Instrument Navigation & Electronics

Temperature Calculations

$Ts = Tt / (1+0.2M^2)$

$RAM\ RISE = (TAS/100)^2$

$RAT = Ts * (1+ (0.2Kr * M^2))$

Use of alternate source of static pressure vented inside the aeroplane causes the ALTIMETER to over read ASI to over read and VSI to show a momentary climb

The backup alternate source of static pressure is breaking the VSI

Altimeter

- Sealed aneroid capsule with 1013.25hpa and Casing fed by static pressure
    1. **Sensitive Altimeter -** 2 aneroid capsules and a bi-metallic insert for temperature changes
    2. **Servo Altimeter-** Servo for digital accuracy. Lag error eliminated by a EM pickup device. Vibrator reduced friction.
- **Increase in ALT** will reduce casing pressure and let capsule expand
- **Decrease in ALT** will increase casing pressure and contract capsule
- Servo Alt Accuracy

Height	MSL	40000	60000	100000
Tolerance	30	100	300	4000

Density Altitude = PA + 120(ISA DEV)

Temperature error = (IA/250) * ISA Deviation

Errors

1. **Instrument Error-** Manufacturing defects
2. **Lag Error**
3. **Position Error**
4. **Pressure Error**
5. **Temperature Error**
6. **Hysteresis Error-** Lag in climb or descent *(Depends on time passed at an altitude)*
7. **Static Port Block (Last ALT reading stays stuck)**
8. **Leak in static tube-** Reads CABIN ALT in pressurised A/C and in non-pres. A/C over reads

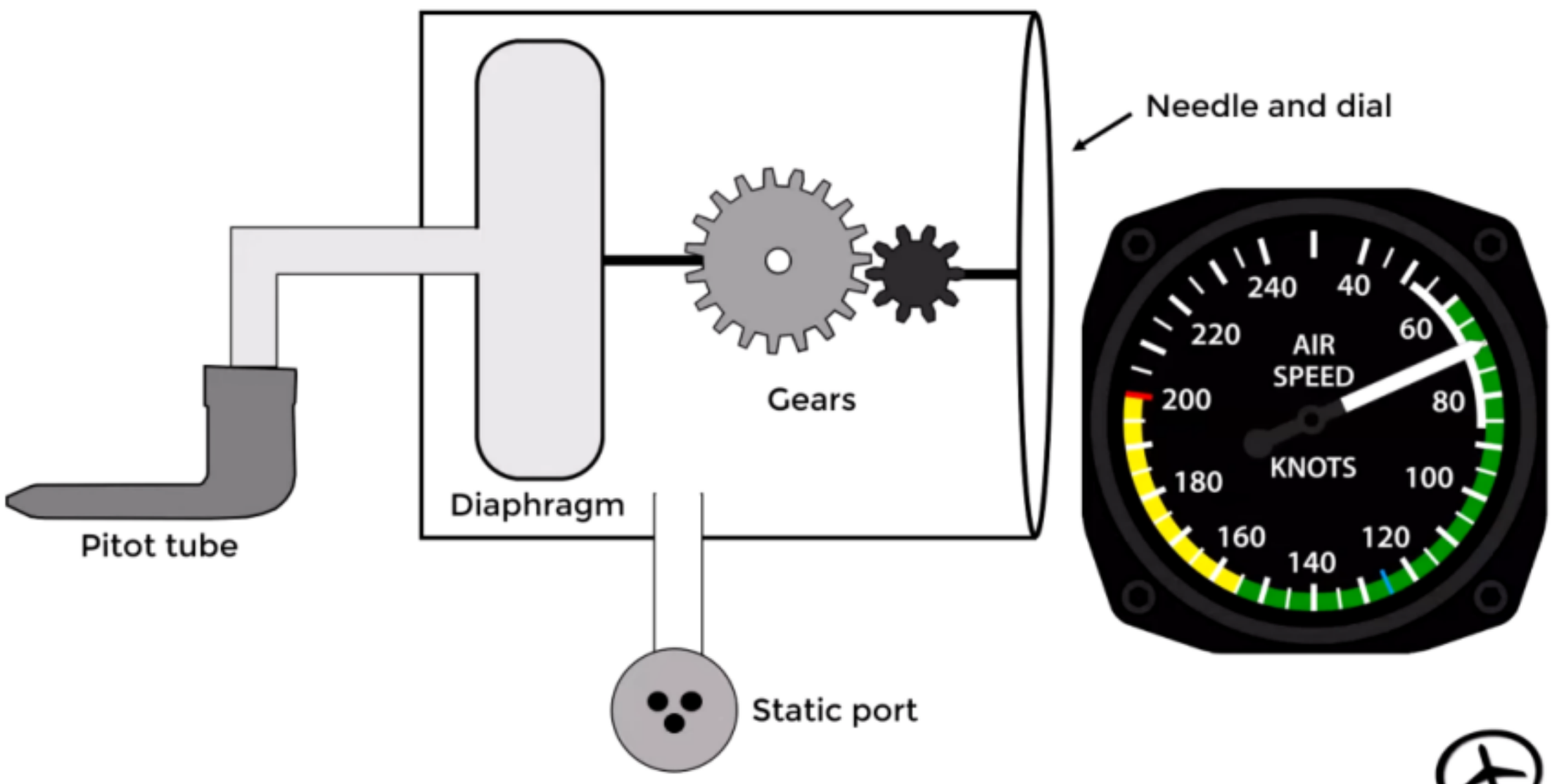
Notes

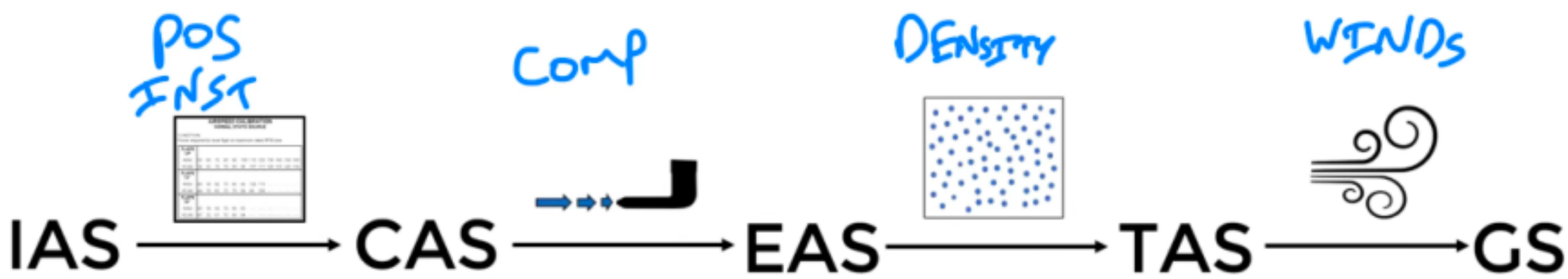
1. Altimeter under indicates (under neads) when actual Temp >ISA or when temp

increases.
2. Altimeter over indicates (over reads) when Temp < ISA orwhen temp decreases COl
3. Cold air-Density greater - given pressure will occur at lower altitudes than warmer air consequently altımeter over reads. Error approx. 4 o f indicated altitude for every 10°C temp deviation]
4. Altimeter over indicates (over reads) when side slipping towards a blocked static port (vent).
5. Under indicates (under reads) when side slipping away towards the blocked static port.

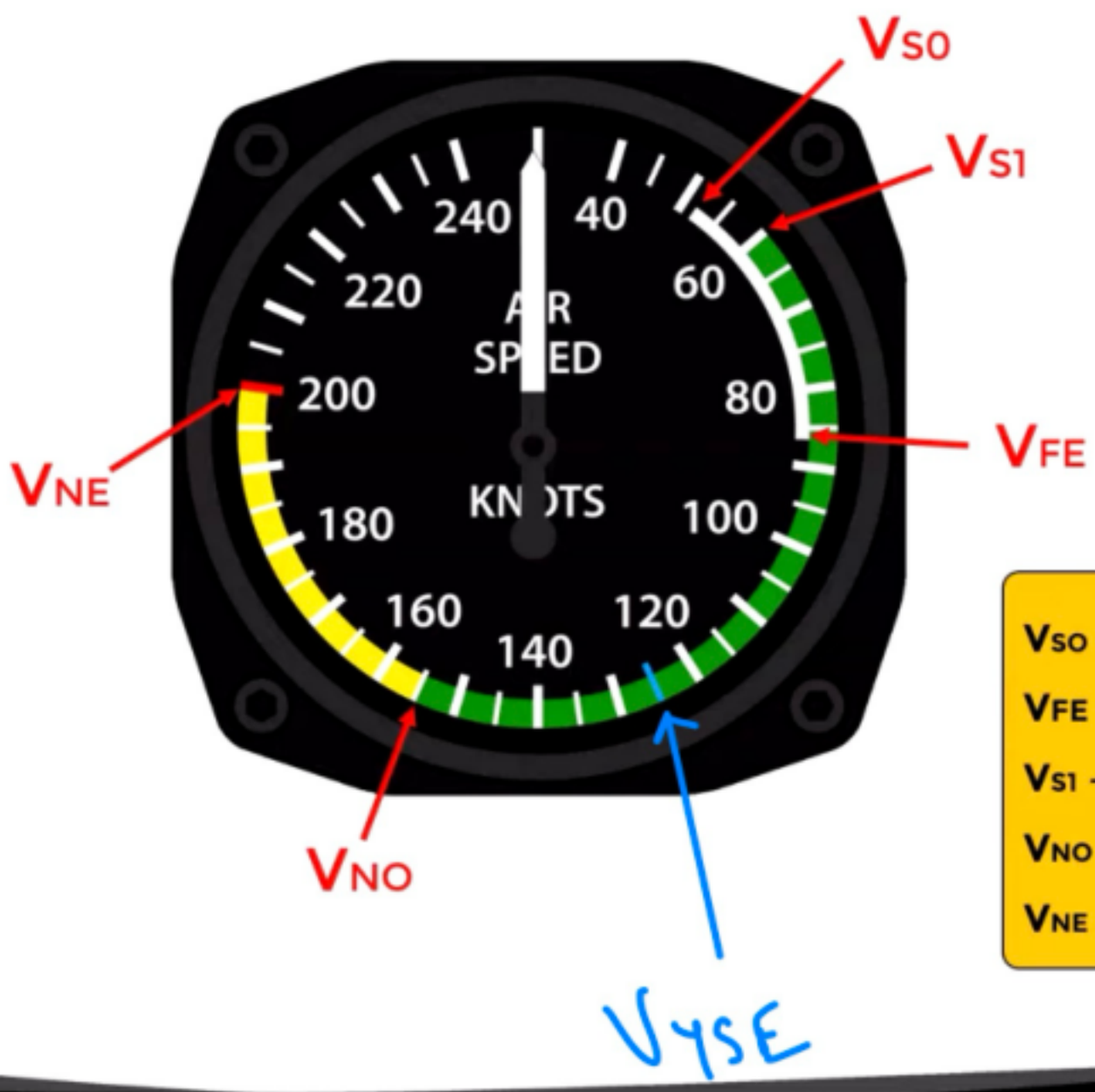
- **TAS** obtained from EAS and Zd
- **CAS** obtained from EAS and Zp

Air Speed Indicator





1. Compressibility error considered only for TAS > 200kt
2. EAS <= CAS
3. Compressibility correction to CAS for EAS is always negative and depends on MACH only
4. A/c always takes off the the same EAS with const, weight and config.
5. **Compressibility factor K is ALWAYS <=1 and depends on Mach only**



ARC	INICIO	FIN
WHITE	V_{SO}	V_{FE}
GREEN	V_{S1}	V_{NO}
YELLOW	V_{NO}	V_{NE}
RED	V_{NE}	---

V_{SO} – Stall speed in landing configuration.

V_{FE} – Maximum flaps extended speed.

V_{S1} – Stall speed in a specific configuration.

V_{NO} – Normal operating limit speed.

V_{NE} – Never exceed speed.

Second striped needle (Barber's Pole) shows the VMO verses altitude expressed in *CAS(1) or EAS(2) ONLY.*

VFE has an approved flap position.

ASI calibrated to ISA MSL datum values

Blockages

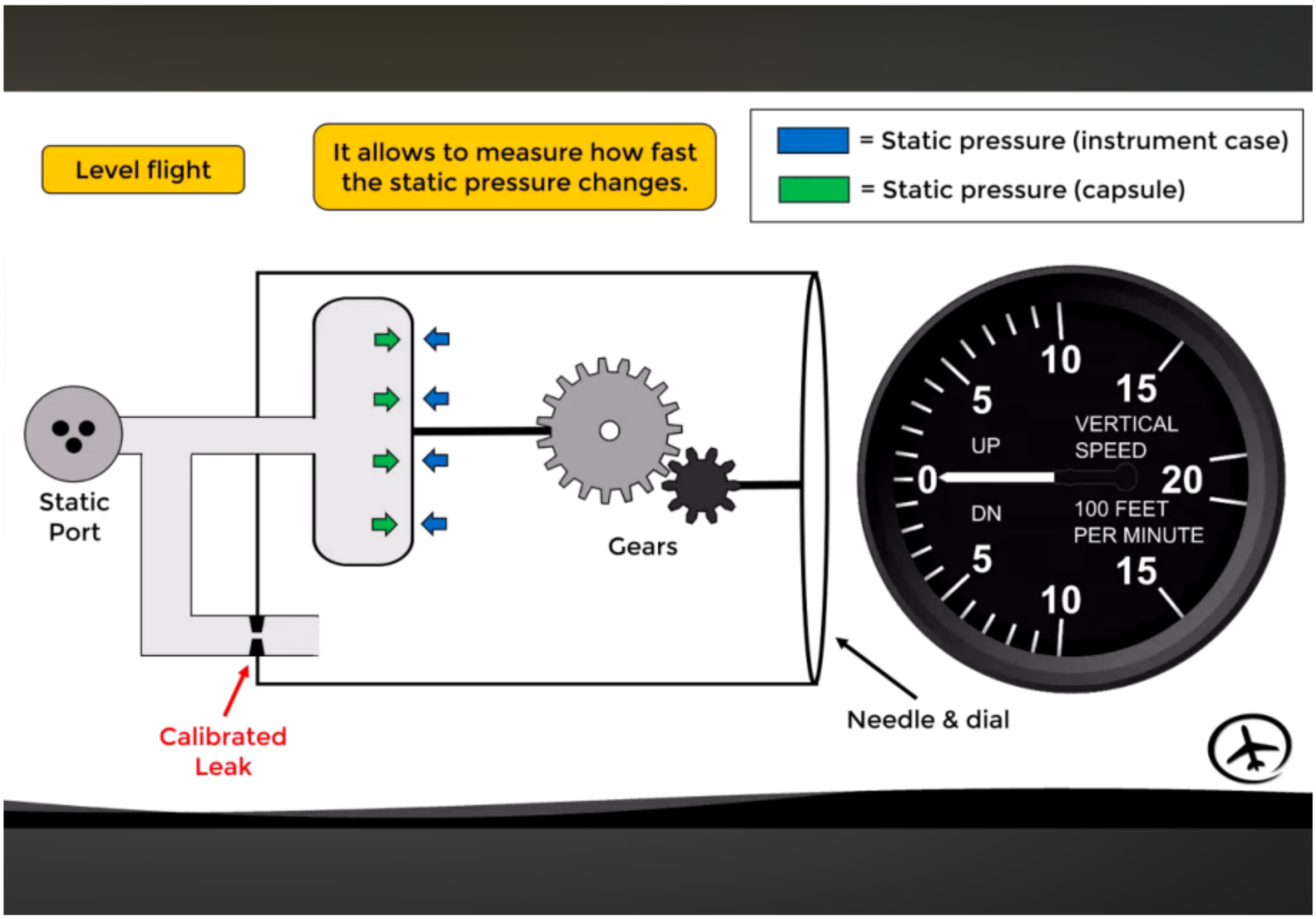
1. **PITOT Main Intake-** (ASI stuck on 0)
   - Dynamic P from capsule escaped via drain hole and both equalise at static.
2. **Drain Hole**- Normal but water issue
3. **Both blocked-**
   - ASI becomes Altimeter
   - Correct reading at last altitude
4. **Static Block-** Opposite of altimeter
5. Pitot Leak- ALWAYS UNDER READ

