Performance

Eliott Johnson

01 General 12

Performance legislation

- Performance class A aeroplane: > 9 Pax or 5700 kg and all multi-engined jet aeroplane
- Performance class B aeroplane: Propeller aircraft with max pax seating ≤ 9 and mtom ≤ 5700 kg
- Max cruise thrust does not exist
- Gross performance = calculated performance with no safety factor
- net take off flight path = actual flight path of the aeroplane reduced by a safety margin
  - ↳ based on number of engines

General performance theory

- Speeds

Jets

- V_{MD} = min thrust required
  - ↳ V_x = best angle of climb = best endurance
  - = holding = min glide angle
- V_y = best rate of climb = best range

Prop

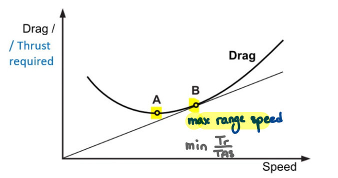
- V_x = max endurance
- V_{MD} (at most efficient altitude for power unit)
  - ↳ V_y = max range
- Higher fuel flow at altitude because of reducing power output

Rate of Climb

$$\boxed{ROC = \text{climb gradient} \cdot TAS \quad [\%]}$$

$$\boxed{\text{climb gradient } [\%] = \left(\frac{\text{Thrust} - \text{Drag}}{\text{weight}}\right) \cdot 100}$$

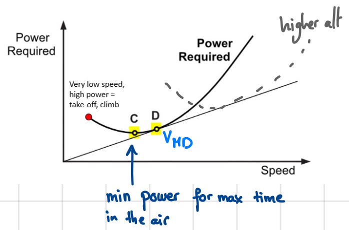
↳ Change in $\frac{\text{height}}{\text{horiz. air distance}}$



A: Drag curve - lowest point:
- V_{md} (minimum drag or minimum thrust required)
- best (maximum) L/D ratio
- best glide angle
- for jets = Vx and best Endurance
- for props = best Range

B: Drag curve - tangent (1.32 V_{md}):
- for jets = best range
- best EAS / Drag ratio

Speed over drag ratio is maximized



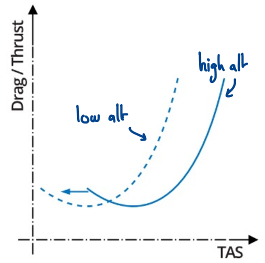
Power = Thrust x TAS (or Drag x TAS)

C: Power Required - lowest point:
- for props best endurance (V_{mp} - minimum power)
- V_x, minimum ROD in power off glide

D: Power Required - tangent:
- V_{md} (minimum drag)
- best TAS / Power ratio
- best (maximum) L/D ratio
- for props = best range
- for jets = best endurance

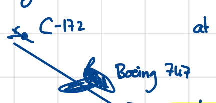
Slightly higher power for best range

- No engine
- Max endurance = V_{MP}
- Max range = V_{MD}



- Descent at constant IAS
  - ↳ descent gradient is constant — constant drag = constant gradient
  - → RoD decreases — because density increases (which would increase IAS) so we pull up a bit and reduce RoD

- High vs low mass

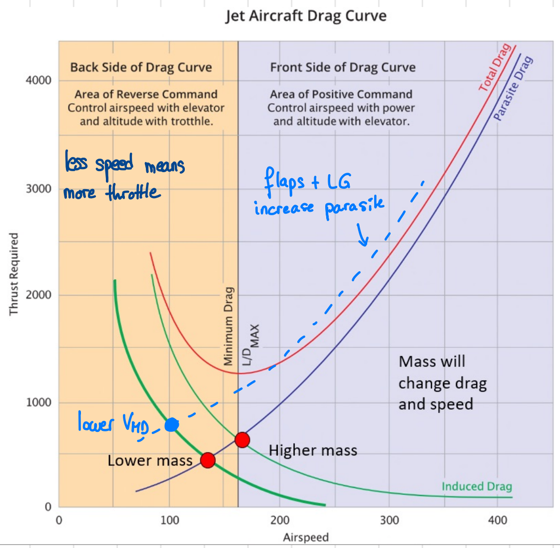


at given AOA, same H-distance

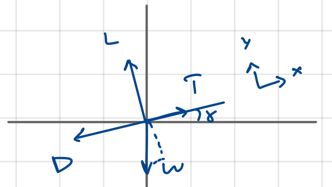
greater V-speed and forward speed

- High mass → Vx and Vy are increased
  - → speed for best angle of descent increases
  - → for given AOA ⇒ increase in airspeed and power

