Performance

General

Performance legislation

Class A: > 9 seats OR MTOM > 5700 kg | Jet + Turboprop → engine failure must be considered at all stages of flight

Class B: ≤ 9 seats | MTOM < 5700 kg | Propeller → engine failure is not assumed < 300 ft

Class C: > 9 seats OR MTOM > 5700 kg | Piston

For all classes of aircraft calculating the takeoff distance, no more than 50% of HW and no less than 150% TW is assumed

Definitions:

- **Measured performance** is the performance achieved by the manufacturer under test conditions for certification
- **Gross performance** is the fleet average of airplane performance that must be respected across the board if sufficiently maintained and flown in relation to a series of techniques found within the manual. These techniques allow for all airplanes to operate via the same margins
- **Net performance** is the gross performance diminished to allow for various contingencies that cannot be accounted for operationally.
- The **Safety margin** required for public transport, is based on the probability of an event/incident/accident being less than 1 in 1 million. Statistically this is known as a remote probability.

Net takeoff distance > Gross Takeoff distance > Measured takeoff distance

Net landing distance > Gross landing distance

Net descent gradient > Gross descent gradient

Net = Gross + safety margin | note: Gross > Net (safety margin is negative)

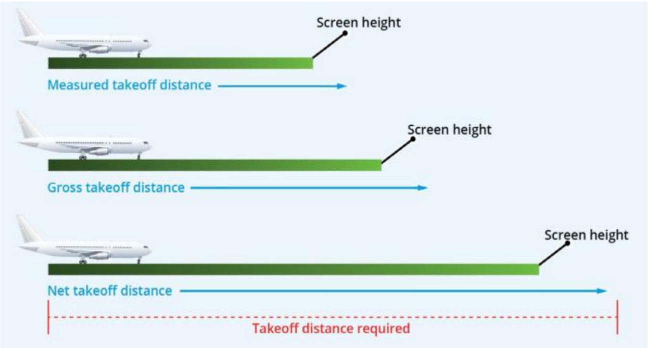
Gross performance is actual flight performance with NO safety margin

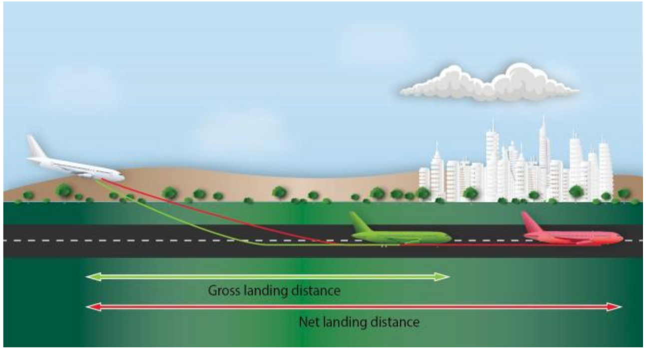
Net is gross reduced by safety margin

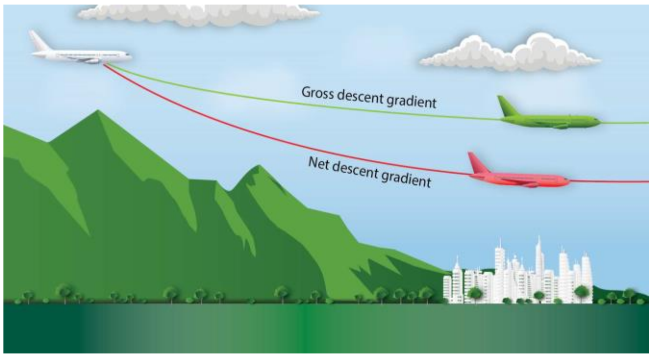
Earlier point at which wheel brakes may be applied by the pilot: when only the main wheels are firmly on the ground, provided the nose gear can be lowered in a controlled manner

Impingement drag: due water striking the landing gear and airframe

Displacement drag: resisting forward movement of the wheels







Wet ice: ice with a layer of water (any depth) on top of it or ice that is melting

Compacted snow: snow compresses into a solid mass such that airplane tires will run on it without further compaction of the surface

<u>General performance theory</u>

Density altitude is pressure altitude corrected for ''non-standard'' temperature

Density altitude increases if pressure ↓ and temperature ↑

Absolute ceiling is the altitude at which the theoretical rate of climb, with all engines operating at maximum continuous power, is reduced to zero feet per minute.