PUDSOD

Pitot Blocked | Underread | Descent

Static Blocked | Overread | Descent

Vertical Speed Indicator



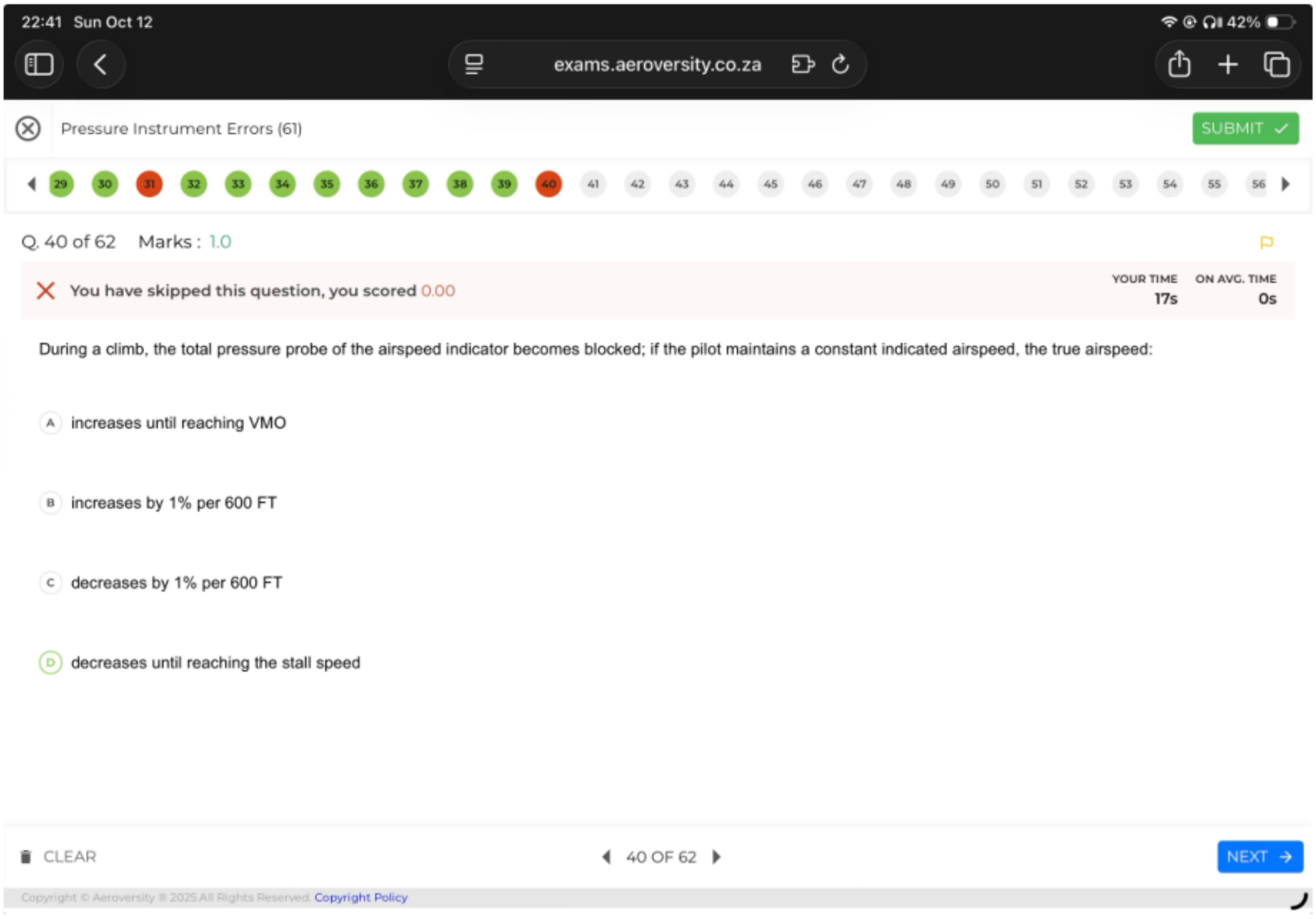
- Climb- Capsule contracts
- Descent- Capsule Expands
- Logarithmic scale

IVSI

- Accelerometer
- In a climb, piston pushes downwards and forces pressure into casing
- In a descent, piston is pushed upwards and sucks pressure from the casing
- Not good for steep turns and manoeuvres.
- Steep turns give false climb

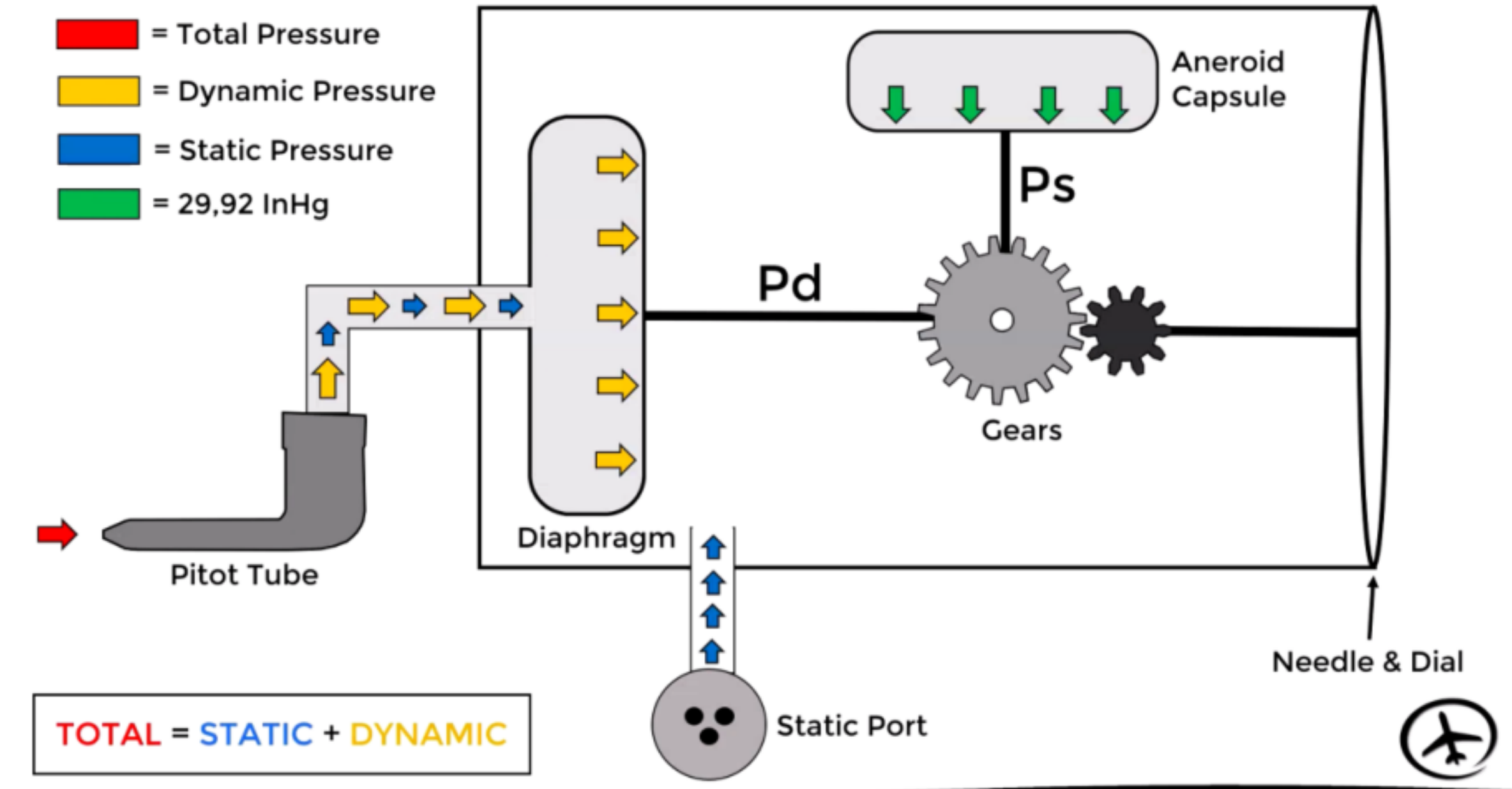
Static block brings the instrument slowly to 0 reading

- If VSI stuck on a reading on ground, use that as 0 reference.



Machmeter (ASI + ALTIMETER)

A barometric android capsule subjected to static pressure and an air speed sensor subjected to dynamic pressure




```
Mach = TAS / LSS

LSS = 39 * (√T in Kelvin)
```

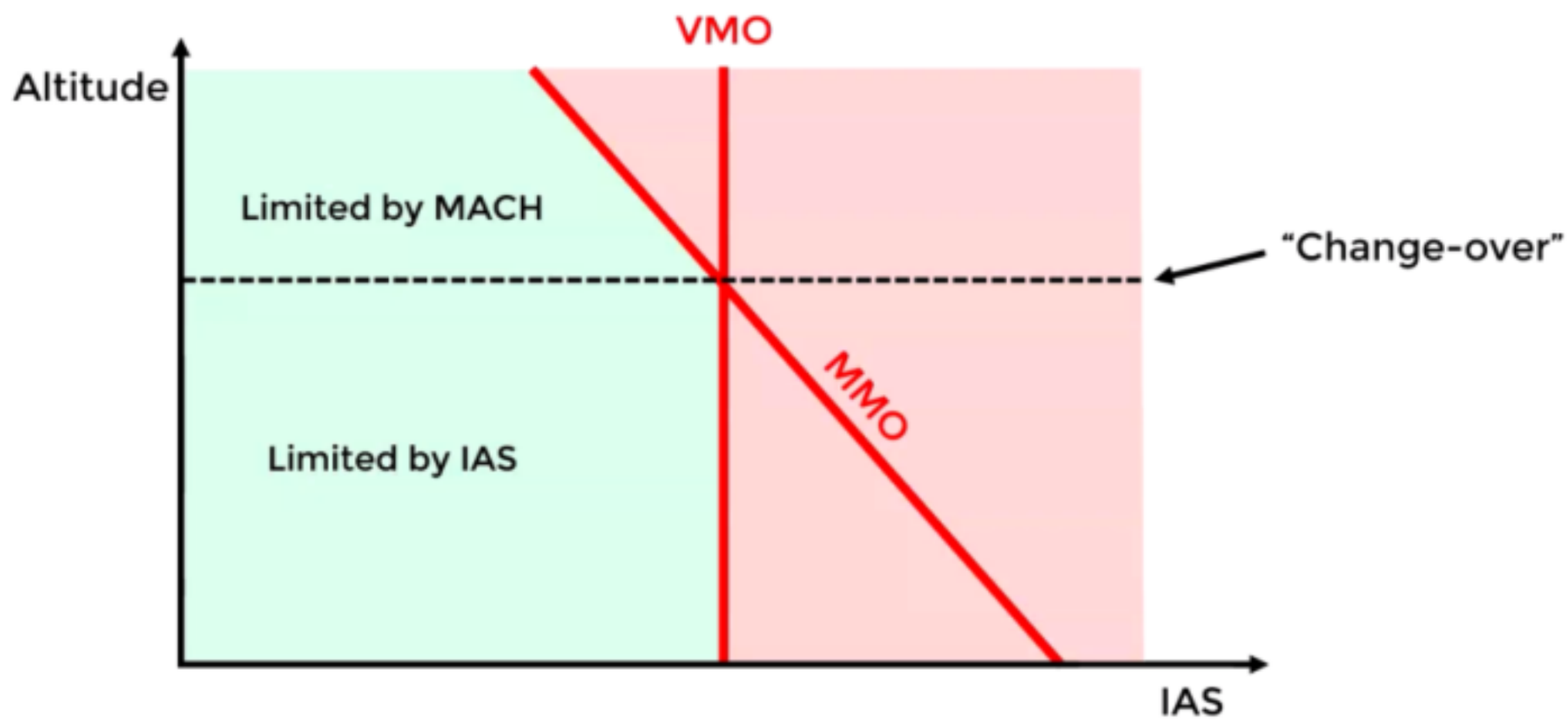
- TAS proportional to (Pd/density) and LSS to (Ps/density)
- Hence, Mach prop to **Pd/Ps**
- Reading independant of OAT
- Position error only