- Fuel consumption ∝ T (temperature) at Mach = constant because $M = \frac{TAS}{LSS}$
- C_L (lift coefficient) is independent of altitude



Climb



in x

① $T = \sin(\gamma) W + D$

$$\boxed{\gamma = \sin^{-1}\left(\frac{T-D}{W}\right)}$$

in y

$L = W\cos(\gamma)$

$W = \frac{L}{\cos(\gamma)}$

① $\frac{T-D}{W} = \sin(\gamma)$

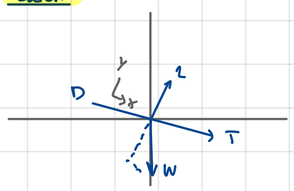
$\frac{T}{W} - \frac{D}{L}\cos(\gamma) = \sin(\gamma)$

Small angles $\cos(\gamma) \approx 1 + \dots$

$$\boxed{\frac{T}{W} - \frac{D}{L} = \sin(\gamma)}$$

climb gradient

Descent



in x

$T + \sin(\gamma)W = D$

$T = D - W\sin(\gamma)$

in y

$L = \cos(\gamma) W$

$$\boxed{n = \frac{1}{\cos(\text{bank angle})}}$$

- Upslope runway

- Stopping distance decreases
- accelerated stop distance increases
- 5% increase / 1% upslope
- increases take-off distance more than accelerate stop distance

- Clearway
  - min width = 500 ft
  - max 50% of TORA, i.e. TODA is max 150% of TORA
  - under control of airport authority

- Grass runway

- increases take off and landing distance
  - ↳ dry · 1.2
  - ↳ factor = 1.15

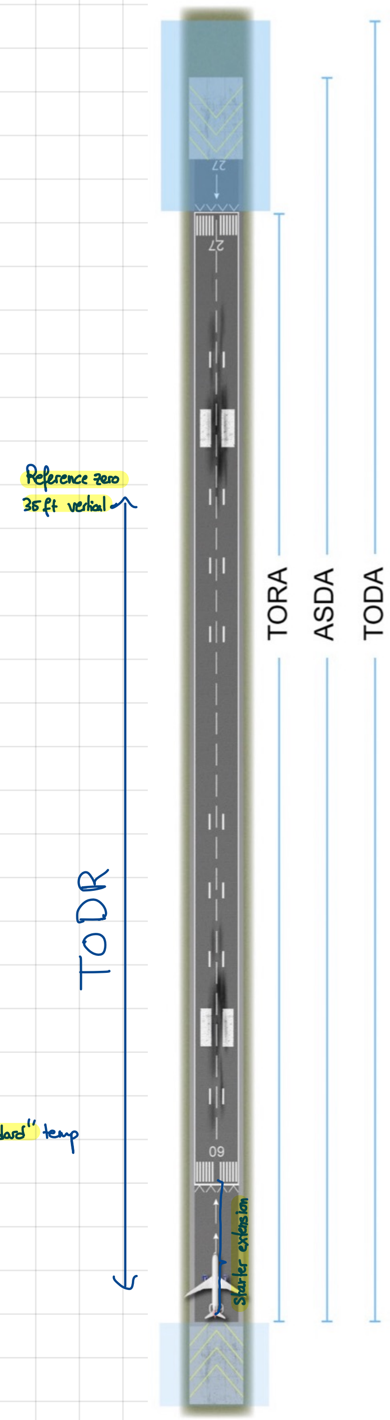
- Concrete runway
  - Wet → 1.0

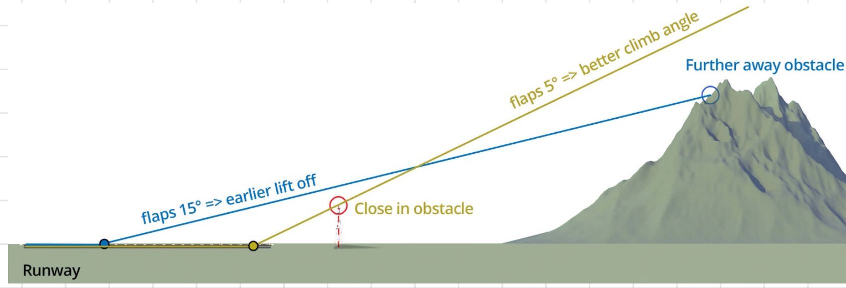
- No stopway/clearway
  - TOD · 1.25 ≤ TORA

