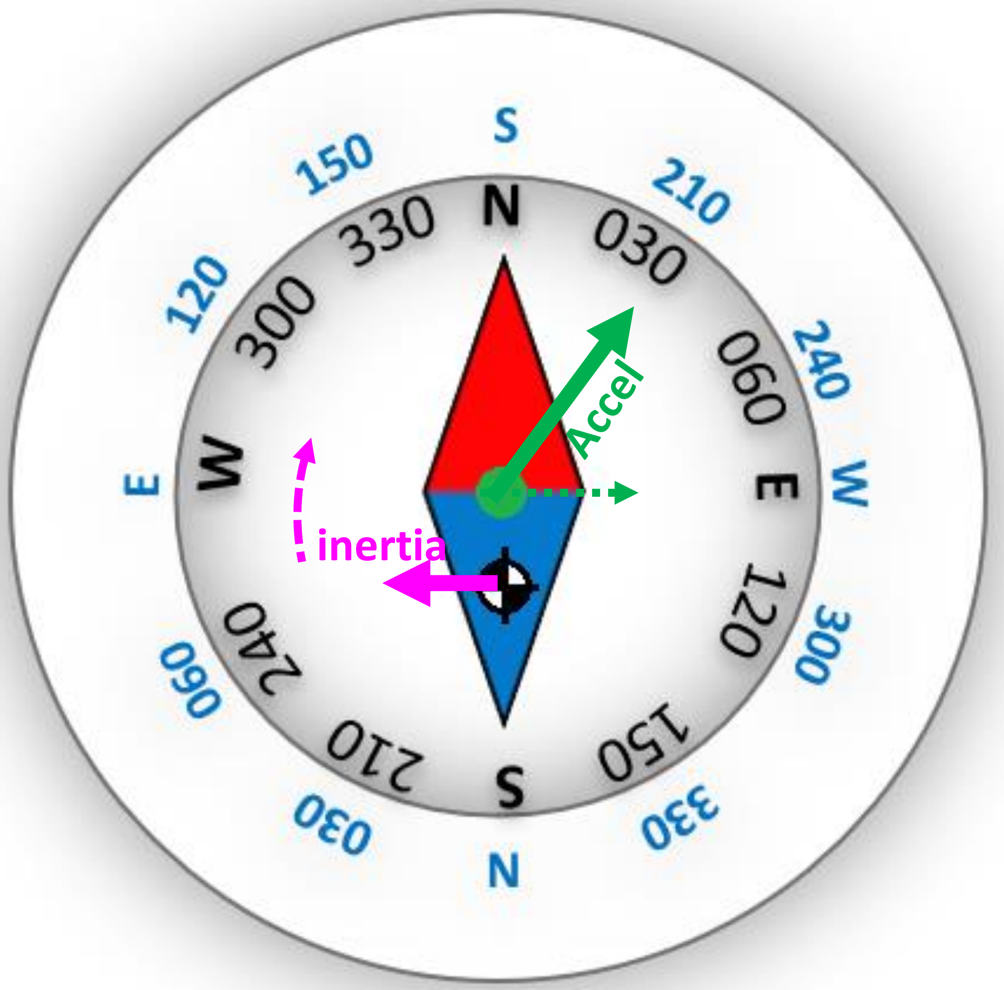
If we **accelerate** or **decelerate** toward **North** or **South**





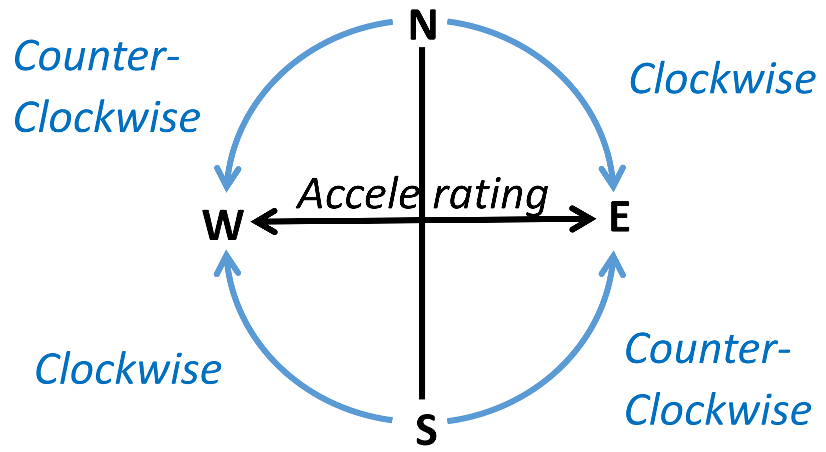
There will be **no error** caused by acceleration