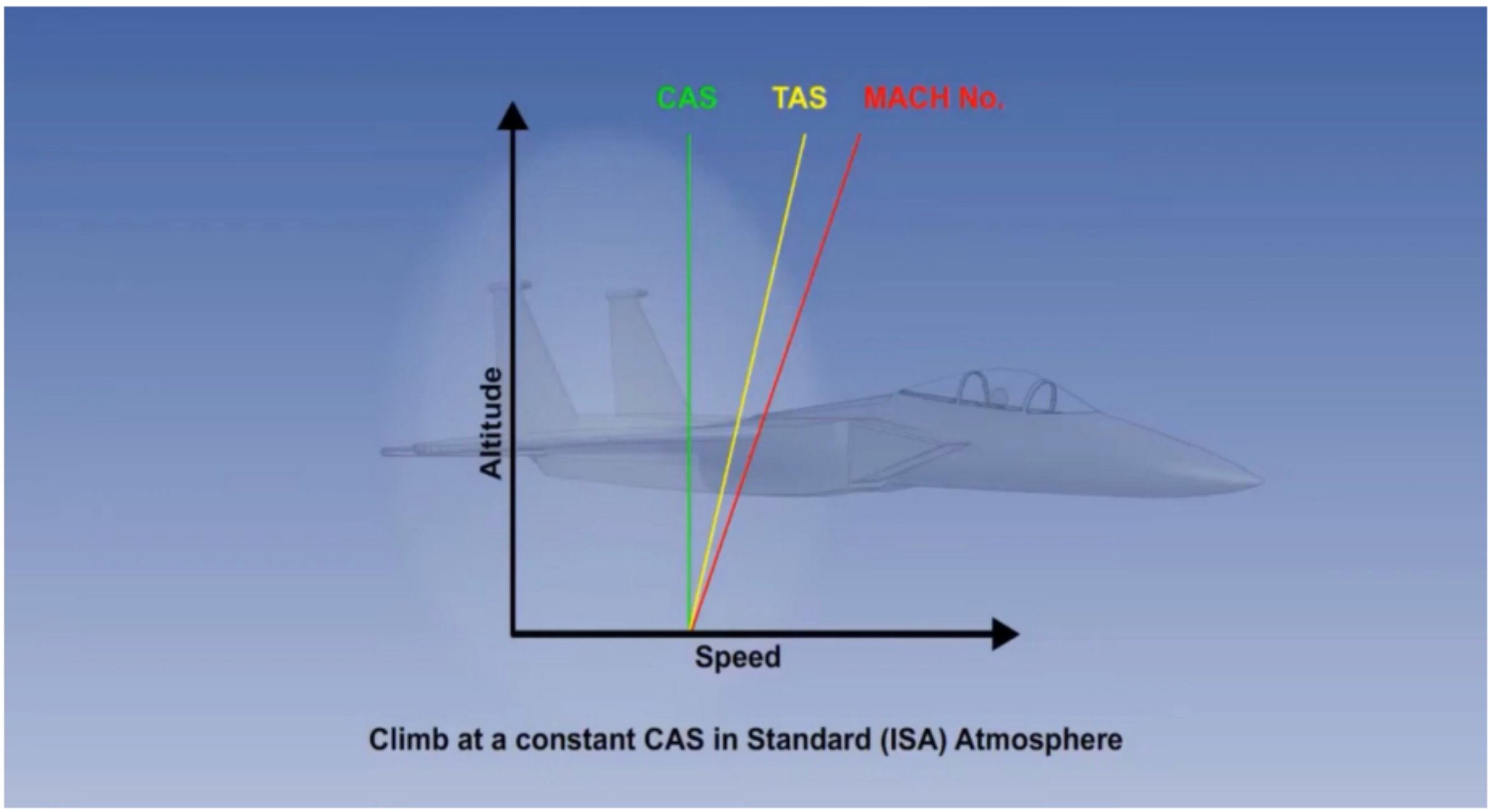
Blockages

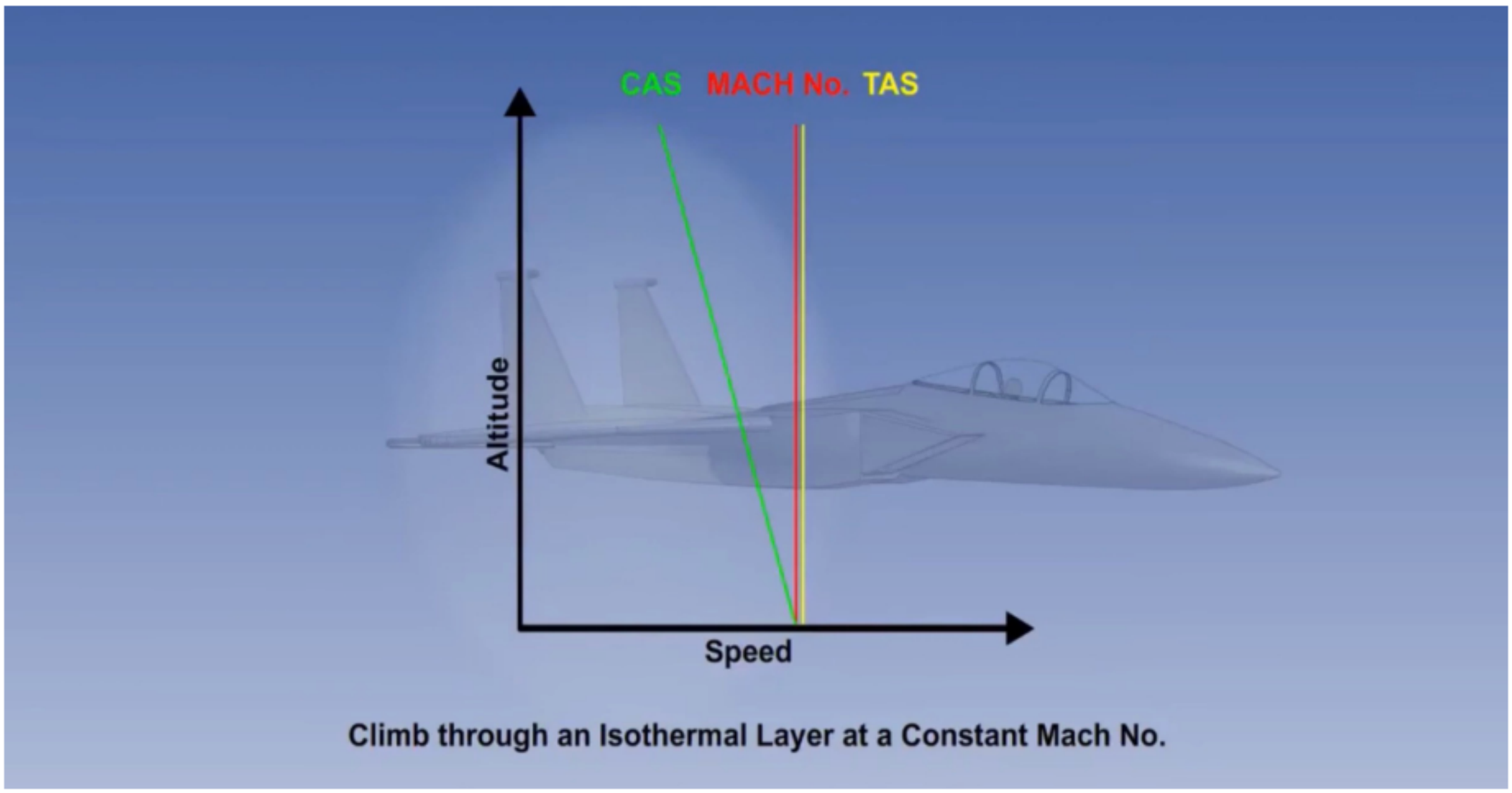
1. **PITOT Main Intake-** **(MM stuck on 0)**
    - Dynamic P from capsule escaped via drain hole and both equalise at static.
2. **Drain Hole-** Normal but water issue
3. **Both blocked-**
    - MM frozen at last reading if altitude maintained.
    - In Climb/Descent, **MM becomes an altimeter.**
4. **Static Block-** Opposite of altimeter

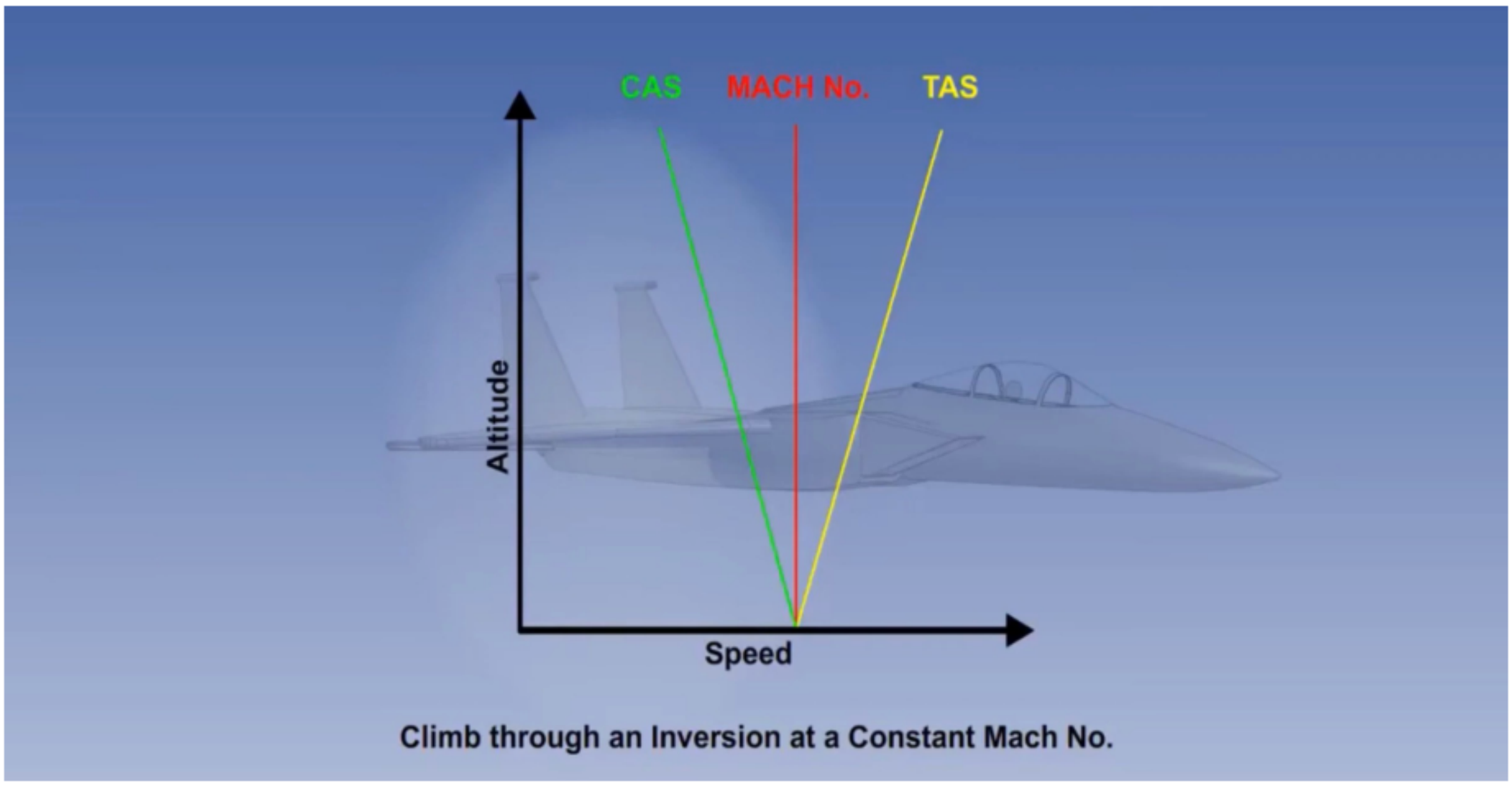
USE OF IAS AND MACH

- At low altitudes the speed is limited mainly by structural issues (VMO).
- At high altitudes, speed is limited by the adverse effects of shock waves (MMO).









Assuming the flight level and Mach number remain constant, if
OAT increases, TAS increases
OAT decreases, TAS decreases
IAS/CAS stay constant

Maximum TAS when CAS=VMO and M = MMO

How to solve for EAS/CAS/TAS/MACH

<u>With Constant CAS in a climb:</u>

- ECTM +

Given:

CAS constant: place an = above the C

Everything to the left of the = gets a - on top.

Everything to the right of the = gets a + on top.

```
  -  =  +  +
- E  C  T  M  +
```

Therefore, in a climb with constant CAS, EAS decreases, TAS increases and MACH increases.

How to solve for EAS/TAS/MACH

<u>With Constant CAS in descent:</u>

+ ECTM -

Given:

CAS constant: place an = above the C

Everything to the left of the = gets a + on top.

Everything to the right of the = gets a - on top.

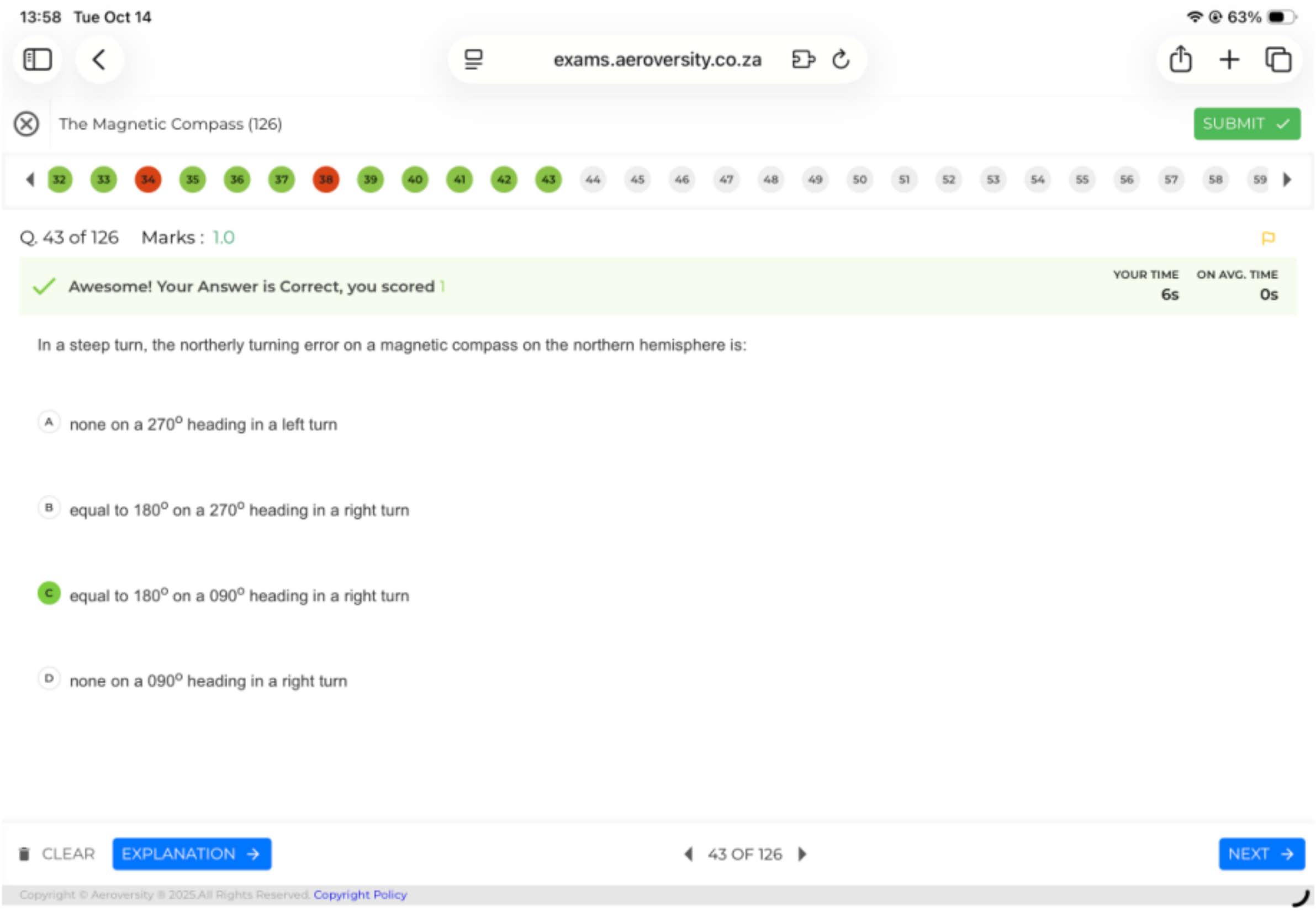
```
  +  =  -  -
+ E  C  T  M  -
```

Therefore, in a descent with constant CAS, EAS increases, TAS decreases and Mach decreases.