- Stopway/clearway
  - TOD ≤ TORA
  - TOD · 1.15 ≤ TODA
  - TOD · 1.3 ≤ ASDA

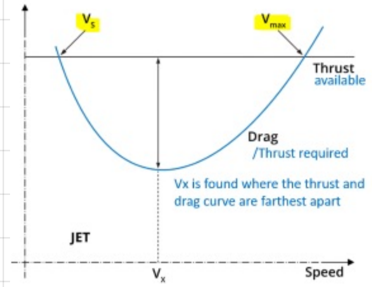
- Aerodynamic ceiling = 0 ft/min
- Service ceiling = 100 ft/min

- pressure altitude = density altitude at standard temperature
- density altitude = pressure altitude corrected for "non standard" temp



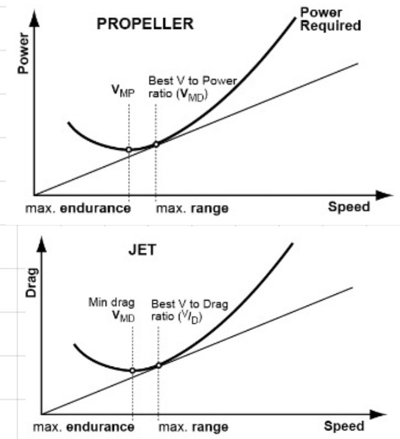


- Specific Range (SR) = $\frac{\text{still air distance}}{\text{unit of fuel}}$

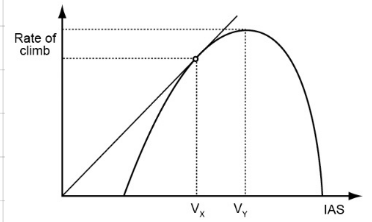


Level flight, range and endurance

- Specific fuel consumption (SFC)
  - → For jet: Fuel flow / unit thrust
  - → For piston: Fuel flow / unit of power
- Specific endurance: 1 / fuel flow — NH / unit mass fuel
- Specific range = TAS / Fuel flow (best at high altitude and low temperature)
- Minimum Fuel Flow (FF): Speed for max endurance (V_{md} for jets)
- If temp increases → specific range decreases (as performance decrease)
- For propeller airplane → max endurance is at low altitudes
- Endurance is always independent of wind and flown at V_{MP}
- Fuel consumption is proportional to mass
  - ↳ lighter aircraft ⇒ optimum altitude gets higher
  - → Drag and IAS decrease (we can go slower to maintain flight level)
- Jet aircraft cruise at 85% to 90% of their max RPM
- Propeller
  - if increase Power from max endurance
    - → range will first increase then decrease (too much power required)
    - → Endurance will decrease
  - Max achievable IAS / TAS decrease steadily with altitude (less power available)



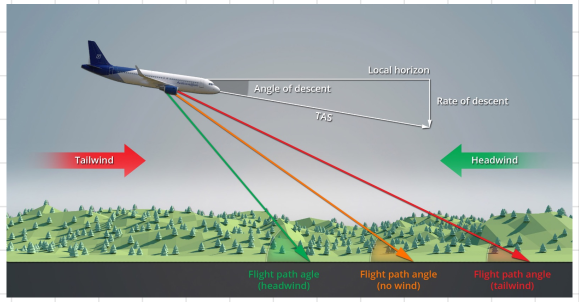
Climbing



- Vx (max angle) is achieved with minimum thrust required speed (bottom of drag chart)
- Vx and Vy increase with TAS with altitude
- Max ROC speed increases with increasing mass
  - memo: higher mass, all speed increase
- Gradient is always higher than climb angle (different unit)
- Max ratio btw thrust available and thrust required during climb → Vx (max angle)
- Engine failure
  - Vx → Vxse — Vyse ← Vy (sex, yes!)
  - SFC increases
  - Thrust available reduce by 50%
  - Excess thrust reduce by more than 50% (assymetric thrust + additional drag)
- Aft CG → increases max range and absolute ceiling

Descending

- If headwind, reduce angle of descent and maintain CAS



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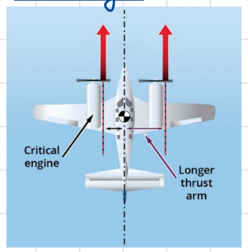
Airworthiness requirements