Specific Fuel consumption: Fuel flow/Power [Prop] | Fuel flow/Thrust [Jet]

Specific Air Range [SAR] = TAS/Fuel burn [if ''Specific Range'' is used, they are referring to SAR]

Specific Ground Range [SGR] = GS/Fuel burn

Climb angle = horizontal plane – flight path | Descent angle = horizontal plane – flight path

Climb gradient (%) = distance travelled/altitude gain | Descent gradient (%) = distance travelled/altitude loss

Flight path angle = horizontal plane – velocity vector | increases during climb in a HW

Flight path gradient = corrected flight path vector over the ground and the altitude gained

The **climb/descent angle** refers to the **angle** of the aircraft **relative to the air mass** the aircraft is climbing or descending in

The **flight path angle** refers to the **angle relative to the earth's surface**, and is therefore **dependent on HW or TW**

Wind effective gradient (%) = ROC (ft/min) ÷ GS (kt)

When ↑ OAT - Mass - Pressure altitude (altitude) → Climb Gradient – ROC – Climb angle ↓

When in a HW → Flight path angle ↑ and Ground distance ↓ [same ROC but less ground distance flown = higher FPA]

V_X is the speed for the best gradient or angle of climb → greatest altitude gain in the shortest horizontal distance

It is the speed obtained at the biggest difference between Thrust available and Thrust required

V_Y is the speed for the best rate of climb → greatest altitude gain in the shortest time

In a OEI situation: $V_X < V_{Xse} < V_{Yse} < V_Y$

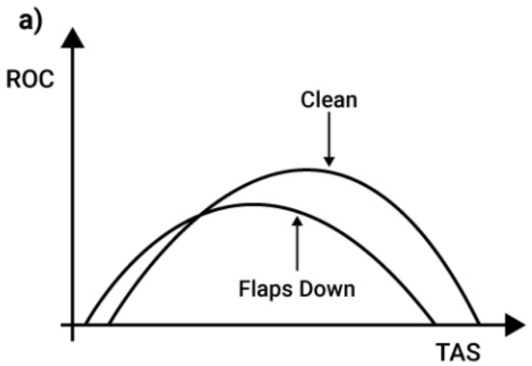
When **flaps and slats are retracted**, V_X and V_Y ↑

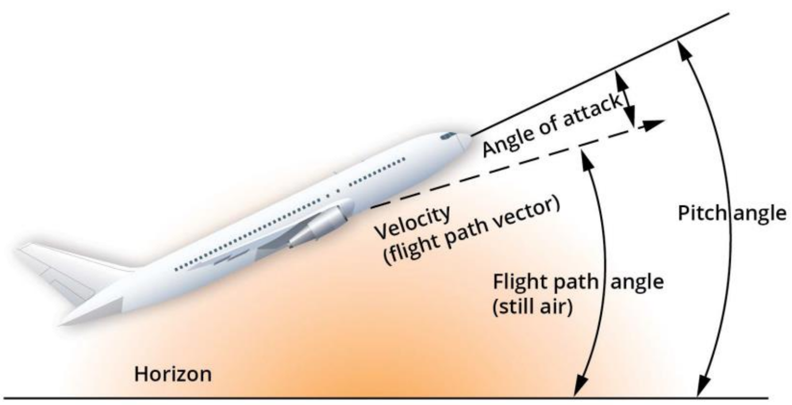
Heavier and lighter airplane glide the same distance, but it takes different time and heavier airplane is faster to reach it.

Heavier aircraft has a greater glide angle and ROD

The parameter affecting gliding distance is wind: HW reduces it, TW increases it

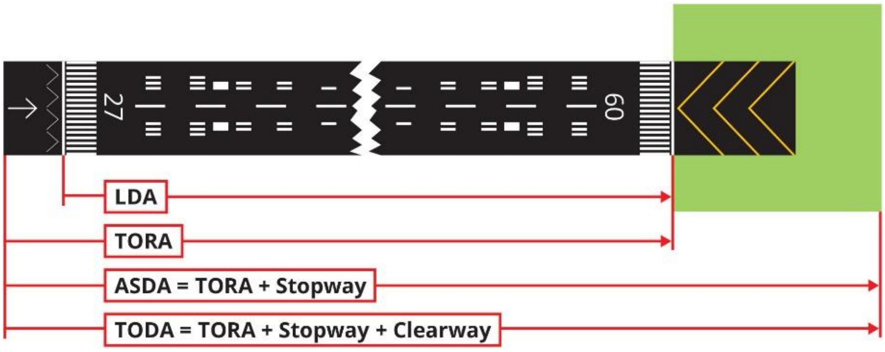
A frangible obstacle is classed as an obstruction in the takeoff path that is a minimum hazard to an aircraft





Runway definitions:

- Clearway [CWY]: an area beyond the paved runway, free of obstructions and under the control of the airport authorities at least 150 m wide (500 ft).
- Stopway: an area beyond the runway which can be used for deceleration in the event of a rejected takeoff.
  It is identified by large yellow chevrons on either end of the main runway.
  It shall be:
  - At least as wide as the runway
  - Centered upon the runway centerline
  - Capable of supporting the airplane during an aborted takeoff without causing structural damage to the aircraft
  - Designated by the airport authorities for use in decelerating the airplane during an aborted takeoff



- Screen height: an imaginary barrier, located at the end of TODA or the beginning of the LDA.
  - TODA Class A = 35 ft (15 ft if wet)
  - TODA Class B = 50 ft
  - LDA all classes = 50 ft

Turns are not permitted after takeoff < 50 ft or if half-wingspan > 50 ft, the half-wingspan length

If CWY > 50% TORA → TODA = TORA x 1.5

Example

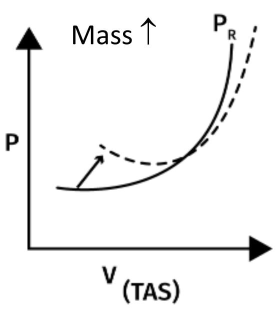
TORA = 2000 ft → 50% TORA = 1000 ft

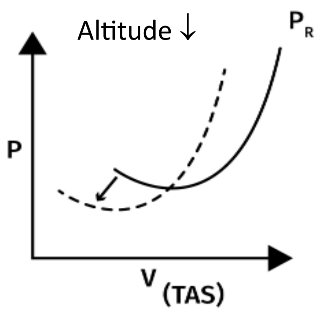
CWY = 1200 ft > 50% TORA

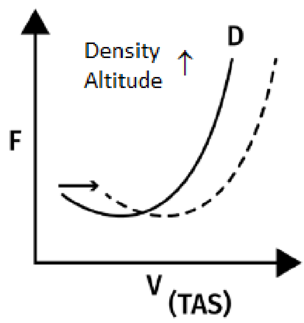
TODA = TORA x 1.5 = 3000 ft

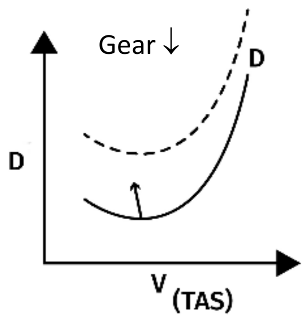
Variables influencing performance

- Pressure altitude
- OAT
- Winds
- Weight ↑
- Configuration
- Anti-skid system
- Airplane CG
- Runway surface and slope







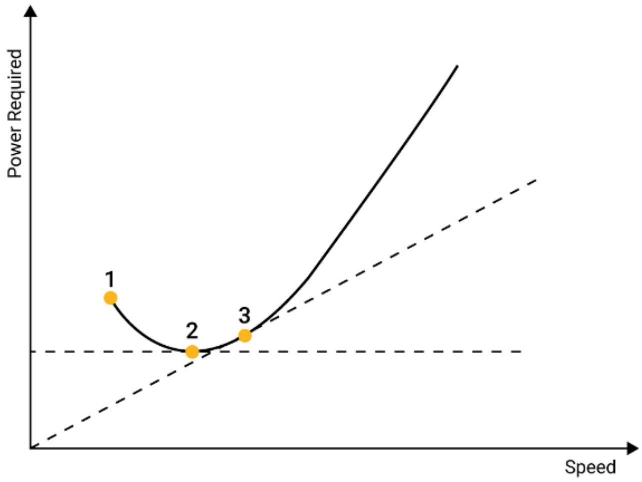


Many jet engines are **flat rated (flex takeoff)**, that is, they are restricted to a maximum thrust even though the engine can produce higher thrust. The reason being that at lower temperatures **too much thrust may be generated** and the pressures within the compressors may be exceeded. For this reason an assumed or **flex temperature**, higher than the actual temperature, is used. It is **not an operational limit**. In a flex takeoff **TOGA is available.**

A **derated thrust** setting is considered to be a limit (as per AFM) and TOGA cannot be selected

In the Power Required vs Speed curve the points are:

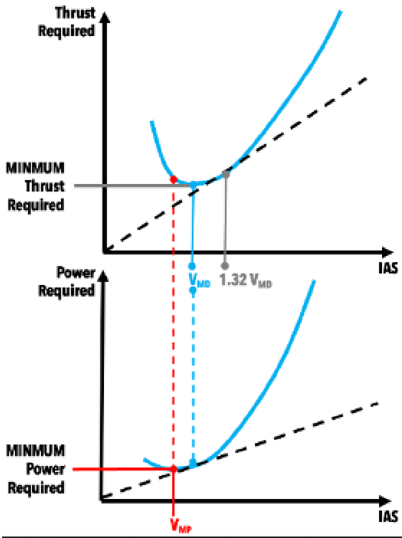
1. Takeoff/Climb
2. Max Endurance (Cruise) V_{MP}, V_X, Max endurance
3. Max Range (Cruise) V_{MD}, V_Y, Max range [= V_{MD} in Drag curve]