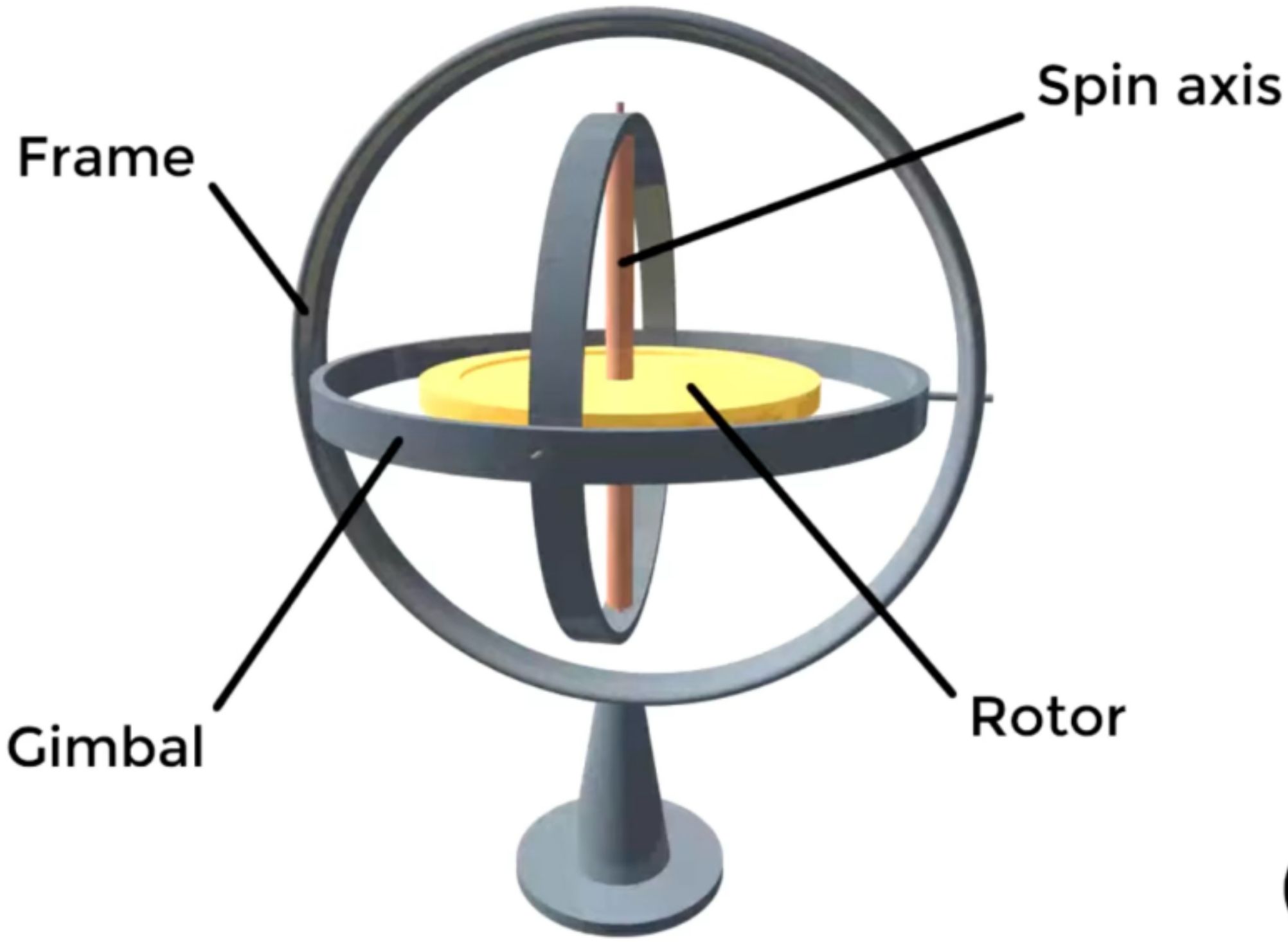
Magnetic Compass 🧲🧭

- COG lies below pivot point to reduce influence of ***magnetic inclination***
- Acceleration errors caused by ***magnetic dip***
- *Deviation is not corrected but determined by calibration* ***(Compensation corrects it)***
- Deviation is the angle between compass needle and horizon
- Compass errors due to North change
- Quadrant deviation is corrected by soft iron pieces (those pieces are influenced by geomagnetic field)
- Compass vs Deviation has a swinging curve
- In a **gyromagnetic compass** flux valve feeds the error detector which feeds the precession amplifier which feeds the torque motor which precesses the gyro

```
Shoot = 1/2(Lat) * 15°
```



Gyroscope



Rigidity = $mr^2 * \omega$
(Inertia = mr^2 and RPM = ω)

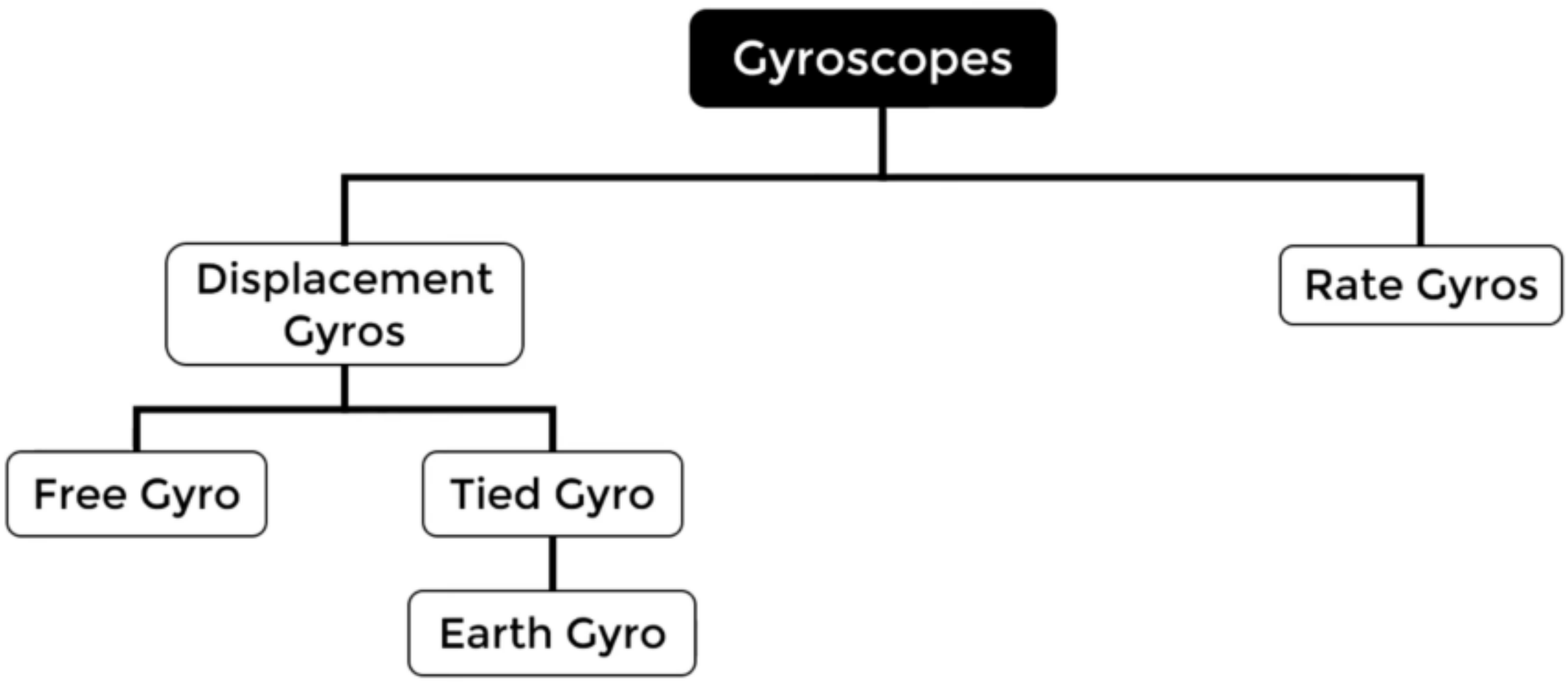
Precession = $(T/mr^2) * \omega$

An air driven gyro system operates on the principle of air being removed from the case via suction pump or Venturi

Displacement Gyros

1. **Space (FREE) Gyro**
   - 3 DOF
   - Only in older inertial systems
2. **Tied Gyro**
   - 3 DOF
   - Maintains axis if rotation
3. **Earth Gyro**
   - Tied to earth

Rate Gyros (2 DOF)



Errors of Gyro

Drift (Horizontal) and Topple (Vertical)

- **Apparent Wander**
  - Max at poles and Min at EQTR
  - NH, HDG decreases and DRIFT is to RIGHT & Spin Axis Clockwise
  - SH, HDG increases and DRIFT is to LEFT Spin Axis Anti-Clockwise

```
15 * sin(LAT)  [per hour]
```

- **Apparent Topple**
  - Zero at poles and Max at EQTR

```
15 * cos(LAT)  [per hour]
```

- **Transport Wander**
  - Due to a/c movement

```
(Ground Speed/60) * tan(LAT)  [per hour]
```

Attitude Indicator

- Vacuum powered and sometimes electric
- Vertical gyro with 3DOF
- Excessive pitch/bank leads to mechanical stops preventing gyro rotation freely and hence topples for few minutes
- Apparent wander compensated by **pendulous vanes in vacuum** and **electrical torque motor in electric**
- Caging knob to prevent toppling and for alignment. Used only in straight and level flight.

14:37 Wed Oct 15 60%

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Gyroscopic Instruments (155) SUBMIT

13 14 15 16 17 18 19 20 21 22 23 24 25

Q. 26 of 155 Marks : 1.0

Awesome! Your Answer is Correct, you scored 1

YOUR TIME 17s ON AVG. TIME 0s

When an aircraft has turned 90 degrees with a constant attitude and bank, the pilot observes the following on a classic artificial horizon:

A too much nose-up and bank correct

B too much nose-up and bank too low

C attitude and bank correct

D too much nose-up and bank too high

Answer Explanation

Artificial Horizon turning errors:

- Turning through 90°: Under reads bank angle; Pitch error – indicating a climb

- Turning through 180°: Bank angle correct; Pitch error – indicating a climb (maximum pitch up error)

- Turning through 270°: Over reads bank angle; Pitch error – indicating a climb

- Turning through 360°: Bank angle correct; Pitch correct

Artificial Horizon Acceleration Errors:
- Accelerate = nose up and right roll indicated
- Decelerate = nose down and left roll (left wing low) indicated

Attitude Indicators

The attitude indicator - also referred to as the gyro - horizon, attitude gyro, and artificial horizon - is constructed to show the attitude of your aircraft in relation to the natural horizon when for any reason you must, or choose to, control your aircraft by visual reference inside, rather than outside, the cockpit. Irrespective of variations in instrument design, all attitude indicators relate a gyro - controlled

