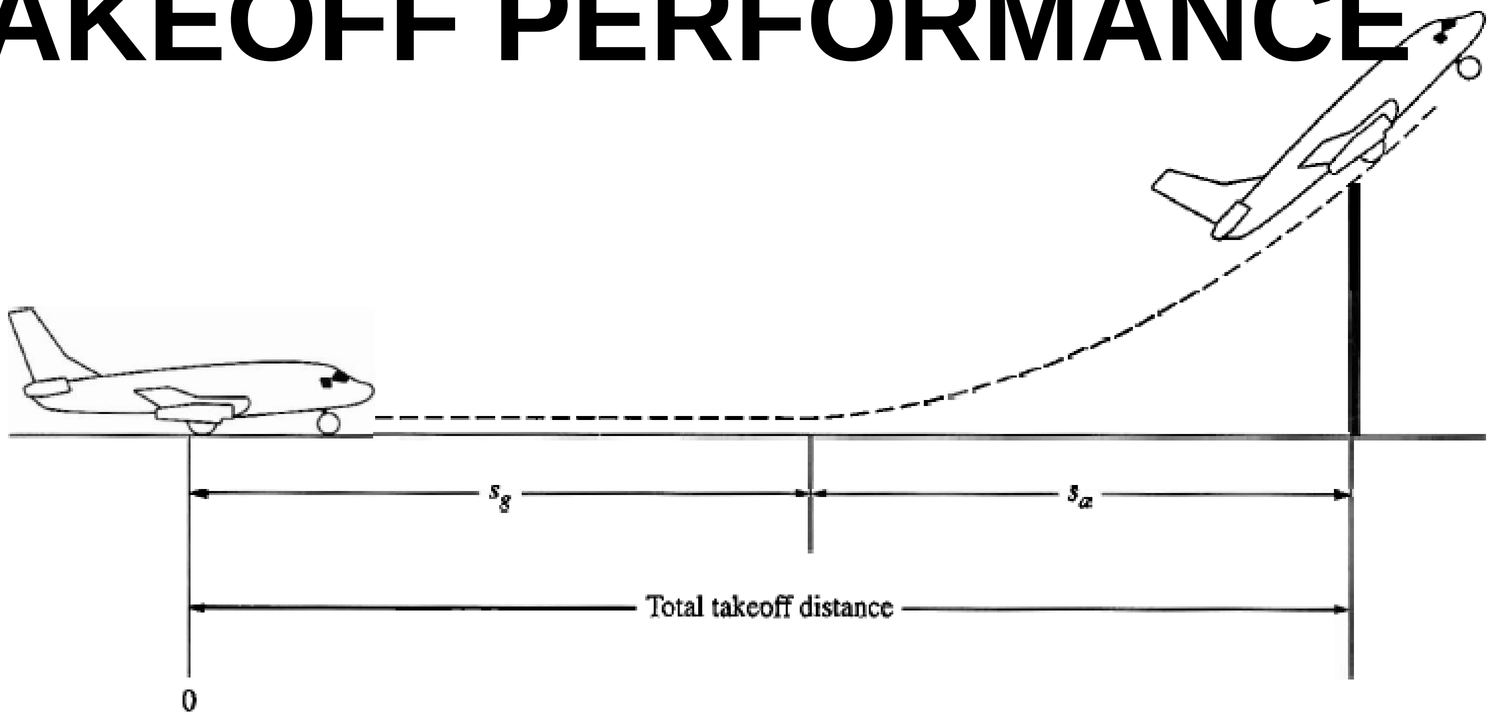
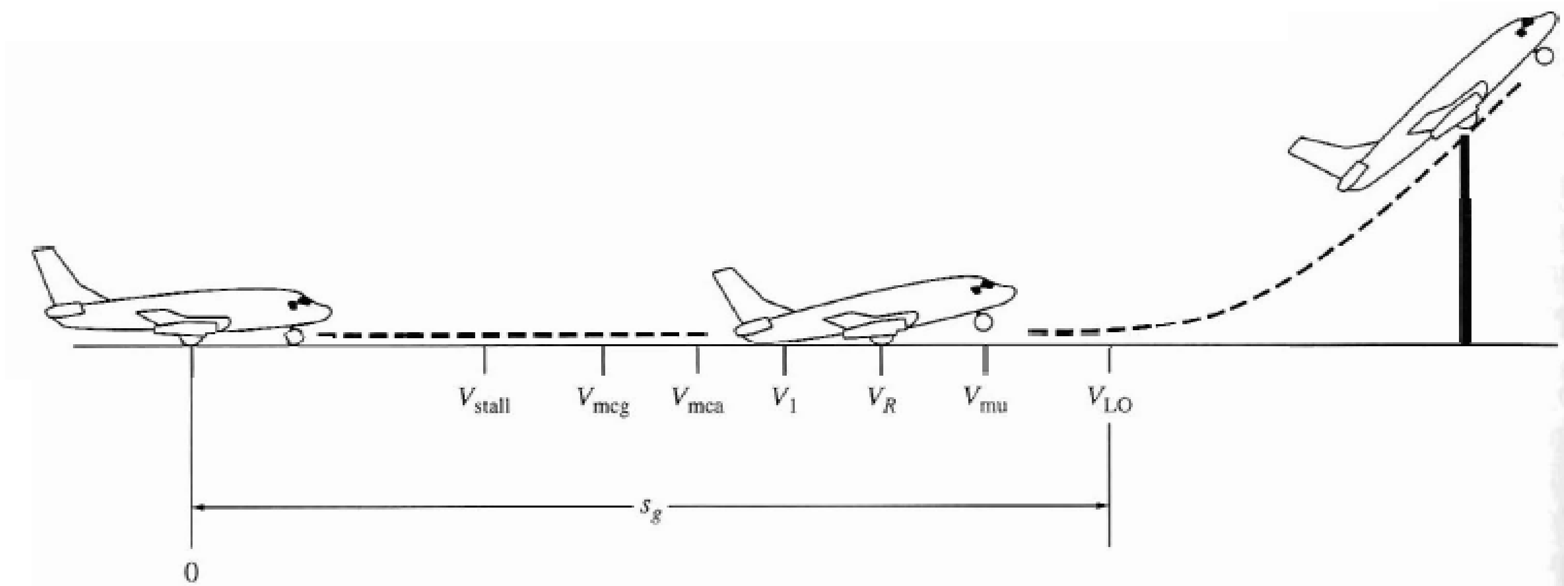
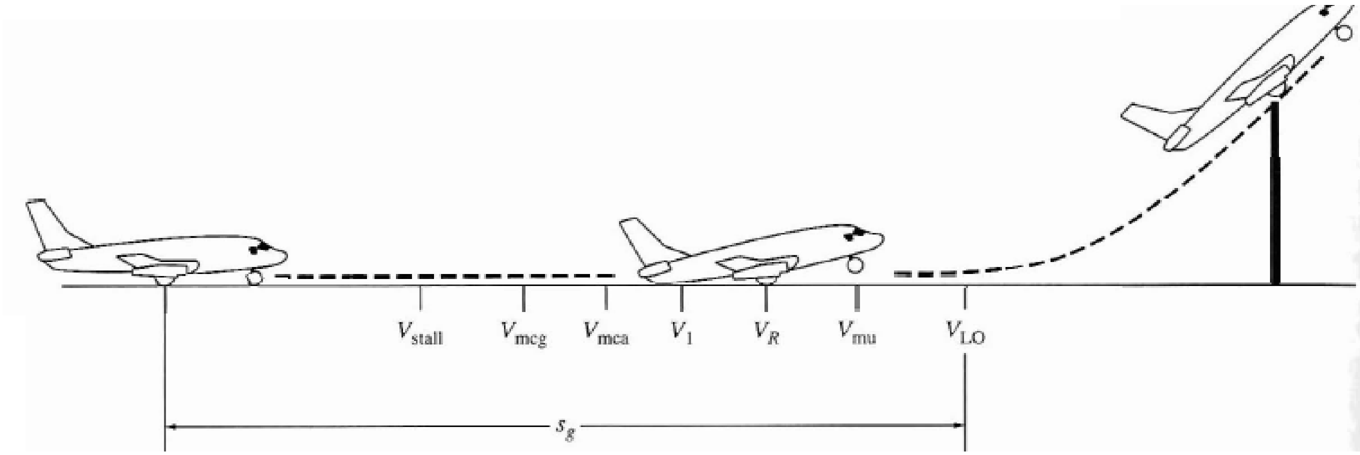
TAKEOFF PERFORMANCE