If we **accelerate** or **decelerate** toward any direction other than EAST or WEST



There will also be an error, but smaller than toward EAST or WEST since the component is smaller

Acceleration Error



Northern Hemisphere

Accelerating toward EAST/WEST
Shows apparent turn toward **NORTH**

Decelerating toward EAST/WEST
Shows apparent turn toward **SOUTH**

Remember: *Since the DRC designed in the Southern Hemisphere, will have the CG in the other side (red). So all the error will be reversed*

Southern Hemisphere

Accelerating toward EAST/WEST
Shows apparent turn toward **SOUTH**

Decelerating toward EAST/ WEST
Shows apparent turn toward **NORTH**

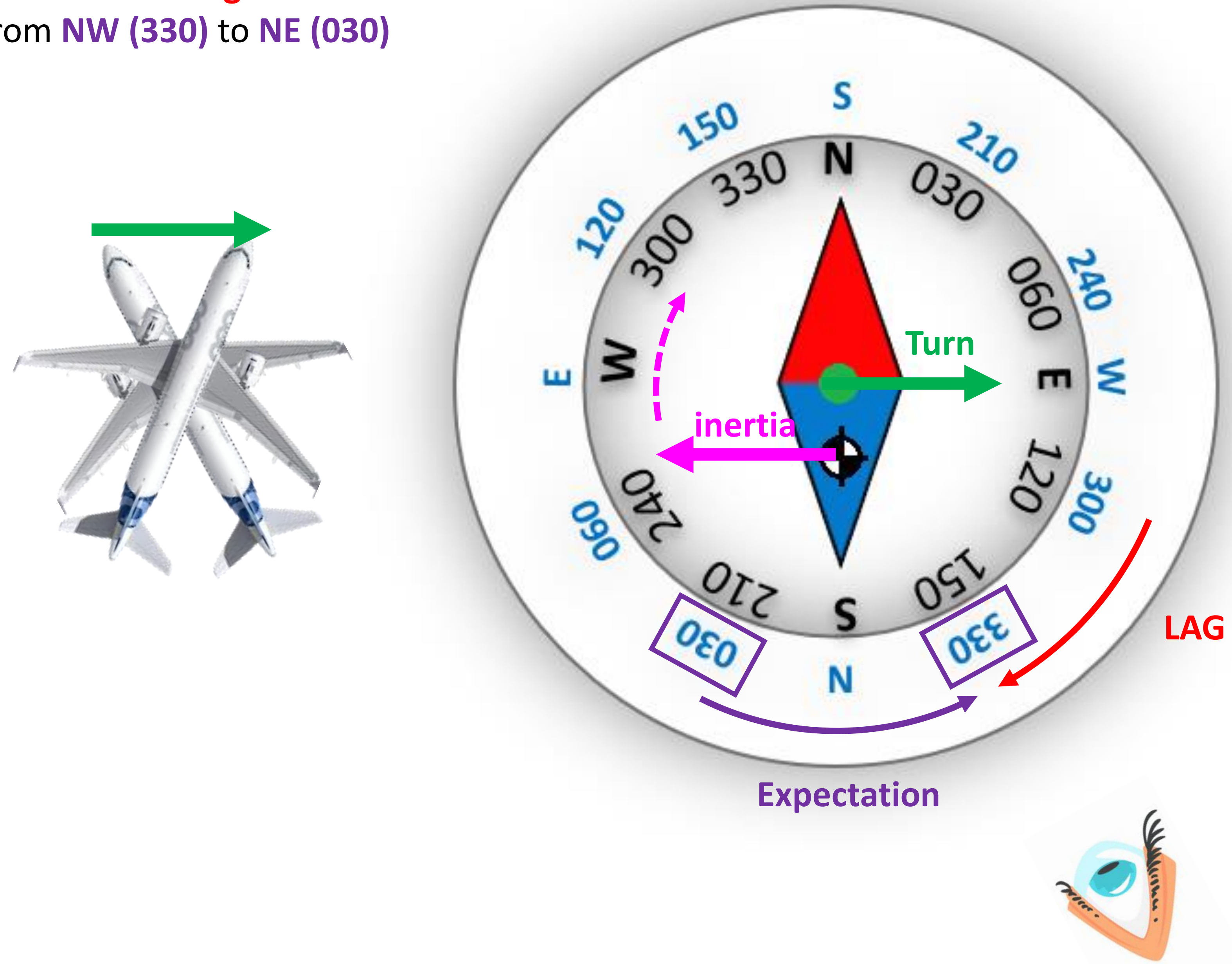
Accelerating toward EAST/WEST
Show apparent turn toward
THE CLOSEST POLE