CLEAR EXPLANATION → 26 OF 155 NEXT →

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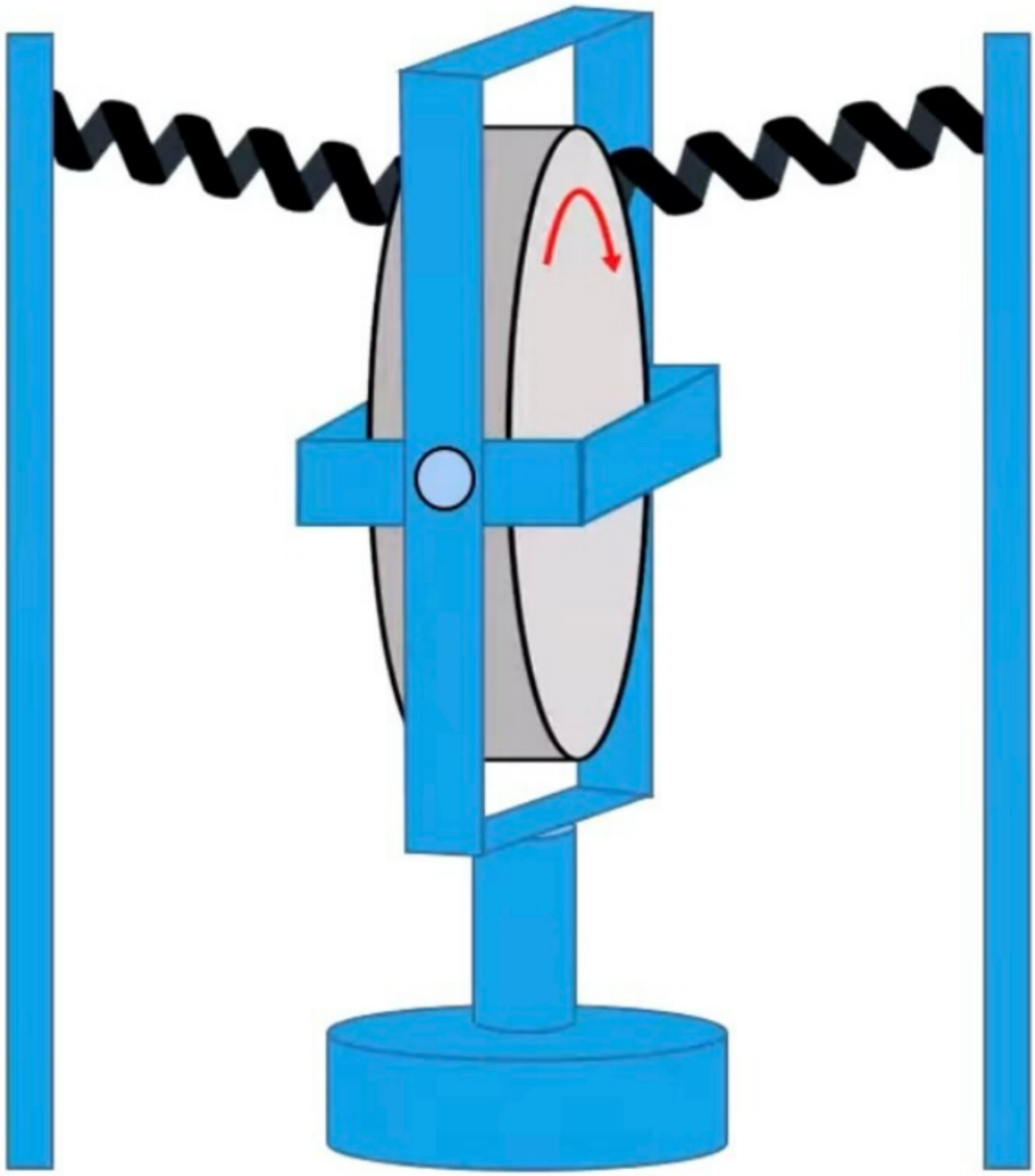
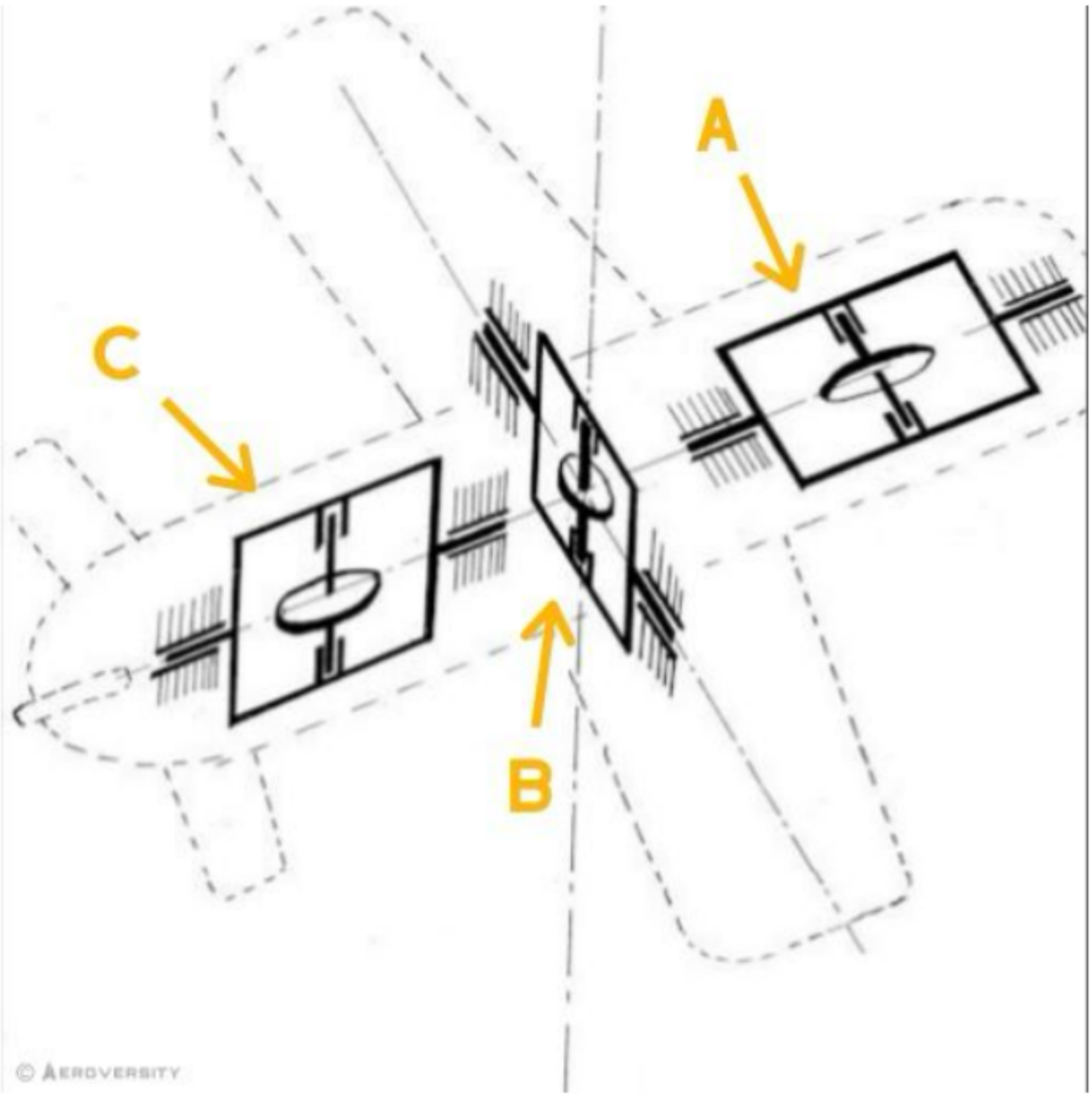
- Gyro axis of an electric artificial horizon is tied to the Earth vertical by two mercury level switches and two torque motors
- A standby Horizon or emergency attitude indicator has its own gyro and power supply
- The vertical reference of a data generation unit is vertical axis with 2DOF

Turn Coordinator



- Horizontal rate gyro tilted at 30°
- Pitch Axis
- 1DOF
- Electric
- Rate of precession measured
- 2 Calibrated springs limit the movement and bring it to original position after turn
- Low bank angle leads to yaw measurement
- Turn indicator is inversely proportional to TAS

Turn and Slip Indicator gyro has no tilt



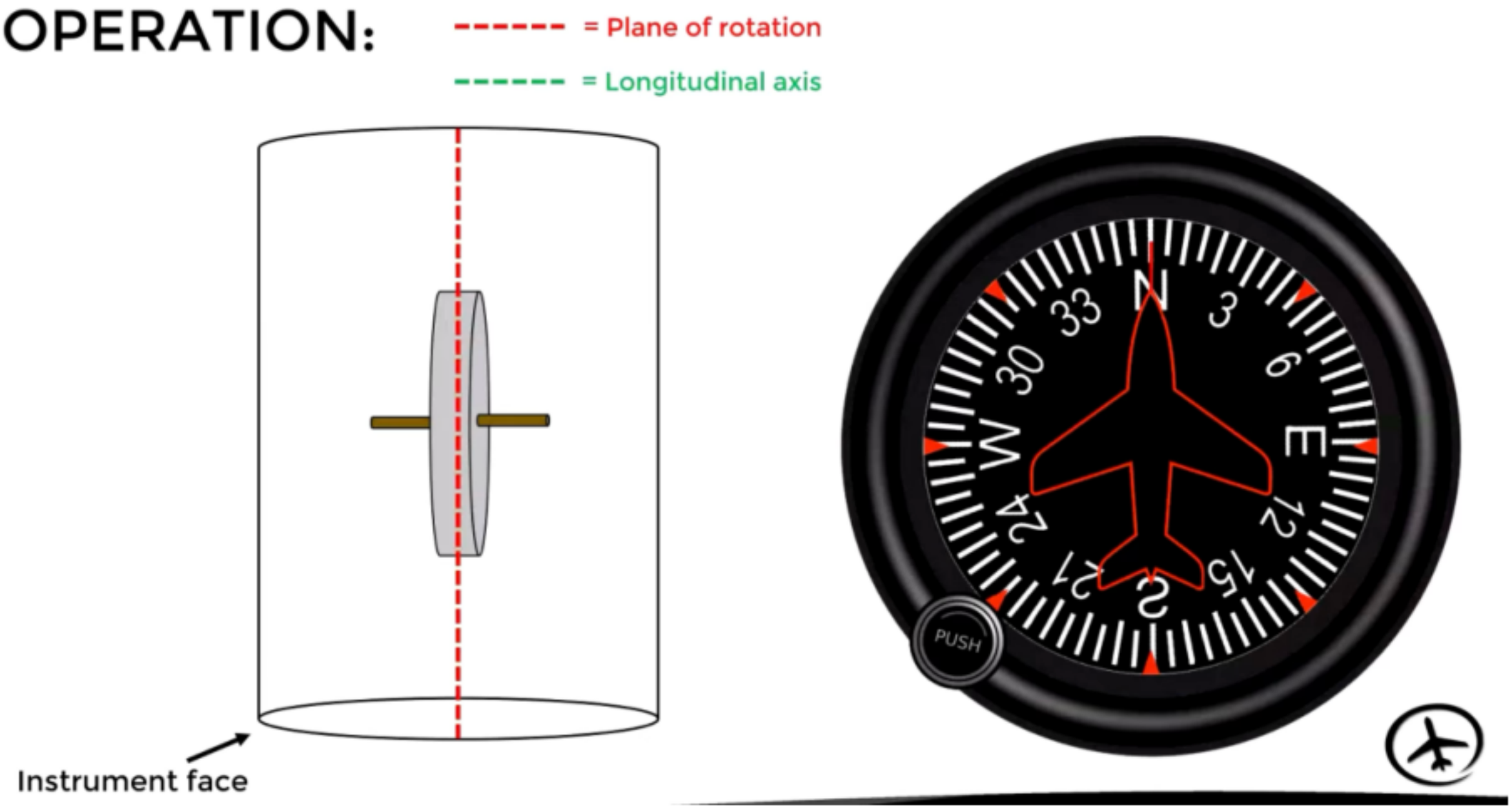
A YAW

B ROLL

C PITCH

Directional Gyroscope

OPERATION:



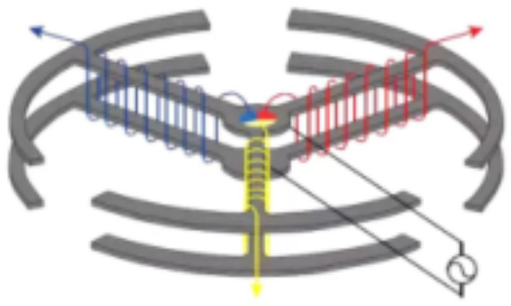
- Vacuum powered
- Horizontal and 2DOF
- Mechanical stops prevent toppling in excessive pitch/bank
- Apparent wander needs to be corrected manually by pilot using cage/adjustment knob
- The system, which detects the local vertical supplies a levelling erection torque motor
- Gimbal error due to bank/pitch
- Earth rate corrected by latitude nut

```
Rate 1 Turn angle = (TAS/10) + 7
```

Gyromagnetic/Slave/Remote Compass

- Automatic magnetic correction system applied to directional gyro in slave mode
- No manual correction required unless FREE MODE
- No turning and acceleration errors

SYSTEM COMPONENTS:



Magnetic Detector
(Flux Valve)

Heading Indicator

Horizontal Gyroscope

Control Panel

Amplifier

Precession Motor

Flux valve determines orientation of a/c vs magnetic north (HEADING)

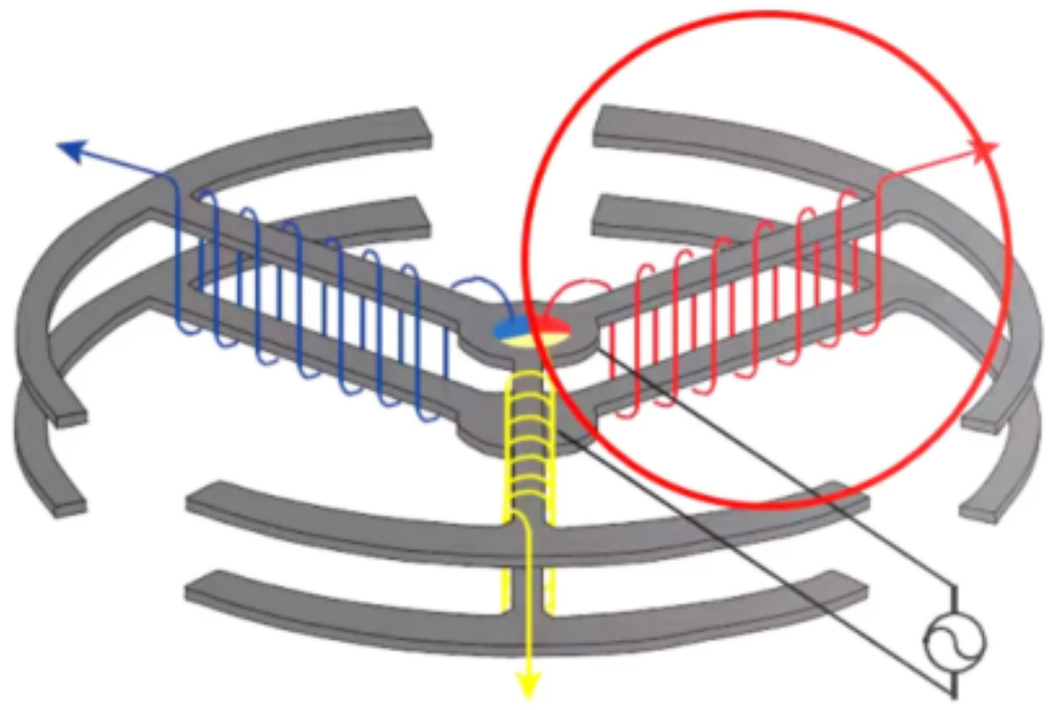
```
if flux_heading == indicator_heading
{no correction required}
//This is the error detection unit

else { AC current is generated and sent to amplifier which
directs it to control panel in DC current,
Control panel makes precession motor re-align the gyro for
North}
```

- Flux valve at wingtips and tail outside of a/c system interference
- Housed in sealed capsule with liquid to dampen vibrations
- Suspended on universal joints limited by 25° pitch/bank
- Permalloy (Iron+Nickel)
- Powered by 400Hz AC