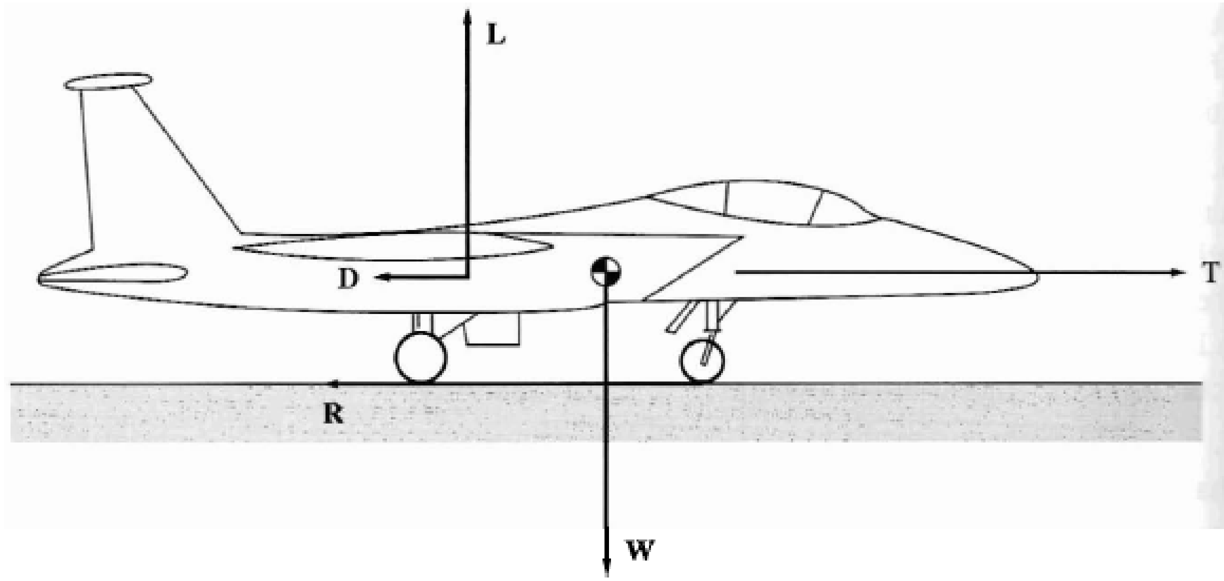
- An airplane is motionless at the end of a runway. This is denoted by location O. The pilot releases the brakes and pushes the throttle to maximum takeoff power, and the airplane accelerates down the runway. At some distance from its starting point, the airplane lifts into the air. The distance the airplane cover along the runway before it lifts into the air is called the ***ground roll*** (sg). The total takeoff distance also includes the extra distance covered over the ground after the airplane is airborne but before it clears an obstacle of 50 ft for military aircraft and 35 ft for commercial aircraft. This is denoted by ***sa***. The sum of ***sg*** and ***sa*** is the total takeoff distance.