Acceleration error is the greatest when
- accelerating/decelerating toward EAST/WEST,
- and at high magnetic latitudes

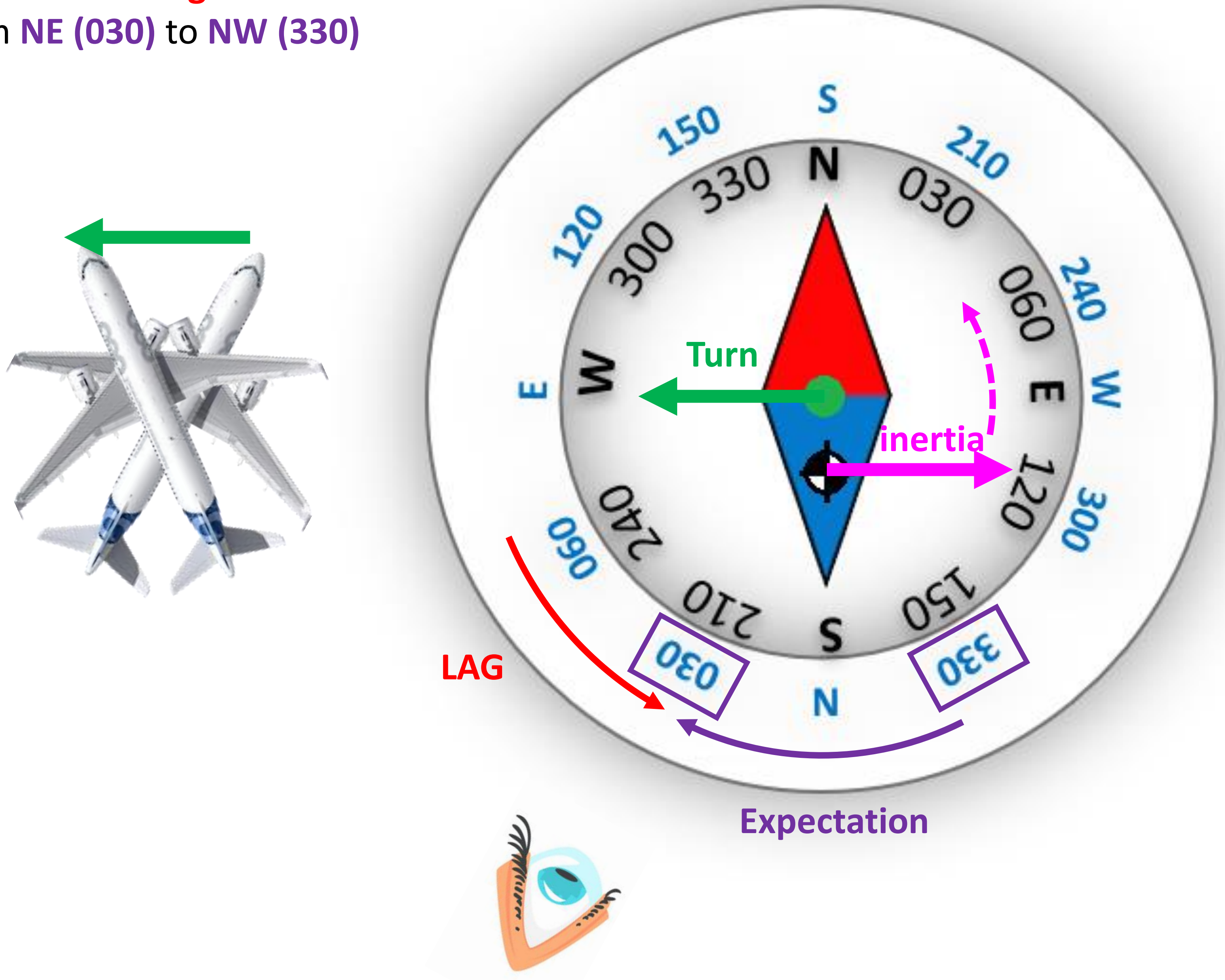
Note:
Accelerating at the magnetic equator will show the correct heading