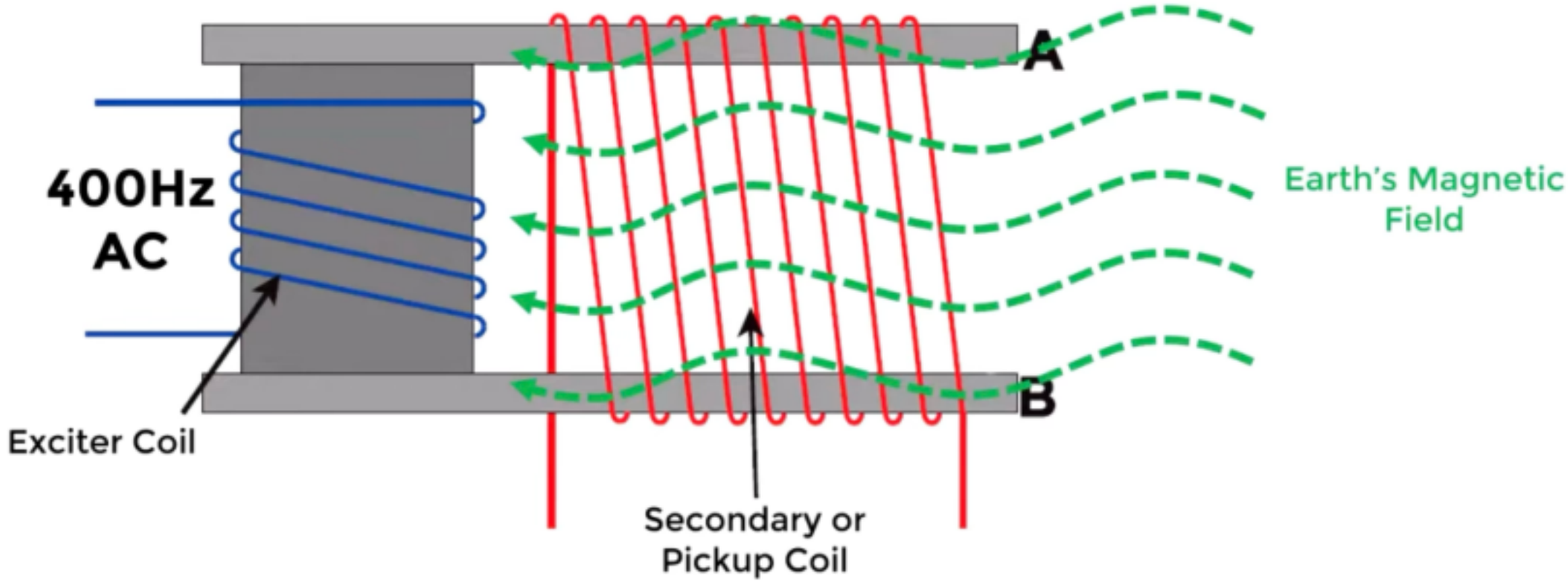
FLUX VALVE

- It consists of a 3-arm structure made of soft ferromagnetic metal.
- It has a main exciter coil in the center and 3 secondary or pickup coils (one on each arm).



Permalloy

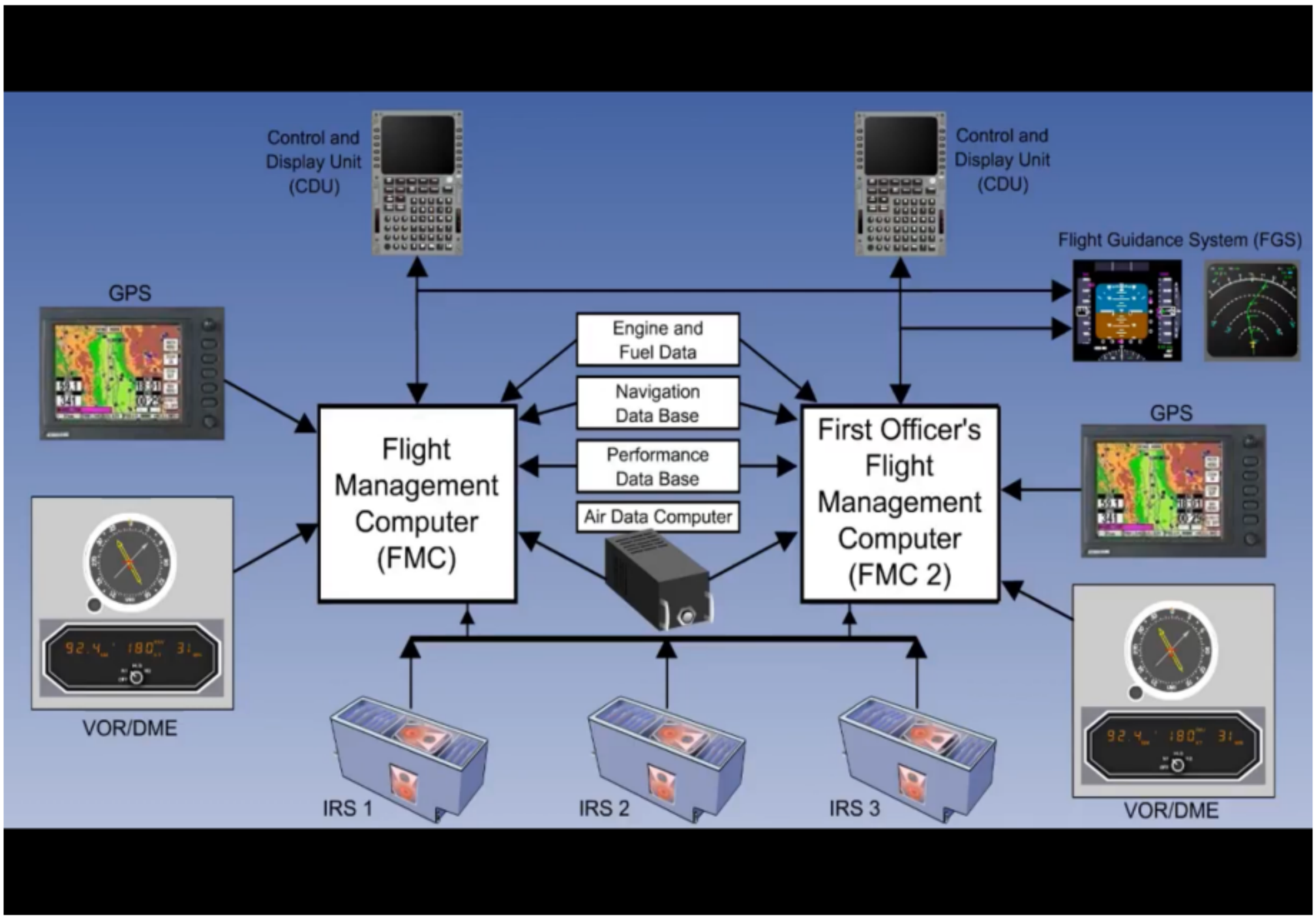
Iron and Nickel



This external magnetic field affects the flux balance.

- 3 outputs averaged for exact heading and fed to correction system.

FMS



- For multiple DME sensor, position error with 95% probability in non-precision approach is less than 0.3NM
- Used **only for non-precision** approaches (RNAV, VOR, NDB)
- Cost Index is a/c operating cost divided by fuel cost
- 0 Cost Index is fuel efficient and max. Range
- Vertical profile depends only on weight, cost index, and fuel quantity
- Fuel prediction is based only on current W/V
- Overfly Function consists in manually selecting a flight plan waypoint to fly over when sequencing it instead of flying by at the transition
- NDB not used to compute a/c position
- XTK is abeam distance error from desire flight plan leg
- FMS does not give aircraft position

Dual Mode (Interlinked FMCs)

Independent Mode (Different Readings)

Single Mode (1 FMC INOP)

EFIS

2 individual systems

1. Electronic Attitude Director Indicator **EADI**
2. Electronic Horizontal Situation Indicator **EHSI**
3. Control Panel
4. Symbol Generator
5. Remote Light Sensor Unit

- 3rd backup Symbol Generator

Colour Codes

White	present status information
Green	also present status information, where contrast with white symbols is required, or for data with a lower priority
Magenta	command information, pointers, symbols and fly-to conditions
Cyan	non-active and background information
Red	warning information
Amber	cautionary information, faults and flags

EADI DISPLAY (PFD)

1. Flight Director Command Bars
2. LOC & G/S Deviation Indicators
3. Active NAV AIDS
4. CAS and V speeds
5. Airspeed Trend

6. Auto flight Modes
7. AP Status
8. Altimeter & VSI
9. HDG
10. RADIO ALT

Active Waypoint

Inactive Waypoint

Off Route Waypoint

Airport

Tuned Nav Aid

Unused Nav Aid

Wind Direction

LESSON SUMMARY

- The principal display modes are VOR, ILS, MAP and PLAN
- VOR mode can be displayed in 'Full VOR' mode or 'Expanded VOR' mode
- ILS mode can be displayed in 'Full ILS' or 'Expanded ILS' mode
- The modes are selected using the controls on the EHSI section of the EFIS control panel
- A weather radar display is **not** available in Full VOR, Full ILS and PLAN modes
- The information displays available in the principal and expanded modes should be noted
- The compass rose may be referenced to magnetic or true north from the IRS between latitudes 73° North and 60° South, and to true north above these latitudes
- EHSI modes can be independently selected on the captain's and first officer's control panels
- Failure of a data signal is highlighted, or 'flagged' in yellow, or may be in message format
- The common symbols should be noted

1

Expanded VOR Mode

2

Full VOR Mode

3

Expanded NAV Mode

4

Full NAV Mode

5

Centre MAP Mode

6

Plan Mode

TRK

Instant$^{\uparrow}$ = 115

Select = 120

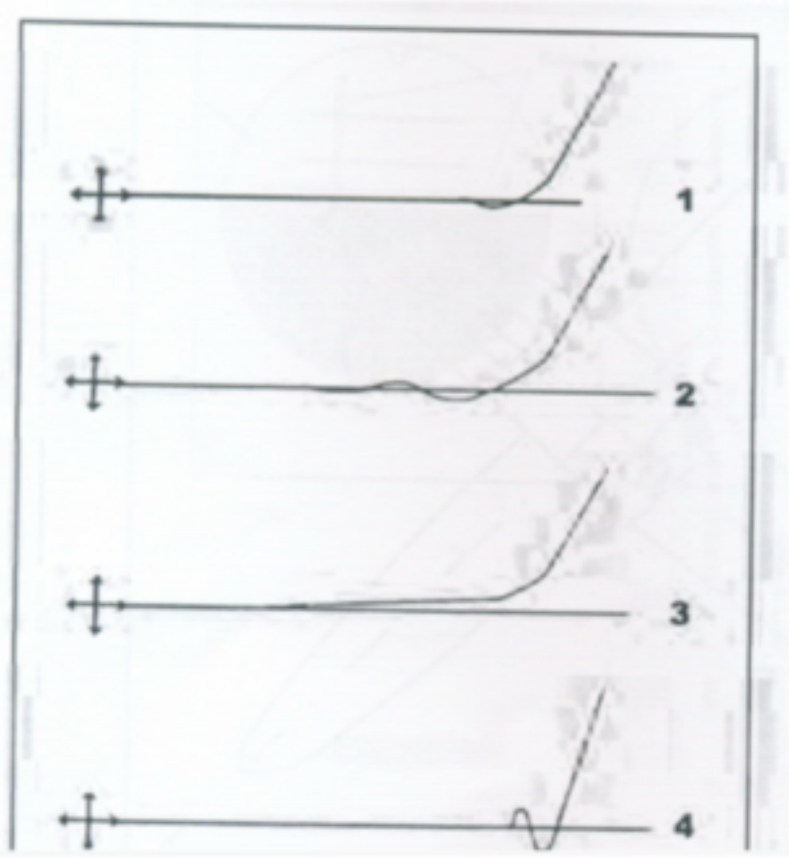
HDG = 125

Cyan/blue	Black	Brown	Green	White	Magenta	Amber/ Yellow	Red
Sky	Blank areas/ off-condition	Earth	Engaged modes	Current data/ values	ILS deviation pointer	Cautions	Warnings
Non-active			Selected data/values	Armed modes	Flight Director bar	Faults	Flight envelope limits
Background information				Fixed ref symbols / aeroplane symbol	Selected heading	Abnormal sources	System limits
				Sky	Active route/flight plan	Flags	
				Turbulence	Turbulence		
© Aeroversity					Active waypoints (can also be white)		

Q. 48 of 74 Marks : 2.0

Sorry. Your Answer is Incorrect, you scored -0.0

YOUR TIME 18s ON AVG. TIME 0s



Four scenarios of VOR axis interception are represented in the appended annex. The one corresponding to the optimal interception path calculated by a flight director is number:

A 3

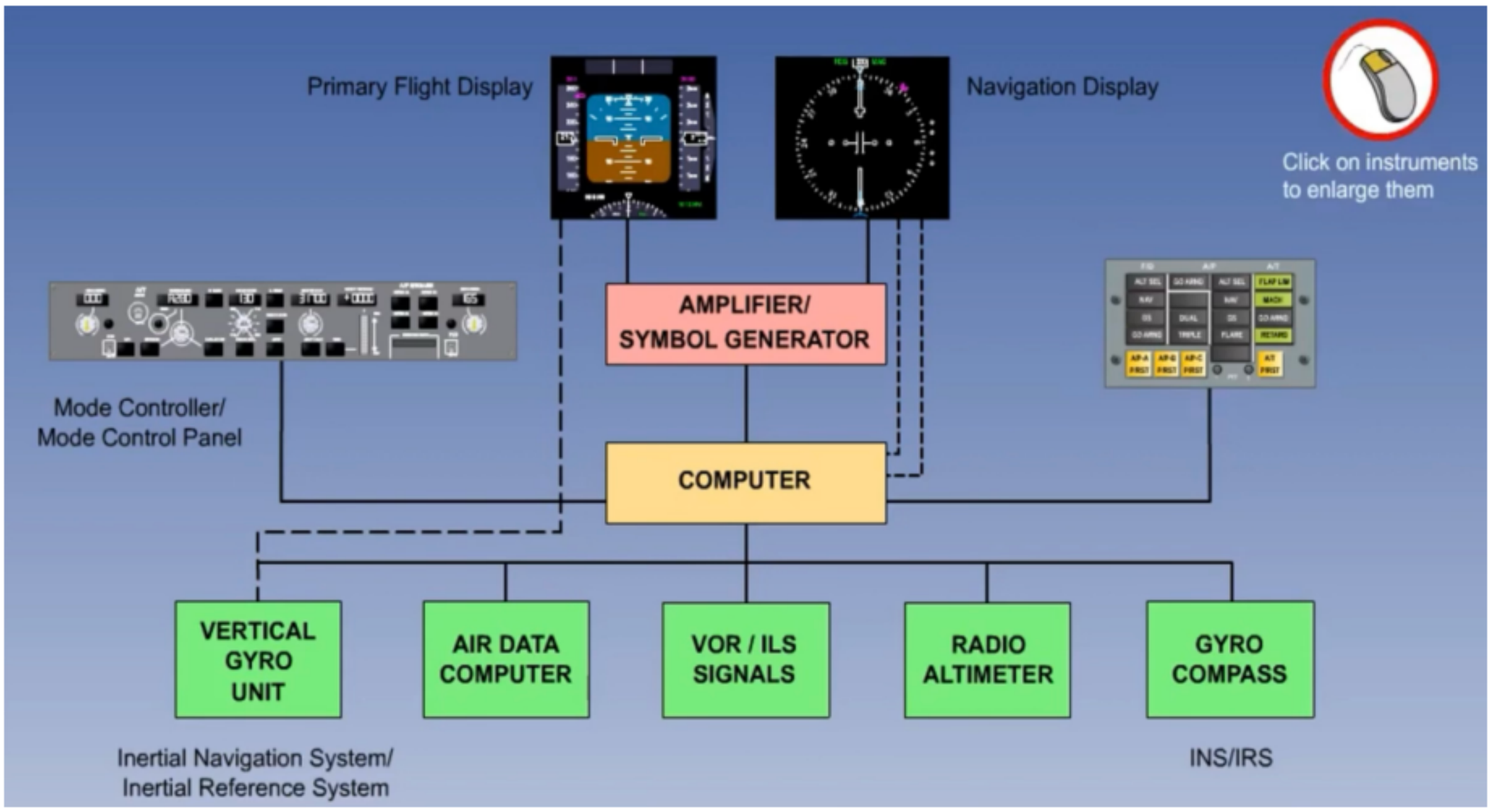
B 1

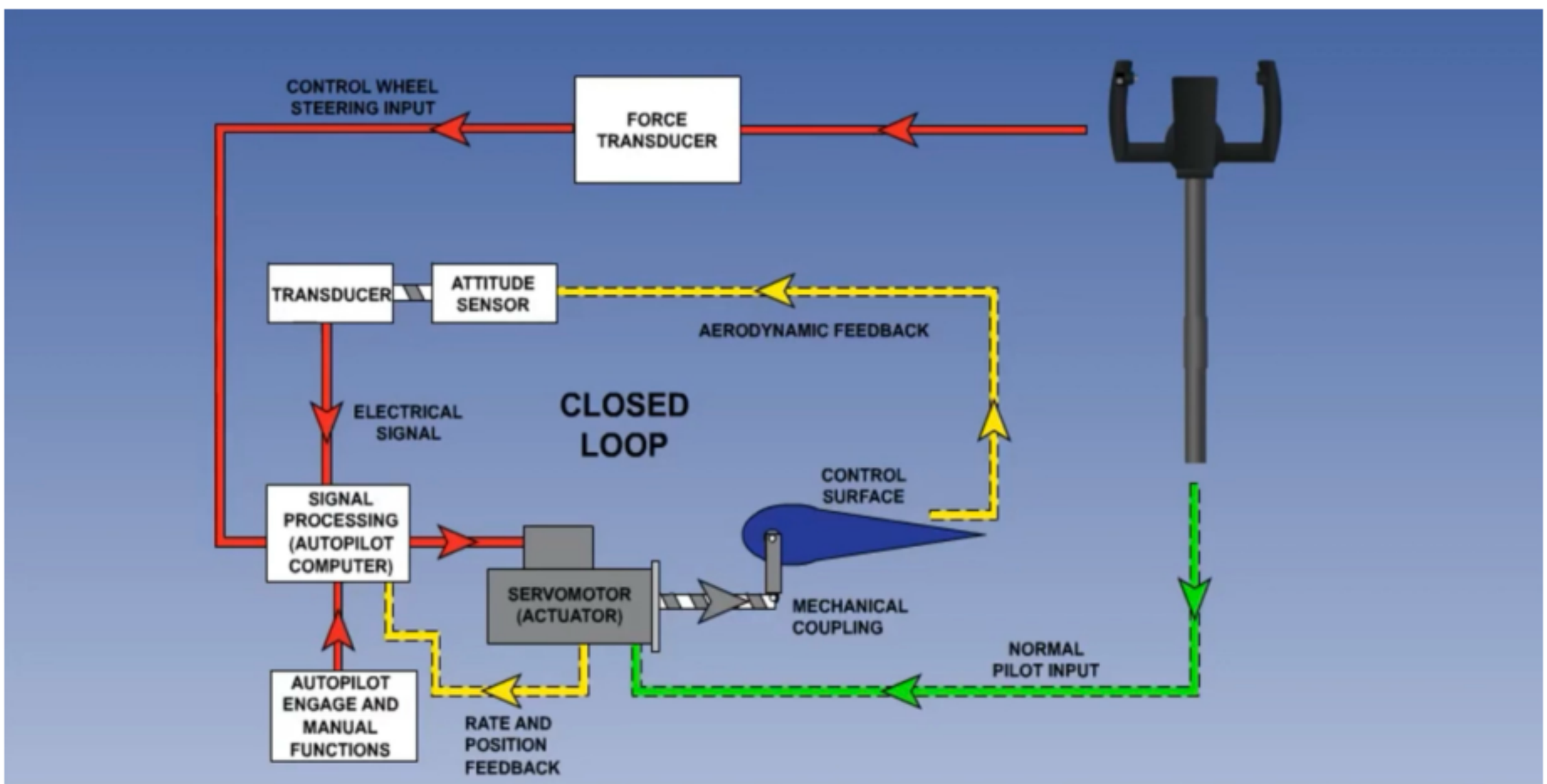
C 2

D 4

- Command is MAGENTA
- Weather only on EXPANDED and MAP
- FMA and TCAS RA on PFD
- FD Vertical Bar is centred if optimum path to join HDG
- No certification required for onboard operating systems
- Only present fuel flow displayed
- All EGT limits displayed EXCEPT COMMANDED EGT
- PLAN is oriented to TRUE NORTH
- White circle (INTC) indicates a location where you will intercept a particular radial to a VOR and track it inbound

Autopilot & FD



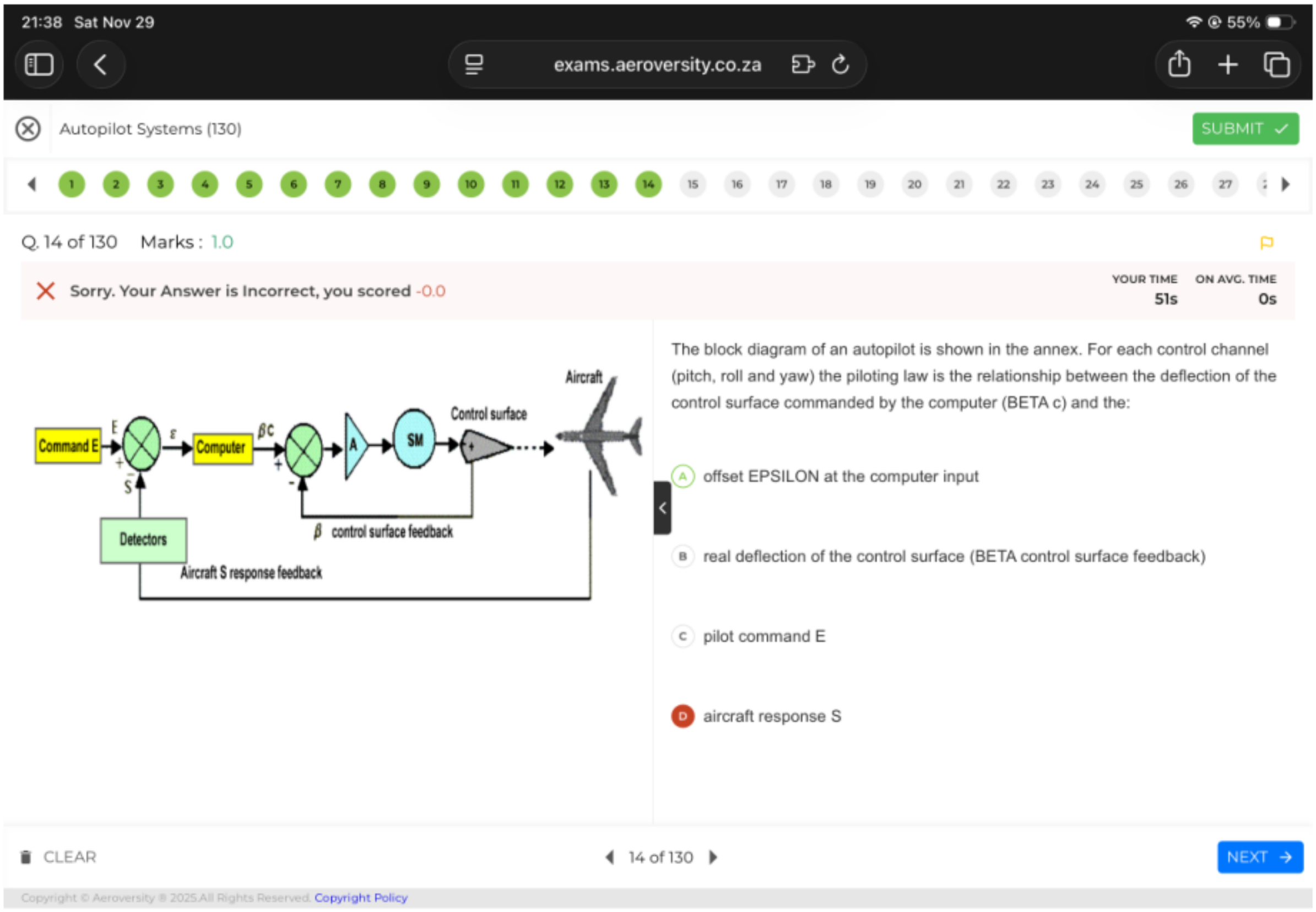


Closed Loop or Inner Loop Stabilisation

Basics

- Roll (Primary Axis)
- Pitch (Secondary Axis)
- Yaw (Tertiary Axis)
- Uses CAS, ALT, VSI, HDG, attitude
- Single Pilot IFR OPS require MIN 2 channel A/P
- *Series Servo moves control column too (ONLY YAW USUALLY)*
- *Parallel Actuator moves control stick*

- Manual pitch trim disengages A/P
- MACH TRIM is independent of the auto pilot
- Automatic synchronisation function prevents the aircraft control system from jerking when ***engaging*** the auto pilot
- Pitch AUTO TRIM cancels the hinge moment, eases servo load, restores control to pilot during A/P disengage.



The "guidance" functions of an autopilot consist in controlling/monitoring the movements of the centre of gravity in the three dimensions of space.

Stabilization: The autopilot basic function is stabilization around its CG.

Guidance: Monitoring the movement of the CG in space (navigation)

ENGAGE INTERLOCK RELAY

1. DISENGAGE BUTTON (3)
2. POWER MONITOR
3. RATE GYRO VALID
4. ENGAGE SWITCH
5. COMPUTER SELF TEST
6. SERVOMOTOR SELF TEST

7. HYDRAULIC PRESSURE
- **Even 1 failure disengages A/P**

Modes
CWS mode allows the pilot to give a manual input via a forced transducer. Releasing input makes the A/P maintain the new attitude.
Purpose is to consider as target parameters, the current pitch and roll angles at the time the mode becomes active

- **ROLL MODES:**
    - HDG SEL (with Bank Angle Limiter)
    - LNAV (FPLAN from FMS)
    - VOR LOC (Flying overhead maintains heading for 2 min)
- **PITCH MODE: (conjunct A/T SPEED)**
    - ALT HOLD
    - VERT SPEED & ALT AQUIRE
- **AUTO THRUST:**
    - SPEED
    - N1/EPR (THRUST)
    - LVL CHG (ALT AQUIRE)
        - A/T switches from SPEED to N1 usually constant 95% in CLIMB and IDLE in DESCENT)
        - After CLIMB, switches to SPEED and ALT HODE)
    - VNAV (FMS FPLN)
        - A/T switches from SPEED to N1 and annunciation is (- - - -)
        - Speed managed by FMS THRUST
    - C/O after MACH 0.7

Auto Land

- ILS
    - **2 NAV SYS**
    - **2 A/P MANDATORY**
    - **2 RADIO ALT**
    - **If 3 A/P, failsafe (LAND3 and LAND2) FAIL OP to FAIL PASSIVE**

Crew Alert & Warning System

Class A (WARNING) - **RED IMMEDIATE ACTION**
Class B (CAUTION) - **AMBER SUBSEQUENT ACTION**
Class C Anything other than RED (Mostly GREEN or WHITE) SUBSEQUENT ***MAY*** BE REQUIRED