In a Power/Thrust required vs TAS:

- Lowest point for JET is V_{MD}
- Tangent from origin JET is = Max Endurance = 1.32 V_{MD}
- Lowest point for PISTON is V_{MP} = Max Endurance = Min Power
- Tangent from origin PISTON is = Max Range = V_{MD}

V_{MP} ↑ as altitude ↑ as power required ↑ [Power = Drag * TAS]

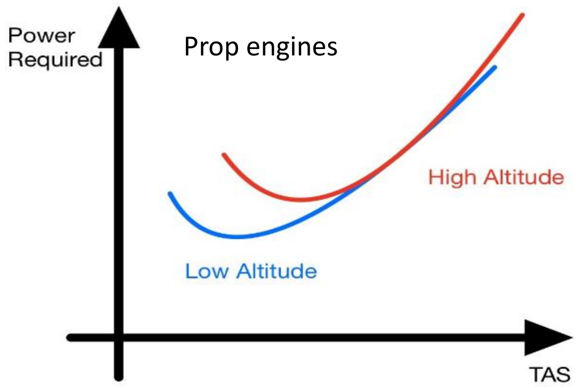


DRAG/THRUST REQUIRED CURVE

- **Lowest Point of curve** - V_{MD}, Best L/D Ratio and best glide.
  - ⇒ **For JET:** V_X = Maximum Endurance Speed
  - ⇒ **For PROP:** Maximum Range Speed.
- **Tangent** - 1.32 V_{MD}
  - ⇒ **For JET:** Best Range Speed, V_Y

POWER REQUIRED CURVE

- **Lowest Point of curve** - V_{MP}
  - ⇒ **For PROP:** Best Endurance Speed.
- **Tangent** - V_{MD}, Best L/D Ratio
  - ⇒ **For PROP:** Maximum Range
  - ⇒ **For JET:** V_X = Maximum Endurance



Correction factors

+5% takeoff distance each +1% of upslope

On a Dry runway V_1 ↑ and ASDA ↑ by uphill slope

Correction factors Class B:

- Landing: Grass = 1.15 | Wet paved = 1.15

Dynamic hydroplaning [rotating tire – takeoff]: $9 * \sqrt{PSI}$

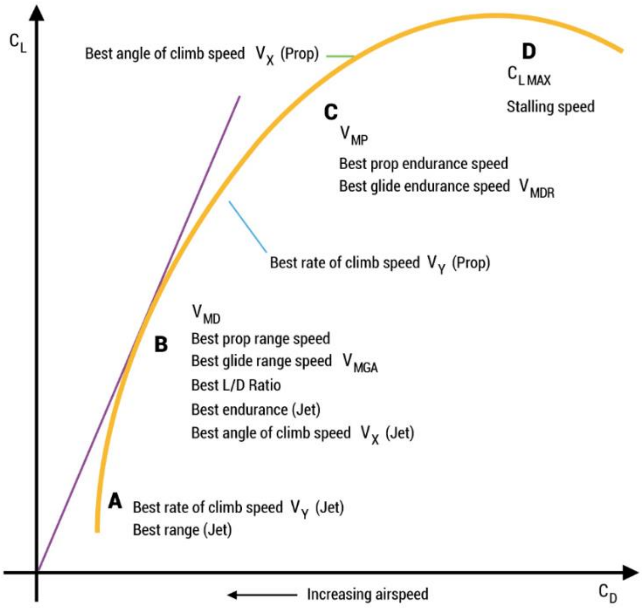
Viscous hydroplaning [non-rotating tire – landing]: $7.7 * \sqrt{PSI}$

Gradient (%) = 100 * Glide slope (°)

Level Flight, Range and Endurance

Max Range = $\left(\frac{TAS}{Drag}\right)_{MAX}$

	Max endurance	Max range
Propeller	V_{MP}	V_{MD}
Jet	V_{MD}	1.32 V_{MD}



Max endurance is reached at:

- Prop: sea level
- Turbo prop: about 10000 ft
- Jet: high altitude

For a propeller airplane, SFC and SRG increases until the increase in the GS is offset by the increase in power required. The increase in power required, caused by an increasing TAS in the climb, offsets the gains in SFC and SRG as you climb.

SFC = FF/Thrust | Specific range = NM/kg | Specific Endurance = 1/FF

V_{S1g} (C_{Lmax})means the 1-g stall speed at which the airplane can develop a lift force (normal to the flight path) = weight.