Turning Error

In the **Northern Hemisphere**,
If we **turn through North**
from **NW (330)** to **NE (030)**

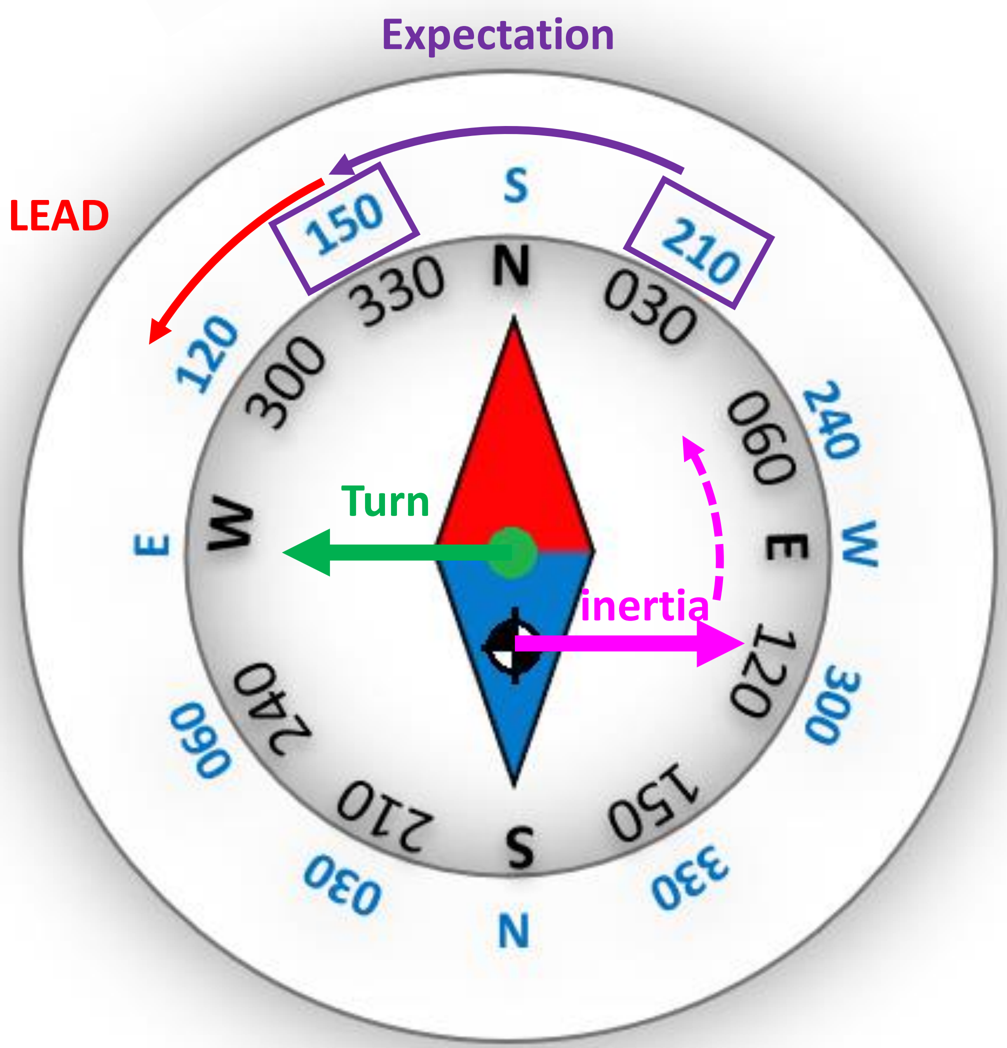


In the **Northern Hemisphere**,
If we **turn through North**
from **NE (030)** to **NW (330)**