- Speed definitions
  - V_{S0} = stalling in landing configuration (flaps down)
  - V_{REF} = Speed in landing config. at descent through landing screen height (50 ft)
- Limitations on speeds
  - V_R
    - ≥ 1.05 V_{MC}
    - ≥ 1.1 V_{S1}
    - ≥ V_{S1} for single engine
  - V_2
    - ≥ 1.1 V_{MC}
    - ≥ 1.2 V_{S1}
  - V_{REF} (barrier speed)
    - 1.3 V_{S0} class B
    - 1.2 V_{S1} class A

Critical engine



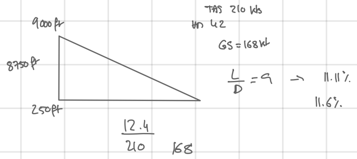
- Effect of engine failure
  - Total drag increase because of rudder deflection
  - Best is: left quartering wind, right engine failure
- High Altitude takeoff
  - V_1 decreases (you need to make decision quicker)
- Max bank angle after takeoff for Performance Class B is:
  - 0° below 50 ft or half-wingspan (whichever higher)
  - 25° above 50 ft
- Landing distances should be multiplied by 1.15 when wet runway

Take-off and landing

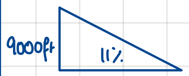
- Screen height 50 ft → ends at 1500 ft
- Landing distance
  - 0.7 LDA = LDR
- Runway slope
  - Increase by 5% for each 1% of downslope
- Correction factor to headwind and tailwinds
  - Not more than 50% of headwind
  - Not less than 150% of tailwind
- Fixed-pitch prop → accelerates during takeoff → blade AOA decreases and thrust decreases
- Constant speed prop → accelerates during takeoff → thrust increase and then decreases
- TODA 1.15
- TORA 1.25
- ASDA 1.3
- Declared safe area ≤ 90 m
- Obstacle accountability area = area beyond TODA where obstacles considered T-O perf

Climb, cruise and descent

- Speed for max rate of climb ↗ with ↗ mass (all speed increase with mass increase)
- Brake horsepower ↘ with ↘ air density
- Fuel consumption ↗ after V_{MP} (speed best endurance)
- With ↗ altitude, drag stay constant but TAS ↗
- Net gradient = gross gradient + 0.5%
- Climb rate of at least 300 ft/min with all engine operating at maximum continuous power
- Min all engine climb gradient = 4%
- V_Y between holding speed and V_{MD}



- Example



net = 11.5%

NAH = $\dfrac{9000 \text{ ft}}{\left(\frac{11.5}{100}\right)}$ = 6080 ft

$\dfrac{NAH}{TAS} = \dfrac{NM}{GS}$

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Use of Aeroplane Performance data

- Takeoff
- Field length requirements
  - No stopway or clearway → balanced field
    - when multiplied by 1.25 must not exceed TORA
  - Stopway or clearway available
    - when multiplied by 1.3 must not exceed ASDA
    - when multiplied by 1.15 must not exceed TODA
- Grass
  - Dry = 1.2
  - Wet = 1.3
- 1% upslope = 5% = 1.05
- No factorization for downslope

Example

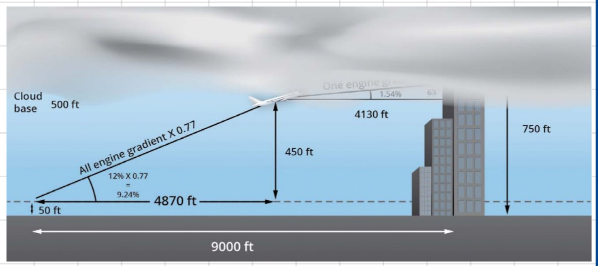
TORA = 4500 ft wet grass, no stopway, no clearway, upslope 1%

$\dfrac{4500}{1.3 \cdot 1.25 \cdot 1.05}$

	STOP		GO
TORA	1270		
TODA	1655	/1.15	1439
ASDA	1485	/1.3	1142

Climb

- Start calculation at screen height of 50 ft
- Below cloud base, take all engine operative multiplied by 0.77
- At cloud base, OEI climb gradient
- min climb gradient = 4%
  - ↳ after balked landing = 2.5%



memo cloud base questions: 2nd lowest value except "headwind" → 2nd highest

- ROC = Climb gradient · GS
- effective gradient · GS = still air gradient · TAS

$\text{climb gradient} = \dfrac{ROC}{TAS}$

Landing

- MEP must land within 70% LDA so multiply by 1.43
- defactorized LD < LDA
- Wet 1.15
- Grass 1.15
- 1% downslope = 5% = 1.05
- No factorization for upslope