In OEI, Thrust required increases, Thrust available reduces by 50% and Excess Thrust decreases by more than 50%

Climbing

The climb gradient is always larger than the angle of climb (5% climb gradient ~ 3° angle of climb)

GC (%) = sinγ * 100 | γ = tan^{-1}(altitude gain/distance flown)
Gradient = ROC/TAS | Gradient = ROC/GS

Climb gradient is dependent on Thrust: (T_{Req} - T_{Ava})/W
ROC is dependent on Power: (P_{Req} - P_{Ava})/W

During climb, the max angle of climb is achieved when flying with the minimum thrust required, so that the excess thrust is maximum and is used to increase the climb angle.

During a climb, in an engine failure V_Y ↑ and rate of climb ↑
V_X and V_Y (TAS) ↑ as altitude ↑, because IAS = ρ*TAS and if IAS = constant and ρ ↓ then TAS has to ↑

Best climb performance is achieved with small angle of flap and slat
If weight ↑, V_X (best angle of climb speed) and V_Y (best rate of climb speed) ↑

Height difference (ft) = [Ground distance (ft) x Climb gradient (%)/100] x TAS/GS
Obstacles clearance (ft) = Height difference + 50 ft (to account for screen height) – obstacle height

Descent

In a glide:

- Descent gradient = constant
- Rate of descent ↓ as you descend

If an aircraft is heavier than another, the minimum glide angle is constant, but airspeed varies

CS-23 | Class B - Theory

MEP		
V_R	$1.05\ V_{MC}$	$1.1\ V_{S1}$
V_2	$1.1\ V_{MC}$	$1.2\ V_{S1}$
V_{REF}	$> V_{MC}$	$1.2\ V_{S0}$

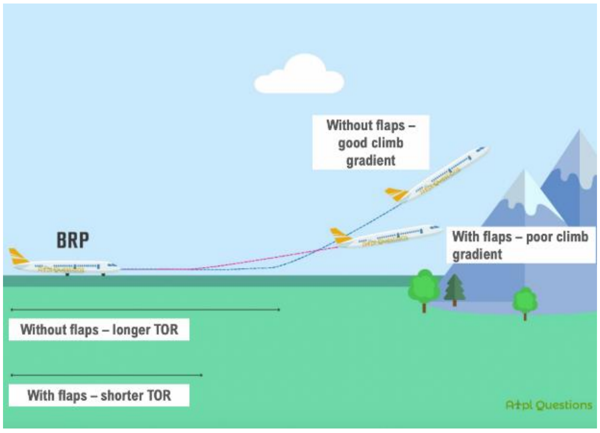
SEP	
V_R	$\geq V_{S1}$
V_2	$1.2\ V_{S1}$
V_{REF}	$1.3\ V_{S0}$

In the event of an engine failure:
- the airplane should be capable of reaching a point (1 000 ft above the intended landing area) from which a safe forced landing can be made
- no cloud < MSA
- most favorable situation is wind coming from the live engine side (due to aircraft weathercocking)
- $V_{MC} \uparrow$ if altitude $\downarrow$

Obstacles are considered if they lie in an area called the "**Obstacle Accountability Area**":
- Wing span > 60 m: ½ wing span + 90 m + 0.125*D is the semi-width to be used
- Wing span < 60 m: ½ wing span + 60 m + 0.125*D is the semi-width to be used.
- The area expands from the appropriate semi-width, at the rate of 0.125 x D (Distance from end of TODA)
- In VFR is effectively substituted by ensuring the weather conditions during operation are sufficient to visually navigate and avoid obstacles

The take-off climb extends from 50 ft above the surface at the end of TODR to 1500 ft above the same surface
Minimum speed on takeoff at the screen height of 15m/50ft is a "safe speed" or $1.2\ V_{S1}$
Minimum speed on landing $V_{REF} = 1.3\ V_{S0}$
V_{REF} is the Landing Reference Speed at a point 50 feet above the landing threshold

Balk landing minimum climb gradient: 2.5% (class B) | 3.2% (class A)
Missed approach minimum climb gradient: 0.75%



Runway length requirements:
- Unbalanced (stopway or clearway)
  - ASDA ≥ TOD x 1.3
  - TODA ≥ TOD x 1.15
  - TORA ≥ TOD

- Balanced (no stopway or clearway)
  - TORA ≥ TOD x 1.25

Rolling takeoff allows the airplane to accelerate slowly as the power is applied to the engines. TOD and ASD both increase
After takeoff when there are close-in obstacles, using a lower flap increase TODA, but improve the climb gradient