Priority **GREEN** for SAFE OPERATION LIGHTS

- BOEING has ALERTING and ADVISORY
- Warnings are audio, visual, sensory

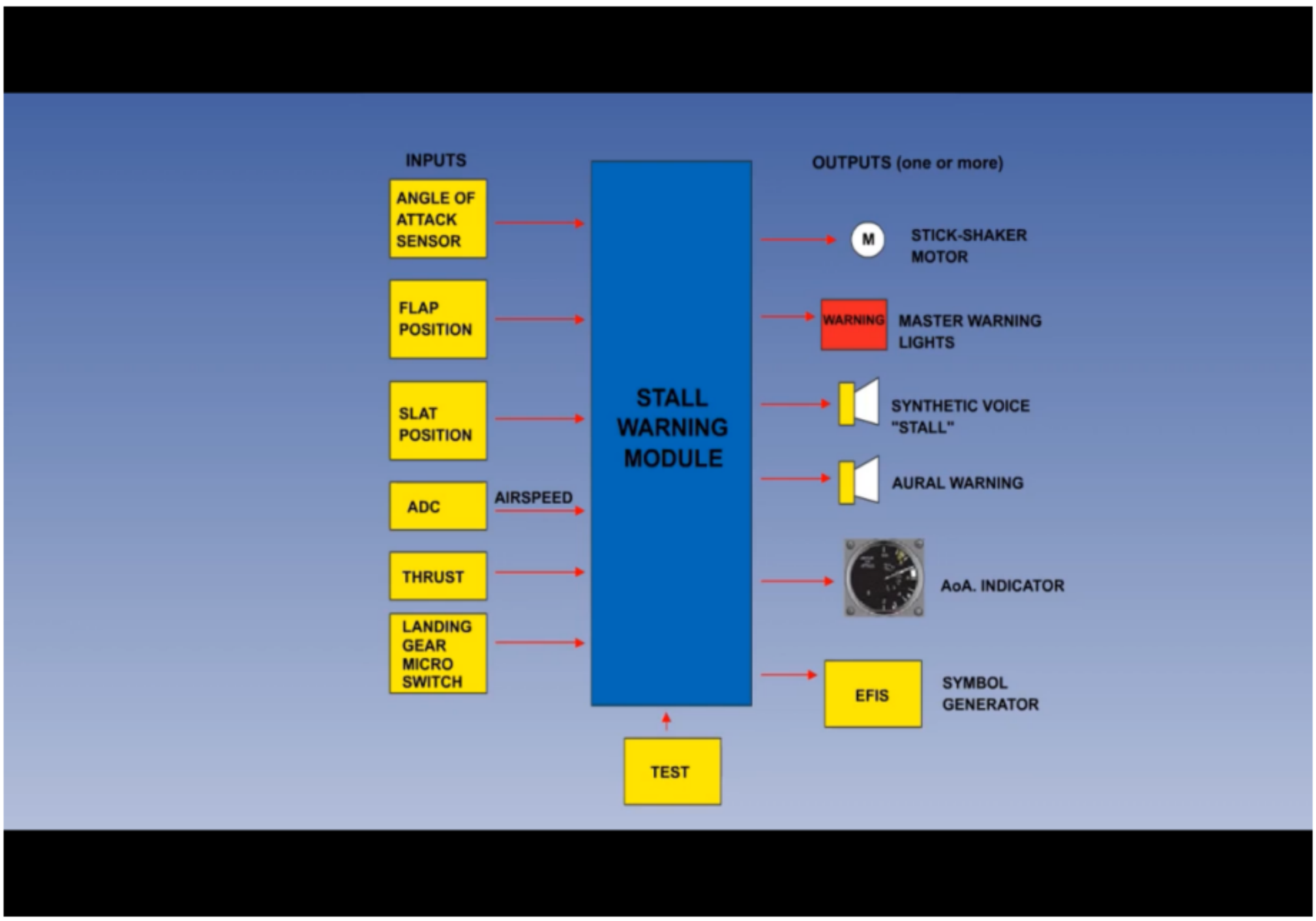
- Alerts are audio, visual

Altitude Alert

Mandatory for all turboprops weighing more than 5700kg or 9+ seats

Overspeed & Stall Warning

- VMO/MMO limits **(INPUT is STATIC PRESSURE ONLY)**
- Plucker sound
- MASTER WARNING blinks but can't cancel warning
- OVERSPEED displayed on ECAM
- Stall warning needs only AOA, config
- Warning goes 5% before stall speed
- Required margin related to stall speed is 7% if regulatory margins not followed
- Audible warnings and stick shaker with flaps and LG in any normal position
- Stick pushed automatically
- Inhibited on ground only



GPWS

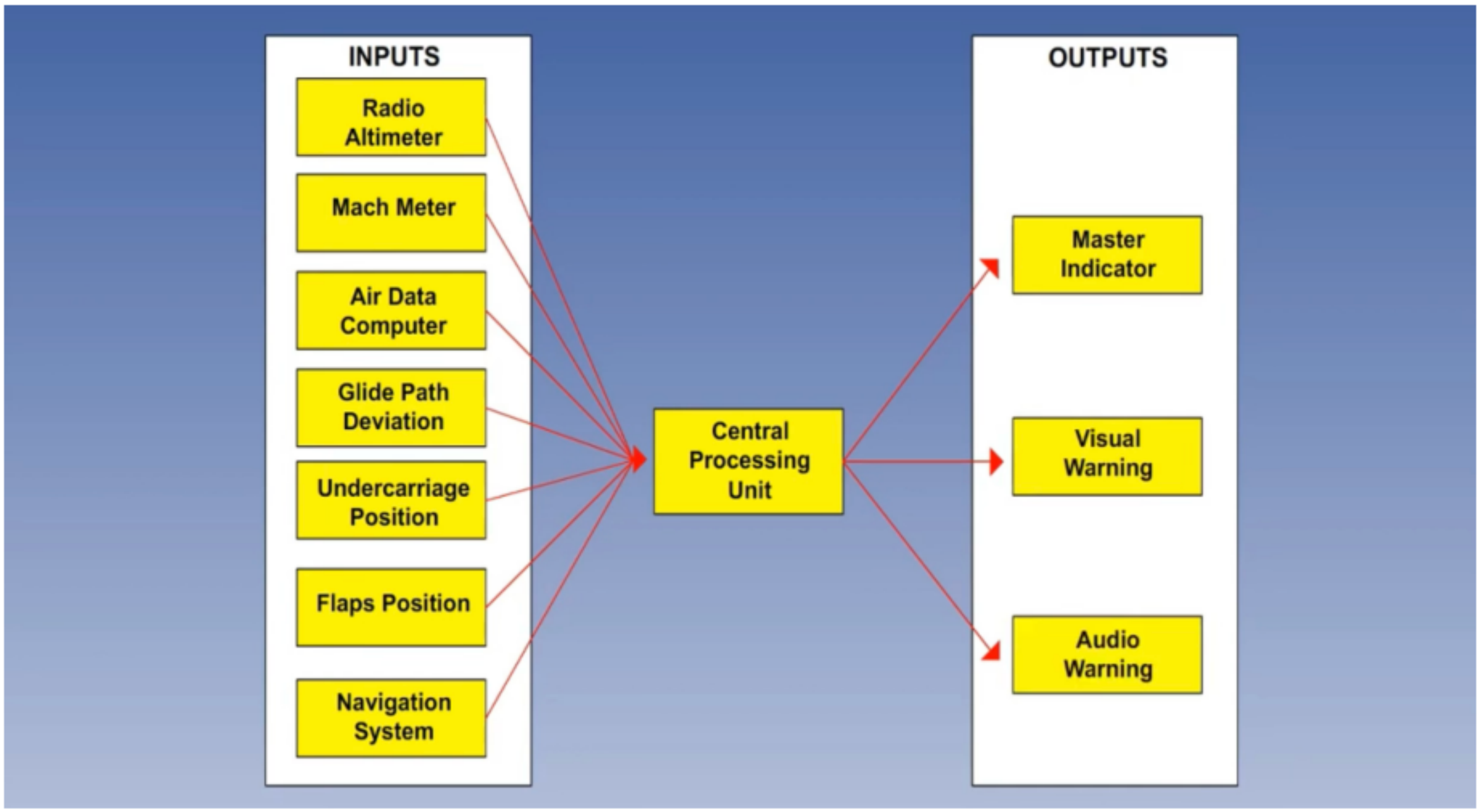
- MODE 1
    - Sink Rate Sink Rate
    - PULL UP

- MODE 2
    - Terrain Terrain
    - PULL UP
- MODE 3
    - DON'T SINK
- MODE 4A (Gear Up below 500ft)
    - TOO LOW GEAR
    - PULL UP
    - TOO LOW TERRAIN
- MODE 4B (Gear Down & FLAPS UP)
    - TOO LOW FLAPS
    - PULL UP
    - TOO LOW TERRAIN
- MODE 5
    - GLIDE SLOPE
    - PULL UP LIGHT
- MODA 6A (50-1000ft)
    - Below DH (MINIMUMS MINIMUMS)
- MODE 6B
    - BANK ANGLE BANK ANGLE
    - 50 40 30 20 10 RETARD
- MODE 7 (HIGHEST PRIORITY)
    - WINDSHEAR WINDSHEAR WINDSHEAR

GPWS MODE		ADVANCED EQUIPMENT Alert	Warning
1. Excessive descent rate		'Sink Rate'	'Whoop Whoop Pull Up'
2. Excessive terrain closure rate		'Terrain Terrain'	'Whoop Whoop Pull Up'
3. Altitude loss after take-off or go-around		'Don't Sink'	'Terrain Terrain'
4. Unsafe terrain clearance while not in the landing configuration	4A. Proximity to terrain. Gear not locked down	'Too Low Gear'	'Too Low Terrain'
	4B. Proximity to terrain - Flaps not in a landing position	'Too Low Flaps'	'Too Low Terrain'
5. Descent below glide-slope		'Glideslope'	-
6. Descent below 'minimums'	6A.	'Minimums'	-
	6B.	'Bank Angle'	-
7. Windshear warning		-	'Wind Shear'

EGPWS (TAWS)

- Terrain displayed on ND
- CAUTION TERRAIN
- GREEN to YELLOW to RED
- Inputs are ADS, IRS, RADIO ALT, FMS, GPS, ILS



RADIO ALTIMETER inputs to TCAS, GPWS, ALS

TCAS

Monitors large number of a/c but **displays upto 30**

- **CAUTION AREA: AMBER SOLID CIRCLE**
  - TA 35-45sec
  - Traffic Traffic
  - TA needs minimum MODE A
- **WARNING AREA: RED SOLID SQUARE**
  - RA 15-35sec
  - RA needs minimum MODE C
  - Climb **(INHIBIT With gears & flaps deployed, if a/c is performance limited)**
  - Increase Climb **(INHIBIT With gears & flaps deployed, if a/c is performance limited)**
  - Decrease Climb
  - Descend
  - Increase Descend **(INHIBIT below 1450 RADIO ALT)**
  - Decrease Descend
  - *Monitor Vertical Speed (Preventive Advisory)*

No RA below 1000 RADIO ALT

No TA below 400 RADIO ALT

- COLLISION AREA:

1. **OTHER TRAFFIC-**
   - **Hollow Cyan Diamonds**

    - Within selected range
    - +/- 2700ft in cruise
    - +8700/-2700 in CLIMB
    - -8700/+2700 in DESCENT
2. **PROXIMATE TRAFFIC-**
    - **Solid Cyan Diamond**
    - Within 6NM
    - +/-1200 ft

BEARING LEAST RELIABLE IN TCAS
DO NOT FOLLOW
JUST FOLLOW VERTICAL COMMANDS

DATA TAG
(+) means intruder is ABOVE 👆
(-) means intruder is BELOW 👇
⬆️⬇️ (Verical Arrows) appear when intruder's vertical rate is 500ft/min or greater

AEROVERSITY NOTES

- No pilot may act as PIC of any South African registered aircraft while TCAS/ACAS is active when he or she is not ACAS/TCAS current
- A thermocouple type temperature sensor is composed of two dissimilar metals joined together at one end called Hot Junction or Measure Junction
- RA advises the pilot to avoid certain deviations from the current vertical rate, but does not require any change to be made to that rate
- The upper antenna of the TCAS2 is directional and separate from the transponder antenna
- TCAS RA does not take into account as stall margin

Q. 68 of 76 Marks : 1.0

✕ Sorry. Your Answer is Incorrect, you scored -0.0

YOUR TIME 15s ON AVG. TIME 0s

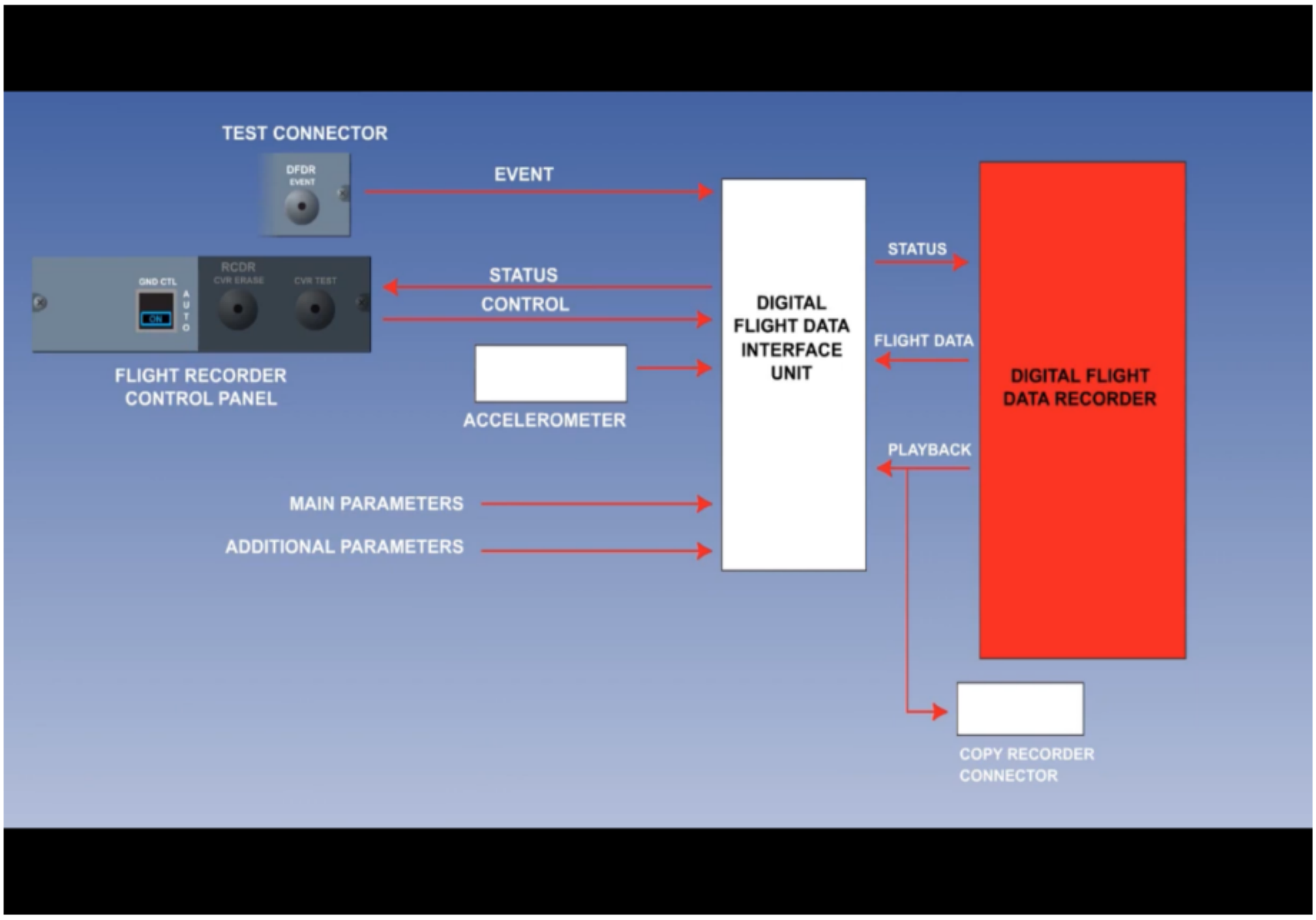
A TCAS Resolution Advisory (RA) voice message "CLIMB - CLIMB NOW" repeated twice is generated:

A when cleared of conflict, and below the cruise altitude

B each time a "CLIMB" RA is announced by a voice message

C after a "DESCEND" RA when a reversal in the vertical manoeuvre sense is required

D after a "CLIMB" RA when the climb vertical rate is too weak

Black Box

- ORANGE or RED
- CVR + FDR
- Tail of the a/c
- Resists fire, heat, shock, water
- AUTO ON when AIRBORNE or ON GND WITH 1 ENGINE RUNNING till 5MIN AFTER ENGINES OFF