V-speeds and Takeoff Performance

Large Aircraft Operations
**Boeing 747**
- Seating: 416
- Internal cabin width: 6.1m

**Airbus A380**
- Seating: 555 (max 840)
- Internal cabin width: 6.58m

Source: Airbus/Boeing
What are V-speeds?

- Large aircraft operate under a wide variety of weights, conditions and configurations.
- Operators are subject to strict regulations governing aircraft performance during all phases of flight. (field length, net climb gradients)
- Certain performance speeds are relative to operating conditions, and therefore change depending on the situation; these are known as V-speeds.
Conditions Affecting V-speeds

- V-speeds change relative to aerodrome conditions, aircraft weight and configuration.
- Gross takeoff weight, pressure altitude, and temperature all affect aircraft performance.
- WAT- weight, altitude, temperature.
- Aircraft configuration affects V-speeds (flap setting, slat setting, bleeds, anti-ice, a/c off/on, anti-skid inoperable), and can be used to improve performance.
- Runway conditions also affect V-speeds. (contaminated runway)
V-speed Definitions

- $V_1$: Takeoff Decision Speed - the speed which dictates whether a malfunction during the takeoff roll results in rejecting the takeoff, or continuing. (go or no go speed)
- $V_R$: Takeoff Rotation Speed - the speed at which aircraft rotation is initiated by the pilot.
- $V_2$: Minimum Takeoff Safety Speed - one engine inoperative climb speed for takeoff configuration.
- $V_{MCG}$: Ground Minimum Control Speed - minimum speed which provides directional control on the ground during failure of the critical engine.
• $V_{MCA}$ - Air minimum Control Speed - minimum speed which provides directional control in the air during failure of the critical engine.

• $V_{MU}$ - Minimum Unstick Speed - minimum speed the aircraft can lift off without demonstrating hazardous characteristics while continuing the takeoff.

• $V_{LO}$ - Lift Off Speed - speed at which the aircraft will lift off.

• $V_{MBE}$ - Maximum Brake Energy Speed - maximum speed an aircraft can initiate a rejected take off from and remain within heat limitations of the braking system.
Relationships Between V-s speeds

- \( V_1 \) must always be >\( V_{MCG} \), <\( V_{MBE} \), ≤\( V_R \)
- \( V_R \) must always be ≥\( V_1 \), >\( V_{MCA} \)
- \( V_{LO} \) must always be ≥\( V_R \), >\( V_{MCA} \), >\( V_S \), >\( V_{MU} \)
- \( V_2 \) must always be >\( V_{MCA} \), >\( V_S \), >\( V_R \)

These relationships will always hold true, but the speeds themselves will change according to aircraft weight, atmospheric conditions, aircraft configuration, and runway conditions.

- \( V_1 \), \( V_R \), and \( V_2 \) will float between their minimum and maximum limits dependant on conditions and requirements.
- The specific speeds are obtained by consulting the performance charts or quick reference cards.
Takeoff Performance

- During the certification process of an aircraft the manufacturer must comply with strict regulations concerning aircraft performance. Performance calculations are done assuming an engine failure at \( V_1 \), a failure before or after will result in better than indicated performance.

- Transport and Commuter aircraft takeoff field length is limited by the longer of:
  - Accelerate/stop distance- the distance required to accelerate to \( V_1 \) with all engines operating normally, experience the loss of the critical engine and bring the aircraft to a stop.
  - Accelerate/go distance- the distance required to accelerate to \( V_1 \) with all engines operating normally, experience the loss of the critical engine and continue with the takeoff and reach 35 feet above the runway at \( V_2 \).
  - All-engine takeoff runway length- 115% of the distance required to reach 35 feet above the runway with all engines operating normally.
• **In the determination of available runway length for take off the CAP aerodrome chart must be consulted.**

• **Takeoff Run Available (TORA):** The length of runway declared available and suitable for the ground run of an aeroplane taking off.

• **Takeoff Distance Available (TODA):** The length of the takeoff run available plus the length of the clearway, where provided. (max. clearway length allowed is 1000 feet.)

• **Accelerate Stop Distance Available (ASDA):** The length of the takeoff run available plus the length of the stopway where provided.
Clearways and Stopways

- **Clearway** - A defined rectangular area on the ground or water under the control of the appropriate authority, selected or prepared as a suitable area over which an aeroplane may make a portion of its initial climb to a specified height. (TODA-TORA)

- **Stopway** - A defined rectangular area on the ground at the end of the runway in the direction of takeoff prepared as a suitable area in which an aeroplane can be stopped in the case of an abandoned takeoff (ASDA-TORA)
Balanced Field Takeoff

- **A balanced field takeoff is a condition where the accelerate stop distance required (ASDR) is equal to the takeoff distance required (TODR) for a given WAT, aircraft configuration, and runway condition.**
- **When the takeoff field length is balanced it results in the shortest possible runway length for the given conditions.**
- **Performance charts are usually based on this balanced field concept as it allows for the highest takeoff weights to be achieved.**
- **The charts will give you the maximum takeoff weight allowable to depart a specific length of runway given the current conditions.**
- **The V-speeds generated by the charts assure adequate performance under the given conditions.**
Conditions Affecting Performance

- **The takeoff field length is dependant on the speed to which the aircraft has to be accelerated and the acceleration available.**

- **WAT:** weight, pressure altitude, and temperature. Increased weight, pressure altitude, and temperature decrease performance.

- **Engine thrust:** Higher temperatures and lower air density reduce the amount of available thrust. Systems like A/C, bleed air, and anti-ice decrease available thrust. Thrust may be decreased purposely in order to maximize engine life if the runway length and aircraft weight allow it. (de-rated or reduced thrust takeoff)

- **Flap setting:** flap configuration will depend on the limiting takeoff factor. Lower flap settings require longer takeoff distances but provide better climb out gradient capability.
• **Wind:** A headwind will positively affect performance, decreasing both ASDR and TODR. A tailwind has a negative affect on performance. Performance charts are permitted to take credit for 50% of headwinds and 150% of tailwinds.

• **Runway slope:** A down slope improves takeoff performance as long as brake energy doesn’t become limiting.

• **Surface condition:** Contaminated runways will increase ASDR.

• **Anti-skid:** An inoperative anti-skid system will increase ASDR.
Questions

- If we increase $V_1$, what effect will it have on ASDR and TODR?
  - It will increase ASDR and decrease TODR.
- If we decrease $V_1$, what effect will it have on ASDR and TODR?
  - It will decrease ASDR and increase TODR.
- What effect will a wet runway have on ASDR?
  - It will increase ASDR.
- What conditions have an effect on $V_{MBE}$?
  - Temperature, weight, runway slope, wind.
- Will cooler temperatures increase or decrease $V_{MBE}$?
  - Increase.
- Will increase in weight increase or decrease $V_{MBE}$?
  - Decrease.
- Will an upslope runway increase or decrease $V_{MBE}$?
  - Increase.
• Is $V_{MBE}$ always greater or less than $V_1$? Why?
• It is always greater than $V_1$ to ensure maximum brake temperatures are not exceeded during a RTO.
• Does the existence of a stopway or clearway allow for increased takeoff weights?
• Yes.
• In the above example will $V_1$ change, if so will it increase or decrease?
• Yes it will increase to maximize use of a stopway, or decrease to maximize use of a clearway.
• Define balanced field takeoff.
• A balanced field takeoff exists when the ASDR is equal to the TODR.
• When would a reduced thrust takeoff be performed?
• Anytime aircraft weight, aerodrome conditions, and runway length allow it.