- As the airplane accelerates from zero velocity, at some point it will reach the stalling velocity **VStall**
- The airplane continues to accelerate until it reaches the *minimum control speed on the ground,* Vmcg. This is the minimum velocity at which enough aerodynamic force can be generated on the vertical fin with rudder deflection while the airplane is still rolling along the ground to produce a yawing moment sufficient to counteract that produced when there is an engine failure for a multiengine aircraft.
- If the airplane were in the air (without the landing gear in contact with the ground), the minimum speed required for yaw control in case of engine failure is slightly greater than Vmcg This velocity is called the *minirnum control speed in the air, Vmca*
- The airplane continues to accelerate until it reaches the *decision speed,* V1. This is the speed at which the pilot can successfully continue takeoff even though an engine failure (in a multiengine aircraft) would occur at this point. If an engine fails before V1 is achieved, the takeoff must be stopped. If an engine fail after V1 is reached, the takeoff has to be completed.



- The airplane continues to accelerate until the takeoff rotational speed, VR is achieved. At this velocity, the pilot initiates by elevator deflection a rotation of the airplane in order to increase the angle of attack and to overcome the weight. Attention should be paid not to stall.
- the angle of attack necessary to overcome the weight may not be achievable because the tail may drag the ground. If the rotation of the airplane is limited by ground clearance for the tail, the airplane must continue to accelerate while rolling along the ground after rotation is achieved. This speed is called the *minimum unstick speed,* denoted by Vus.
- For increased safety, the angle of attack after rotation is slightly less than the maximum allowable by tail clearance, and the airplane continues to accelerate to a slightly higher velocity, called the *lift off speed,* denoted by VLO. This is the point at which the airplane actually lifts off the ground. The total distance covered along the ground to this point is the ground roll *sg.*
- Generally VLO=1.1 Vstall



In addition to the familiar forces of thrust, weight, lift, and drag, there is a rolling resistance R, caused by friction between the tires and the ground.

$$m\frac{dV_\infty}{dt} = T - D - R$$

$$R = \mu_r(W - L)$$

$$\boxed{m\frac{dV_\infty}{dt} = T - D - \mu_r(W - L)}$$

	μ_r (Typical Values)	
Surface	**Brakes off**	**Brakes on**
Dry concrete/asphalt	0.03–0.05	0.3–0.5
Wet concrete/asphalt	0.05	0.15–0.3
Icy concrete/asphalt	0.02	0.06–0.10
Hard turf	0.05	0.4
Firm dirt	0.04	0.3
Soft turf	0.07	0.2
Wet grass	0.08	0.2