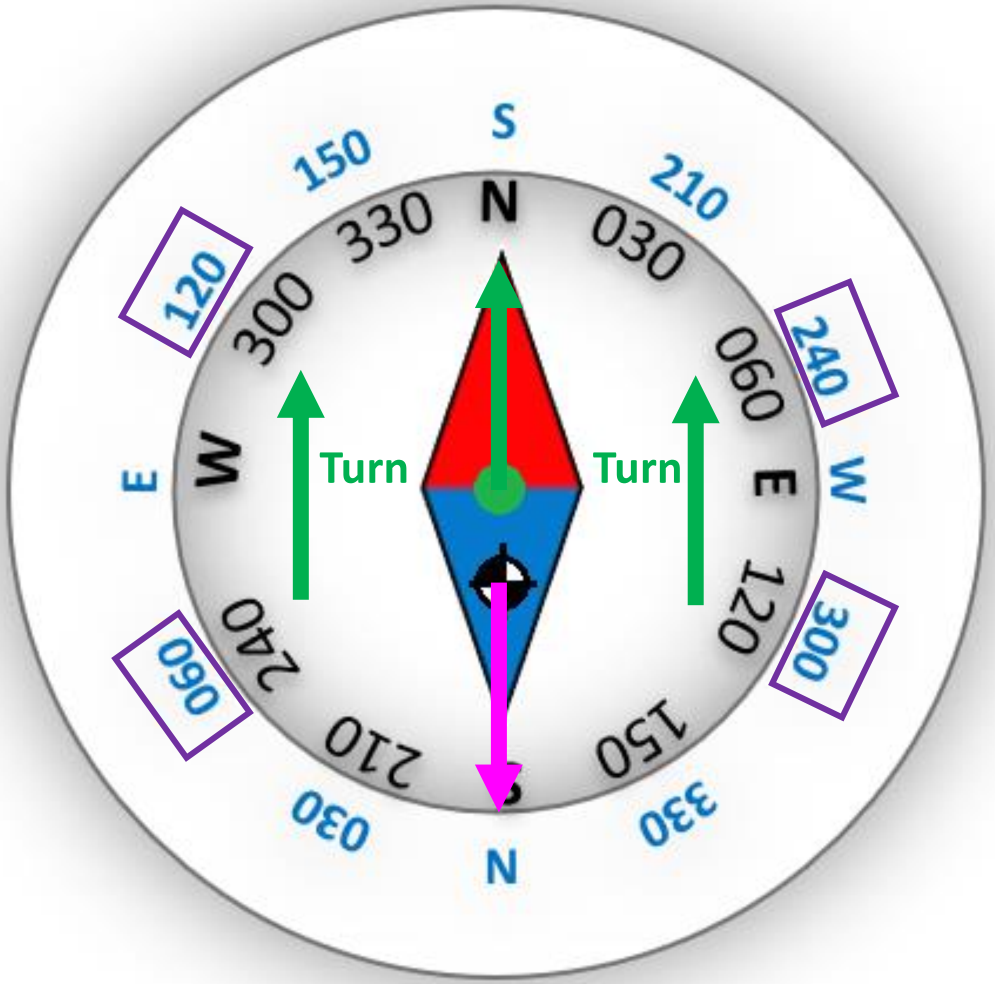


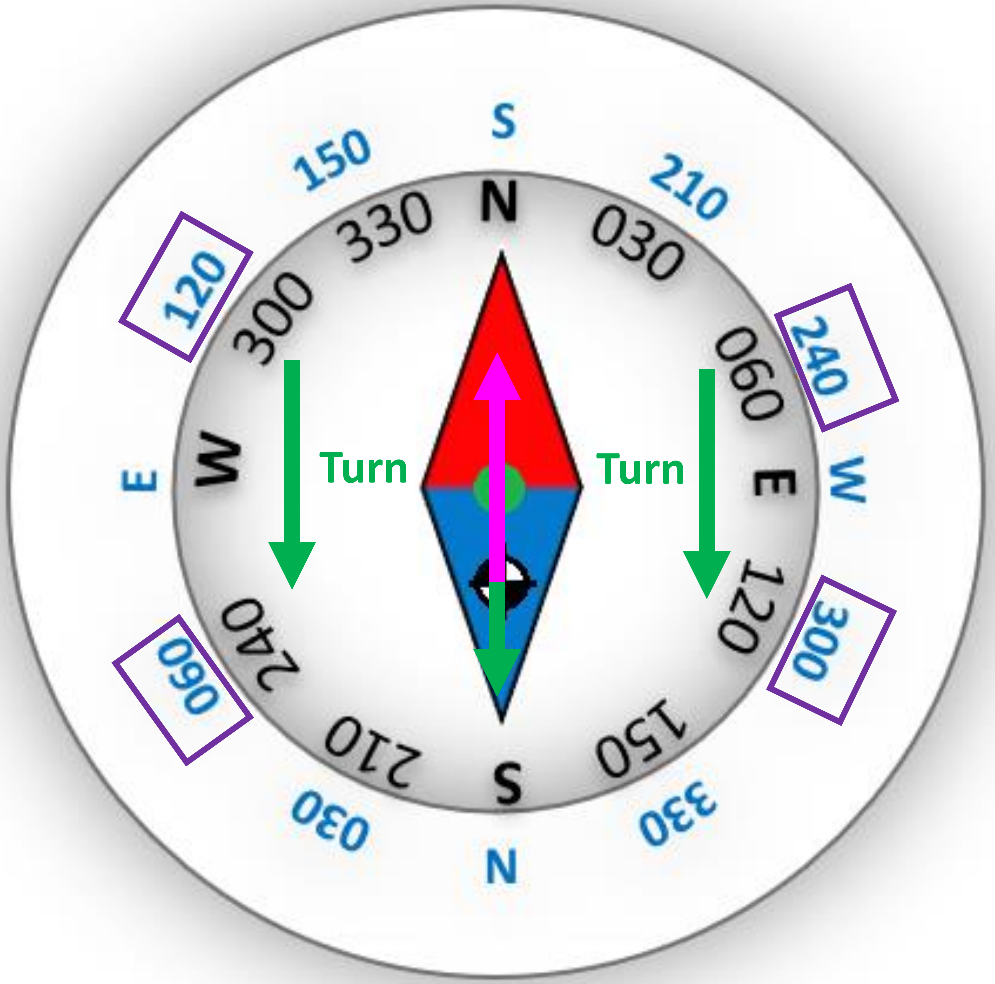
In the **Northern Hemisphere**,
If we **turn through South**
from **SW (210)** to **SE (150)**

In the **Northern Hemisphere**,
If we **turn through North**
from **SE (150)** to **SW (210)**