Note: TAS = IAS + IAS · $\frac{2}{100}$ /1000 ft

⚠ If question asks for "required" or "minimum" → factorization is needed

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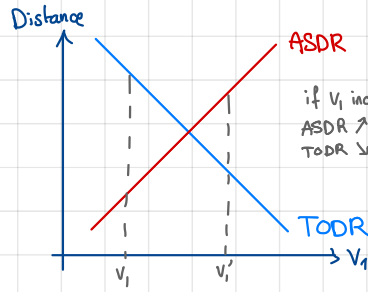
Take-off

memo: mass increase = all speed increase

- V speeds
  - V_1
    - improved climb take-off → higher V_1 and longer TODR
    - using V_1 of 155 kts instead of 142 kts → reduces take-off distance → improves climb performance
    - V_1 < V_{MBE} (max breaking energy)
  - V_R
    - > V_1 and 105% V_{MCA}
  - V_2 take-off climb/safety speed at 35 ft
    - higher V_2 → improved climb capability
    - V_2 > 110% V_{MCA}
    - Flaps reduce V_2 because V_2 is safety speed and flaps increase safety
    - Speed to keep until 400 ft
- V_1 ≤ V_{MBE} (max breaking)
- V_{MC} → min control speed OEI → lower at higher temperature (derated engine, less thrust)
- V_{LOF} lift off speed ↳ max tyre speed
- V_{MCG} and V_1 < V_R ↑ Minimum control ground
- V_{2Min}: minimum take-off speed
  - 1.13 V_{SR} for turbojets and 2-3 engine turboprop
  - 1.08 V_{SR} 4-engine or more
  - 1.1 V_{MCA}
- V_{FTO} (final take-off speed) ≥ 1.18 V_{SR}



if V_1 increases ASDR ↗ TODR ↘

- Screen height class A take-off = 35 ft
  - ↳ lowered to 15 ft if wet for OEI TOD
- All engine at Take-off Run (TOR) apply factor of 1.15
- Accelerated-Stop Distances
  - ASD = distance to engine failure + 2 sec at V_1 + distance full stop
  - Breaking assumed to start at V_1
- No Clearway, no stopway
  - balanced field length gives the minimum required field length in the event of engine failure
  - Single V1 speed
  - OEI take-off distance and rejected take-off distance to full stop are equal

OEI TODR = OEI ASDR

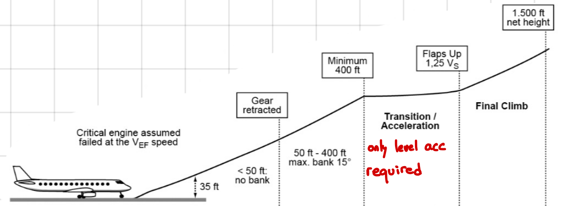
- Clearway, no stopway
  - Lower V_1 (because no stopway, need to take abort decision sooner)
  - Can take higher mass
- Stopway, no clearway
  - Higher V_1 (you have a lot of time to stop)

Question about TOD

highest between { TOD OEI / TOD AEO · 1.15

Climb segments

- Specification only for failure of critical engine



	1st segment	2nd segment	3rd segment	4th segment
Gear	Down	Up	Up	Up
Flaps	Takeoff	Takeoff	Retracted from takeoff to up	Up
Thrust	Takeoff	Takeoff	Takeoff	Max Continuous
Speed	V_2	V_2	Accelerating from V_2 to final segment speed	Final segment speed
Minimum climb gradient required				
2 engines	Positive	2,4 % +0.8	1,2 %	
3 engines	0,3 %	2,7 % 0.9	1,5 %	
4 engines	0,5 %	3,0 % 1	1,7 %	

- 2^{nd} segment
  - max 15°/25° bank between 200–400 ft; 25°/30° bank > 400 ft
    - ↳ if approved
    - ↳ obstacle clearance because 50 ft of net flight path
- 3^{rd} segment
  - max acceleration height depends on max time T-O thrust

Performance Limited Take-Off Mass (PLTOM)

- Take-off mass subject to departure aerodrome limitation

- **Reduced or Derated Take-Off**
  - Max assumed temperature is +55°C
  - Derated take-off thrust can be applied when TOM is limited by ASDA
  - **Reduced / Flex**
    - ↳ can select TOGA
    - → max 25% reduction
  - **Derate**
    - ↳ can not select TOGA (because you calculate lower V_{MCG})
    - → allowed on wet/contaminated RWY
    - → Derate thrust to decrease V_{MCG} (available on contaminated runways)

ACN < PCN

Memo: always 47 F
if not then 60R

- ACN may exceed PCN by 10%.