Approximate Analysis of Ground Roll

$$ds = \frac{ds}{dt}\,dt = V_\infty\,dt = V_\infty \frac{dt}{dV_\infty}\,dV_\infty$$

$$ds = \frac{V_\infty\,dV_\infty}{dV_\infty/dt} = \frac{d(V_\infty^2)}{2(dV_\infty/dt)}$$

$$ds = \frac{m}{2}\frac{d(V_\infty^2)}{T - D - \mu_r(W - L)}$$

$$s_g = \frac{W}{2g}\int_0^{V_{LO}} \frac{d(V_\infty^2)}{T - D - \mu_r(W - L)}$$

Note that the net force T - D -μ_r(W - L), does not vary greatly.
This gives some justification to assuming that the expression T - D - μ_r (W - L) is constant up to the point of rotation. If we take this net force to be constant at a value equal to its value at V= 0.7VLo, then

$$s_g = \frac{W V_{LO}^2}{2g}\left[\frac{1}{T - D - \mu_r(W - L)}\right]_{0.7V_{LO}} + N V_{LO}$$

where the term N VLo has been added to account for that part of the ground roll during rotation, as noted earlier. The velocity at liftoff VLO should be no less than 1.1Vstall

$$V_{stall} = \sqrt{\frac{2}{\rho_\infty}\frac{W}{S}\frac{1}{(C_L)_{max}}}$$

$$s_g = \frac{1.21(W/S)}{g\rho_\infty (C_L)_{max}\,[T/W - D/W - \mu_r\,(1 - L/W)]_{0.7V_{LO}}} + 1.1N\sqrt{\frac{2}{\rho_\infty}\frac{W}{S}\frac{1}{(C_L)_{max}}}$$

The design parameters that have an important effect on takeoff ground roll are wing loading, thrust-to-weight ratio and maximum lift coefficient.

1. *sg* increases with an increase in W/S.
2. *sg* decreases with an increase in (CL)max,.
3. *sg* decreases with an increase in T/ W.

Assuming that T is much larger than D, neglecting the contribution to *sg,* due to the rotation segment:

$$s_g \approx \frac{1.21(W/S)}{g\rho_\infty (C_L)_{max}(T/W)}$$

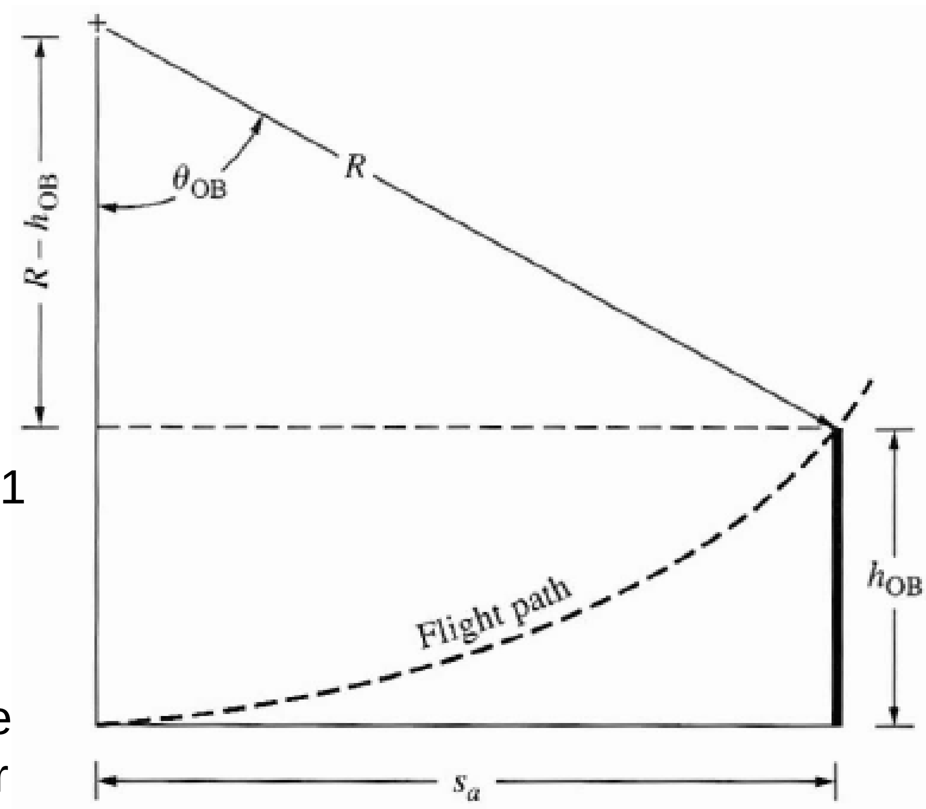
The ground roll is very sensitive to the weight of the airplane via both W/S and T/ W. If the weight is doubled, W/S is doubled and T/ W is halved, leading to a factor-of-4 increase in *sg.* The ground roll is dependent on the ambient density, through both the explicit appearance of rho.