For takeoff wind considerations are as follow:
- Headwind component: ≤ 50%
- Tailwind component: ≥ 150%

For descent problems: Net gradient (%) = Gross gradient (%) + 0.5%

Still Air Distance = Height Difference/Net Gradient (%) x 100

Net glide distance = Ground distance = Still Air Distance x GS/TAS

Descent gradient (%) = (1/(L:D)) * 100

Exercise explained:

Based on actual conditions, an aeroplane has the following performance take-off mass limitations:

FLAPS	0°	10°	15°
RUNWAY	4100 kg	4400 kg	4600 kg
CLIMB	4700 kg	4500 kg	4200 kg

Structural limits: take-off/landing/zero fuel: 4 300 kg

The Maximum Take-off Mass is:

- For each flap setting choose the lowest value (most limiting):
  - 0° = 4100 kg
  - 10° = 4400 kg
  - 15° = 4200 kg
- Choose the highest value between the remaining options: 10° = 4400 kg
- Check such value against the structural limit (4300 kg) and choose the most limiting one: 4300 kg

CS-23 | Class B – Use of performance data for SE and ME airplanes

Gradient = ROC/TAS
Height gained = Gradient (%) x Distance travelled/100

When given a LDA, use 70% (1.43) of it as Max Landing Distance Required (LDR) because we assume not to use the full LDA.
The Landing distance found in the CAP is the gross LDR (without correction factors)
Net LDR = Gross LDR * correction factors [remember to include 1.43 to factor LDR ≤ 0.7*LDA]

Factored = LDR*safety factors
Defactored = LDR / safety factors
Barrier speed = V_{REF} = 1.3 V_{S0}

Vertical distance from obstacle on takeoff (no cloud base)

1. $Height\ difference\ (ft) = \frac{Ground\ distance\ (ft)*Climb\ gradient(\%)}{100} * \frac{TAS}{GS}$
2. $Obstacle\ clearance\ (ft) = Height\ difference + 50\ ft - Obstacle\ height$

Vertical clearance from obstacle on takeoff (with cloud base)

1. $Horizontal\ Distance\ (HD) = \frac{Cloud\ Base - 50}{ROC*0.77} * \frac{GS}{60}$ [NM]
2. $Residual\ Distance\ (RD) = Obstacle\ distance - HD$ [NM]
3. $Height\ gain = \frac{RD}{GS} * ROC_{(OEI)} * 60$ [ft]
4. $Clearance = Cloud\ base + Height\ Gain - Obstacle\ Height$

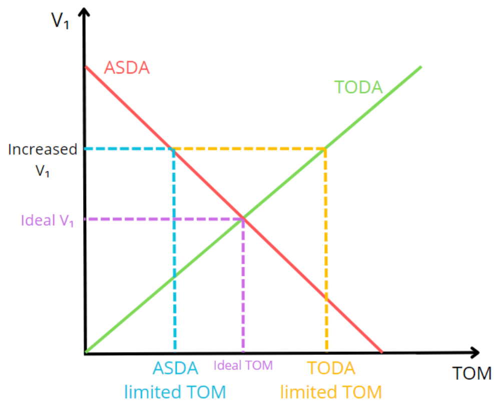
CS-25/Applicable Operational Requirements Performance Class A – Theory

Takeoff

Contaminated runway:
- surface water more than 3 mm deep, or by slush, or loose snow
- compacted now
- ice (including wet ice)

Wet runway = covered in water + shiny appearance + no significant areas of standing water
Damp runway = not dry + not a shiny appearance
On a wet runway, TODA ↑ and ASDA↑ too due to reduced braking friction coefficient (consequently V_1↓)

Balanced runway: TODA = TORA = ASDA or TODR = ASDR | **Unbalanced runway**: TODR < ASDA
TODR = ASDR = V_1 Balanced (ASDA = engine failure TOD)
Adding Stopway: MTOM and V_1 ↑
Adding Clearway: MTOM ↑ but V_1 ↓
Runway with upslope: TODA↑ but ASDA ↑ too because the negative effect on acceleration is larger than the positive effect on deceleration in case of an RTO, thus both distances increase
If V_1 ↑, MTOM ↑ when limited by TODA
If V_1 ↑, MTOM ↓ when limited by ASDA



V_1 is limited by V_{MCG} because if V_1 is too low, we have not enough authority on the rudder, so $V_1 \geq V_{MCG}$

If a lower V_1 is wrongly used in the FMC and a failure occurs after such V_1, the TODR will be longer than the one calculated originally with the right higher V_1
If a higher V_1 is wrongly used in the FMC and a failure occurs after such V_1, the ASDA may exceed the one calculated originally with the right higher V_1

Lineup loss
- doesn't change V_1 as it's more convenient to reduce mass, to avoid obstacle clearance problems in the event of an engine failure (if we reduce V_1, we reduce the obstacle clearance at screen height).
- TODA, ASDA, TODA doesn't account for lineup losses.
- Accountability is required for a 90° - 180° entry/turnaround to the runway.