Obstacle limited Take-off

- If change of track < 15°
  - ↳ 300 m if sufficient navigational accuracy
- Take-off flight path = actual take off distance with no safety margins included
- Horizontal obstacle clearance
  - 90 m + 0.125D
  - 60 m + 1/2 wingspan + 0.125D

- **Contaminated runways**
  - Drag created by slush increase than decreases (once you start hydroplanning)
  - Found in $\boxed{\text{Part B}}$ of the operations manual
  - Derated take-off → new minimum control speeds
  - Snowball = wet snow
  - Compressed snow → TODA constant, ASD increases
  - Max allowed depth of wet snow = 13 mm

Dry	0% contaminated
Damp	Not dry, not shiny
Wet	contamination < 3mm
Contaminated	> 3mm

- (Dynamic) Hydroplaning speed (V_P) (above that speed = hydroplanning)
  - Rotating = $9 \cdot \sqrt{\text{tyre pressure (PSI)}}$
  - Non-rotating = $7.7 \sqrt{\text{tyre pressure (PSI)}}$

  } V_1 should be lower than this
  - occurs for any flap setting

Climb

- Max climb angle achieved at V_X = max $\frac{C_L}{C_D}$ ratio
- Order of speed V_S, V_X, V_Y
- Constant IAS = Constant drag
- Crossover altitude = at which change from constant TAS to constant Mach number

Cruise

- **Long Range Cruise** → lower costs
  - **Maximum range cruise (MRC)**
    - maximum range speed
    - $1.32\ V_{MD}$
  - **Long range cruise (LRC)**
    - Smarter to fly at a 4% higher speed as you only loose 1% range
    - Slightly higher power setting ↳ best speed for economy
    - Higher cost index
    - Higher fuel flow
- Cost index = $\frac{\text{operating costs (crew + maintenance)}}{\text{cost of fuel}}$
- **Buffet Onset Boundary**
  - Aerodynamic ceiling where low and high speed buffet are the same
- **Step climbs**
  - Used to get closer to optimum altitude
- **Cruise altitude**
  - Below optimum altitude → Mach number for LRC decreases with decreasing altitude
  - ATC sometimes instructs to fly above optimum altitude → increases with lower Mach number (Shock stall limited)

En-route one-engine-inoperative

Drift down

- net flight path vertical clearing should be $\boxed{2000\text{ ft}}$
- To calculate drift down path you need:
  - Altitude
  - OAT
  - Mass at start of driftdown
  - Not wich engine has failed as you take the worst case
- Fuel jettison taken into account when calculating obstacle clearance
- Best speed is V_{MD}
  - jets: best angle of climb (V_X)
  - props: best rate of climb (V_Y)

Descent

- Careful if you descend at M_{MO} you might exceed V_{MO} (max operating speed)
- Max endurance = speed for min power
- Continuous Descent Arrival (CDA) → stay higher longer, operate at lower engine thrust
- Descend at Mach = c^{te} → angle of descent increase
  because LSS ↗ → TAS must ↗ → must pitch down
- Descend at IAS = c^{te} → angle of descent is constant

Approach and landing

- **Landing distance Available (LDA)**
  - 50 ft (screen height) to full stop must not exceed:
    - 60% of LDA for turbojets (1.67 correction factor)
    - 70% of LDA for turboprops (1.43 correction factor)
  - if $\boxed{\text{Wet 15\%}}$ addition (1.92 correction factor)
- **Variables**
  - Slopes are considered if ± 2%
- $V_{REF} = 1.23\ V_{SRO}$
- For balked landing, must achieve climb gradient of 3.2% in landing conf. with all engines
- Required RWY length at destination = alternate (for turboprop)
- Approach climb requirements: OEI, flaps approach, $\boxed{\text{gear UP}}$
- Approach in rain you must $\boxed{\text{increase speed}}$ because of deteriorated the boundary layer

04 CS-23 / Applicable Operational Requirements Performance Class A

Use of Aeroplane Performance Data 6

Take-off

- **Climb limited chart**
  - Wind omitted because the climb limit performance taken relative to the air
  - Kink because engine are pressure limited at lower temperature and temp limited at high temp

Drift down and stabilizing altitude

- In the Net Level-off Altitude figure, the temperature line are broken because AC OFF below 17'000ft
- Equivalent gross weight at engine failure: Actual gross weight corrected for OAT higher than ISA+10°C

Landing