Calculation of Distance While Airborne to Clear an Obstacle

The flight path after liftoff is sketched

$$R = \frac{V_\infty^2}{g(n-1)}$$

During the airborne phase, FAR require that V increases from 1.1 V_{Stall} at liftoff to 1 .2Vstall as it clears the obstacle of height h_{OB}. Therefore, we assume that V is an average value equal to 1.15 V_{stall}. The average lift coefficient during this airborne phase is kept slightly less than $(CL)_{max}$ for a margin of safety; ***CL*** = **0.9$(CL)_{max}$**

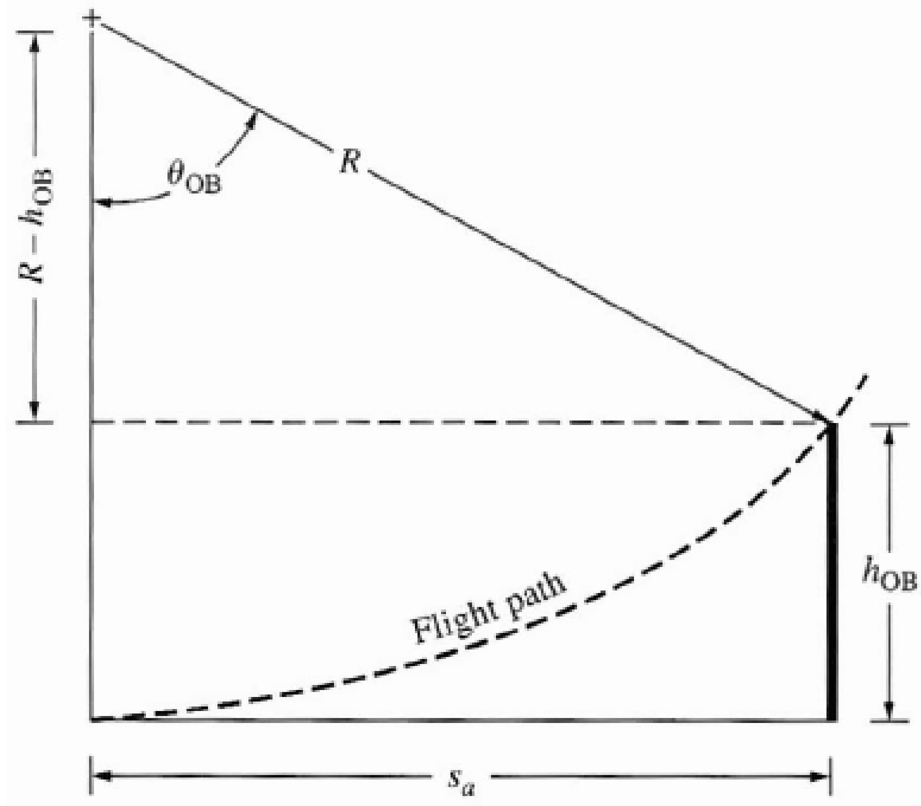


$$n = \frac{L}{W} = \frac{\frac{1}{2}\rho_\infty (1.15 V_{stall})^2 S (0.9)(C_L)_{max}}{W}$$

$$W = \frac{1}{2}\rho_\infty (V_{stall})^2 S (C_L)_{max}$$

$$n = \frac{\frac{1}{2}\rho_\infty (1.15 V_{stall})^2 S (0.9)(C_L)_{max}}{\frac{1}{2}\rho_\infty (V_{stall})^2 S (C_L)_{max}}$$

$$n = 1.19$$



to calculate the distance along the ground covered by the airborne segment:

1. Calculate R from $R = \frac{(1.15 V_{stall})^2}{g(1.19 - 1)}$

2. For the given obstacle height hOB, calculate:

$$\text{Cos}\,\theta_{OB} = \frac{R - h_{OB}}{R} = 1 - \frac{h_{OB}}{R} \longrightarrow \theta_{OB} = \cos^{-1}\left(1 - \frac{h_{OB}}{R}\right)$$

3. Calculate ***sa***. $s_a = R \sin\theta_{OB}$