Reducing the rotation rate on takeoff will ↑ TODA and TORA, but ↓ obstacle clearance

V_{2MIN} is limited by the V_{SR} at high (density) altitude | $V_{2MIN} \geq 1.13 V_{S1/SR}$ (all jet) | $V_{2MIN} \geq 1.08\ V_{S1}$ (+3 engines turboprop)

V_{2MIN} is limited by the V_{MC} at low (density) altitude | $V_{2MIN} \geq 1.1\ V_{MC}$

V_2↑ as air density ↑ (more asymmetric thrust)

The **increased V_2 procedure** aim to improve the TOM and still attain the required climb gradient. To do so the airplane is hold on the runway on the ground until it reaches an **increased V_R (and V_1)**, climbing at an increased V_2 near or equal to V_X

V_{SR} doesn't depend on air density

Reverse thrust is NOT included in a dry runway when calculating ASDA
Reverse thrust is included in a wet runway when calculating ASDA

Climb limited takeoff mass ↑ if flap ↓ and V_2↑ because:

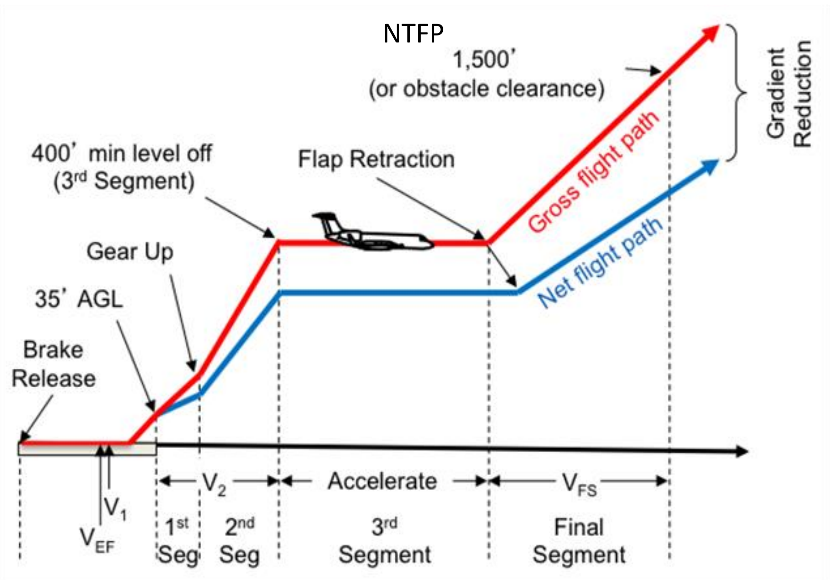
- reducing flap increase climb gradient
- $V_2 < V_x$ (best angle of climb speed), so the higher V_2, the better the climb gradient too

Flex takeoff thrust (**reduced thrust**) is used to decrease the engine performance. TOGA is available if needed.
Derated takeoff thrust (**reduced maximum thrust**) doesn't allow to go over a certain preset thrust, even if 100% throttle is used.
To avoid a pilot overreaction (selecting TOGA too late with risk of runway excursion), Flex (reduced) takeoff thrust is NOT allowed on contaminated runways. Derated is allowed on contaminated and wet runways.
The primary advantage of the derated thrust takeoff, compared to flex takeoff, is that the lower rated thrust will lead to lower values of V_{MCG} and V_{MCA} and this fact may avoid a V_{MCG} limited takeoff, in some circumstances, leading to a greater MTOM at a lower thrust setting.

Final takeoff speed $V_{FTO} > 1.18\ V_{SR}$ and needs to provide at least the gradient of climb required
Tire speed limit major parameters are: Rotation rate of the tire and temperature (tire is filled with dry nitrogen, not air)

Net Take-off Flight Path (NTFP) is divided in 4 stages:
- **Segment 1** starts at the screen height, 35ft above the reference zero point at V_2 and ends when the gear retraction is completed.
- **Segment 2** is flown at V_2 to a minimum of 400 ft gross, known as the acceleration altitude. It is assumed 1 engine out climb from this segment (from V_{EF} = the speed at which the Critical Engine is assumed to fail during takeoff)
- **Segment 3** is flown level while accelerating and retracting flap on schedule to V_{FTO}, the final take-off speed which cannot be less than 1.18 V_{SR} or a safe maneuvering speed.
- **Segment 4** is flown with Maximum Continuous Thrust from 400 ft to ≥ 1500 ft, where the aircraft is said to be en-route

