

022 Instrumentation

022-01 Sensors and Instruments

Power = Work done / Time

022-01-01 Pressure Gauge

Position Error, Maneuver Error, 1 bar = 100000 Pa, 1 bar = 14.5 psi

aneroid (diaphragm)	low	flexible metal chamber	turbine air intake, LP booster pumps, altimeter
bellows	medium	capsule of bellows	cabin differential, manifold, fuel pressure
bourdon tube	high	coiled tube, hydraulics	oxygen pressure, oil pressure, hydraulics

022-01-02 Temperature Sensing

SAT .. static air temp (undisturbed temp outside ac)

TAT .. total air temp (TAT > SAT)

RAT .. ram air temp (indicated, less than TAT)

ram rise .. difference between TAT and SAT

recovery factor .. % of ram-rise that can b measured

$$SAT_K = \frac{TAT_K}{1 + 0.2 K_r M^2}$$

mercury	-37°C to 356°C
bimettalic	-50°C to 400°C
resistance type	up to 500-600°C
thermocouple	-200°C to 2000°C

EMF = constant * hot junction temperature

hot and cold junction, alumel/chromel system

022-01-03 Fuel Gauge

$$C = e \times \frac{a}{d}$$

C .. capacitance

e .. dielectric permittivity

a .. area of plates

d .. distance between plates

$$Q = C \times U$$

Q .. charge

C .. capacitance

U .. potential difference

022-01-05 Tachometer

mechanical	drive shaft turns magnet to produce eddy current
electrical	drive shaft turns generator "magnet rotor"
electronic	impulse counting (phonic wheel) "magnetic sensor"

022-01-07 Engine Torquemeter

electronic	twisting of shaft
oil torque meter	magnesyn synchro system

Torque = Force * Lever Arm

Power = Torque * RPM

Power = Torque * Angular Velocity (Ω)

022-01-09 Engine Vibration Monitoring

piezoelectric crystal or magnetic, dimensionless indication, always amplified & filtered

022-02 Measurement of Air Data Parameters

022-02-03 Angle of Attack Measurement

alpha-sensor (wind vane), conical probe (differential pressure)

022-02-04 Altimeter

hysteresis error – due to mechanical properties of capsules, causes lag, varies with time passed at altitude

instrument error – manufacturing imperfections, friction in the linkage, error is greater at altitude

time lag – should be max 150ft

barometric error – due to incorrect subscale setting (when qnh changed)

temperature error – error due to non-standard-temperatures below aircraft

022-02-05 Vertical Speed Indicator (VSI)

time lag can be improved with accelerometers - „instantaneous VSI“ (IVSI)

022-02-06 Airspeed Indicator (ASI)

CAS = IAS + position & instrument error correction

TAS ~ IAS + 1% per 600'

EAS = CAS + compressibility error correction

PUDSOD – pitot underreads in descent, static overreads in descent

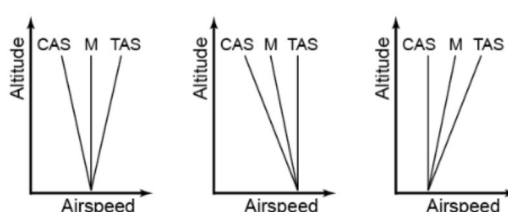
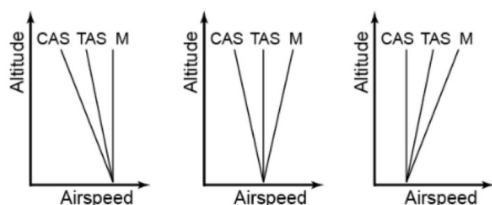
TAS = EAS + density error correction

022-02-07 Machmeter

$$M = \frac{TAS}{LSS} \quad LSS = 38.96 \cdot \sqrt{T} \quad \frac{P_T - P_S}{P_S} \quad M = \frac{CAS}{\text{static pressure}}$$

Standard Atmosphere

Inversion Layer



022-02-08 Air Data Computer

Input: total pressure from pitot tube, static pressure from static ports, total air temperature

output: ALT, VSI, ASI, Mach, TAS, (TAT), SAT

022-03 Magnetism – Direct Reading Compass And Flux Valve

022-03-02 Aircraft Magnetic Field

Hard Iron (Permanent) – during construction
 Soft Iron (Temporary Magnetism)
 swinging vs calibration

022-03-03 Direct Reading Magnetic Compass

ANDS – accelerate north, decelerate south
 UNOS – undershoot north, overshoot south
 overshoot by (bankangle + latitude) / 2, max 30°

022-03-04 Flux Valve

FEAT – Flux valve, Error Detector, Amplifier, Torque motor

022-04 Gyroscopic Instruments

022-04-01 Gyroscope: Basic Principles

real wander – due to imperfectly balanced gyroscope rotor, worn-out bearings, etc.
 apparent wander – earth's rotation (in NH clockwise drift, in SH anti-clockwise drift)
 - drift in ° per hour = $15^\circ * \sin(\text{latitude})$, zero at the equator, maximum at poles
 - topple in ° per hour = $15^\circ * \cos(\text{latitude})$, zero at the poles, maximum at the equator