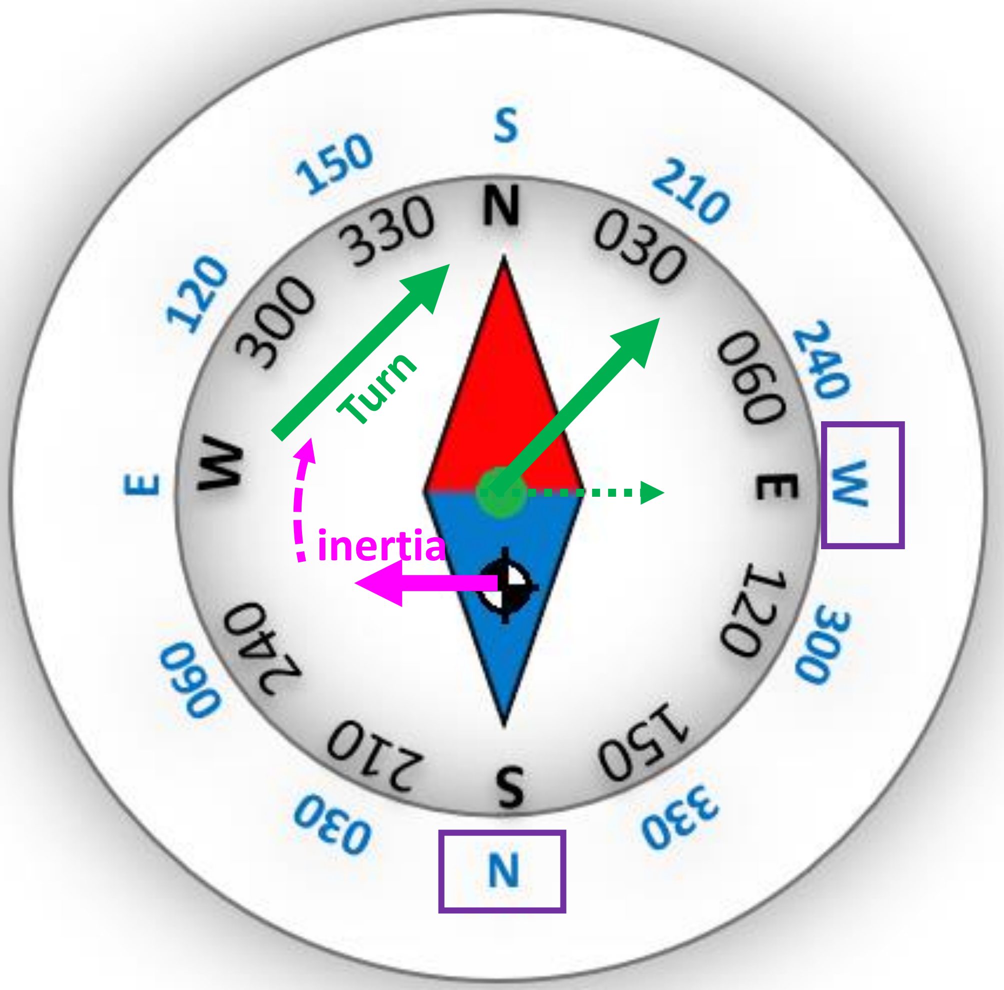
If we **turn** through **EAST** or **WEST**





There will be **no error** caused by turn

If we **turn** through an direction other than **NORTH** or **SOUTH**



There will also be an error, but smaller than through NORTH or SOUTH since the component is smaller

Turning Error

NORTHERN HEMISPHERE

Remember: *Since the DRC designed in the Southern Hemisphere, will have the CG in the other side (red). So all the error will be reversed*

SOUTHERN HEMISPHERE

The swirl liquid will increase the lagging effect

Turning error is the greatest when
- Turning through NORTH/SOUTH,
- and at high magnetic latitudes

Turning through	From/to	Effect	Indication	Correction
NORTH	NW → NE (330 ⇨ 030)	LAG	Underread Overread	UNDER SHOOT
	NE → NW (030 ⇨ 330)	LEAD	Overread Underread	OVER SHOOT
SOUTH	SW → SE (210 ⇨ 150)	LEAD	Underread Overread	OVER SHOOT
	SE → SW (150 ⇨ 210)	LAG	Overread Underread	UNDER SHOOT