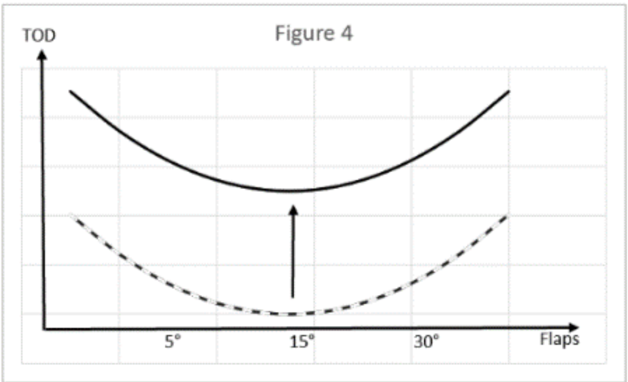
The NTFP requires a 35 ft obstacle clearance for class A (as per segment 1)
If a bank > 15° is needed, the required obstacles clearance margin is increased from 35 ft to 50 ft
Bank angle limit can be increased by 5° upon approval:
- 20° between 200 - 400 ft [standard: 15°]
- 30° > 400 ft [standard: 25°]



Class A Gross Climb Gradient				
	1st Segment	2nd Segment	3rd Segment	4th Segment
Gradient for 2 Engines	> 0 %	> 2.4 %	> 1.2 %	> 1.2 %
Gradient for 3 Engines	> 0.3 %	> 2.7 %	> 1.5 %	> 1.5 %
Gradient for 4 Engines	> 0.5 %	> 3.0 %	> 1.7 %	> 1.7 %

Class A Net Climb Gradient (0.6 + # engines %)	
Gradient for 2 Engines	Gross + 0.8 %
Gradient for 3 Engines	Gross + 0.9 %
Gradient for 4 Engines	Gross + 1.0 %

Effect of engine out on TOD during takeoff



Climb

Crossover altitude: when speed during climb changes from constant IAS to constant Mach and vice versa for descent

IAS = ρ * TAS

Cost Index = aircraft operating cost / fuel cost [it is a number between 0-200]
HIGH Cost Index: HIGH speed & HIGH fuel burn
LOW Cost Index: LOW speed & LOW fuel burn
Low cost index will result in:

- lower climb speed
- lower cruise speed
- higher cruise altitude
- later descent
- slower descent speed

Cruise

Long range cruise speed:

- is slightly higher than the Maximum range speed, so it requires a higher Cost Index.
- gives a specific range which is ~ 99% of maximum specific range and a higher cruise speed but allows for an increase in cruise speed of 4%.

Minimum fuel consumption is given by the Maximum range speed

Step climb is used to increase range and is usually done to climb in a 2000 ft block.
Performing a step climb based on economy, it can be limited by the 1.3g buffet onset

Experiencing buffet at the aerodynamic ceiling (coffin corner) it is recommended to reduced thrust, maintain IAS and descent. Any increase or decrease in IAS could increase the buffet

Specific range = NM/kg

OEI cruise

Drift Down procedure entails setting maximum continuous power/thrust (MCT) on the operating engine(s). it is done when cruising at an altitude above the optimum OEI altitude.
Drift down strategy: fly at V_{MD} (obstacle clearance speed | least rate of sink | best OEI angle of climb) to increase obstacle clearance
Level off altitude is dependent on engine(s) thrust and OAT

Approach and landing

Prop: LD x SF = LDA x 0.7 LDR = LD x 1.43 x SF
Jet: LD x SF = LDA x 0.6 LDR = LD x 1.67 x SF

$V_{REF} > 1.23\ V_{SR0}$

V_{SR0} is a speed at or above the speed an aircraft reaches C_{LMAX} in the landing configuration with a load factor equal to 1

Landing in a wet runway: positive (firm) landing + full use of autobrake with antiskid + reverse thrust + retardation devices

Maximum quick turnaround mass: if landing above it, a certain time should pass for brake cooling before the next takeoff

With ↑ OAT, MLM ↓ as GS ↑

Balked landing climb gradient requirement [all engine operating]:

- class A: 3.2%
- class B: 2.5% [0.75% OEI]

In the landing roll brakes can be applied when both main gears are on the ground AND provided that the nose gear can be lowered in a controlled manner

Approach Climb (-0.3%)
2 engines = 2.1%
3 engines = 2.4%
4 engines = 2.7%

CS-25/Applicable Operational Requirements Performance Class A – Use of airplane performance data

Climb limited takeoff mass is independent of wind.

The climb angle relative to the ground will be affected by wind