022-04-02 Rate of Turn indicator / Turn Co-ordinator – Balance (Slip) Indicator

Angle of bank for Rate 1 turn = $TAS / 10 + 7$

022-04-03 Attitude Indicator (Artificial Horizon)

	air driven	electrically driven
acceleration error	climbing right turn	climb
turning error	90° - climb, under-indication of bank 180° - climb, correct bank 270° - climb, over-indication of bank 360° - correct indication	false bank

023 Inertial Navigation and Reference Systems (INS and IRS)

022-05-01 INS: Inertial Navigation Systems

Inertial Navigation System (INS, platform) acceleration → ∫ → speed → ∫ → distance
 Inertial Reference System (IRS, lasers) error: 1.5 nm per hour

022-05-02 Inertial Reference Systems (IRS)

alignment: 3 to 10 minutes

022-06 Aeroplane: Automatic Flight Control Systems

022-06-01 General: Definitions and Control Loops

inner loop – provides stabilization functions around CG, outer loop

022-06-05 Autoland: Design and Operation

automatic approach (semi-automatic)
 autoland (fully-automatic)
 1 & 2 autopilot = fail passive

3 autopilots = fail operational

022-09 Autothrottle – Automatic Thrust Control System

THRUST	thrust according to performance database
N1/GA	maintain constant N1 or EPR, e.g. take-off, go-around, etc.
FMC SPD	maintain airspeed calculated by FMC (IAS or Mach)
MCP SPD	maintain airspeed pre-selected by the pilot (on autopilot mode control panel, IAS or Mach)
A/T arm	without selecting a speed or N1 target, for limit protection

Autothrottle is not used for engine start.

022-10 Communication Systems

022-10-01 Voice Communication, Datalink Transmission

ACARS – Aircraft Communications Addressing and Reporting System

- DCL – Pre-Departure Clearance, D-ATIS – Datalink ATIS, OCL – Oceanic Clearance
- ATC, AOC – Aeronautical Operational Control (METAR/TAF), AAC – Airline Admin Control (free text)

ARINC, SITA, ATN

022-10-02 Future Air Navigation Systems (FANS)

ADS-C, contracts for periodic, on-event or on-demand events

CPDLC – Controller Pilot Data Link Communications

022-11 Flight Management Systems (FMS)

022-11-03 Operations, Limitations

multiple DME sensor only, position error 95% probability, non-precision approach < 0.3 nm

CI = operational cost / fuel cost

022-11-04 Man-machine interface (Multifunction Control Display Unit (MCDU))

IDENT	verify nav db validity dates
POS INIT	enter airport & gate info, confirm LAT/LONG
RTE	enter route
PERF INIT	zero fuel weight, CI, fuel reserves, cruise alt, etc.
TAKEOFF REF	OAT, speeds, etc.

MCDU – Multifunction Control Display Unit

022-12 Alerting Systems, Proximity Systems

022-12-01 General

warning	red	immediate recognition & corrective action required
caution	amber	immediate awareness & subsequent action will be required
advisory		awareness required, subsequent crew action may be required
message		information on an abnormality or aircraft condition

022-12-03 Stall Warning Systems (SWS)

5kt/5% margin

022-12-08 Radio-altimeter

4.2-4.4 GHz (SHF, FM), below 2500 ft AGL, sweep-rate: 300 times per second,

accuracy: +/- 2ft or 2% when below 500 ft, 5% when above 500 ft

022-12-09 Ground Proximity Warning Systems (GPWS)

Mode 1	SINKRATE, PULL UP	excessive descent rate
Mode 2	TERRAIN	excessive terrain closure, 2B during T/O & land
Mode 3	DON'T SINK	height loss after takeoff or missed approach
Mode 4A	TOO LOW TERRAIN, TOO LOW GEAR	cruise and approach
Mode 4B	TOO LOW TERRAIN, TOO LOW FLAPS	
Mode 4C	TOO LOW TERRAIN	climb after takeoff
Mode 5	GLIDESLOPE	Excessive deviation below glideslope
Mode 6	BANK ANGLE, MINIMUMS	Callouts
Mode 7	WINDSHEAR	Windshear

advance alert times:

40-60 seconds for caution

20-30 seconds for warning

red	+2000ft
amber	+1000ft

yellow	aircraft altitude
dark green	-1000ft
light green	-2000ft
black	<-2000ft
blue	water

022-12-10 ACAS / TCAS Principles and Operations

up to 30 nm, 1 second processing time, up to 30 aircraft simultaneously. TCAS I – TAs only, TCAS II - RAs

022-13 Integrated Instruments – Electronic Displays

022-13-01 Electronic display units

Navigation Display

ARC	45° on either side of the instantaneous track
MAP	45° on either side of the instantaneous track
ROSE	current heading up
PLAN	map oriented to True North

022-13-04 Engine Parameters, Crew Warnings, Aircraft Systems, Procedure and Mission Display Systems

ECAM – Electronic Centralized Aircraft Monitoring System (Airbus)

EICAS – Engine Indicating and Crew Alerting System (Boeing)

022-14 Maintenance, Monitoring and Recording Systems

022-14-01 Cockpit Voice Recorder (CVR)

last 30 min

022-14-02 Flight Data Recorders (FDR)

25h

022-14-03 Maintenance and Monitoring Systems

ACMS – Aeroplane Condition Monitoring System

022-15 Digital circuits and Computers

022-15-02 Software: General, Definitions and Certification Specifications

5 Levels: A (Catastrophic), B (Hazardous), C (Major), D (Minor), E (no effect)