AEEM 3042 – Integrated Aircraft Engineering

Block 2b
Material
Review

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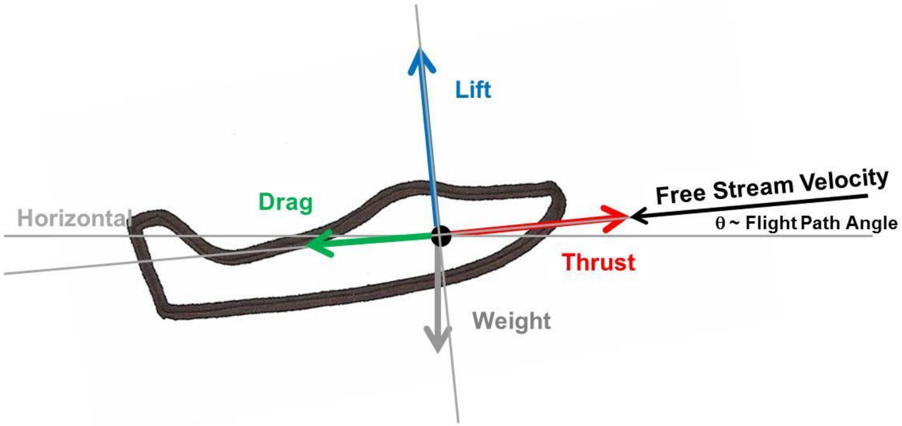
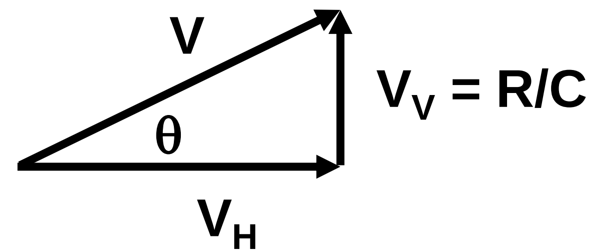
Steady Climbing Flight



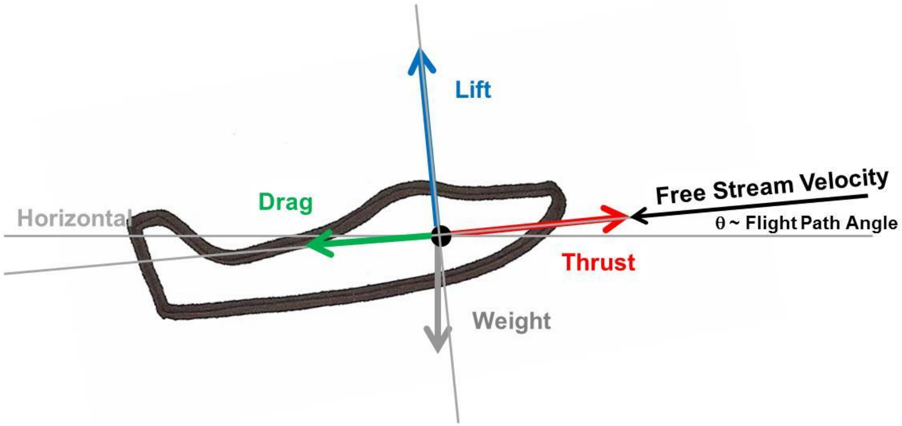


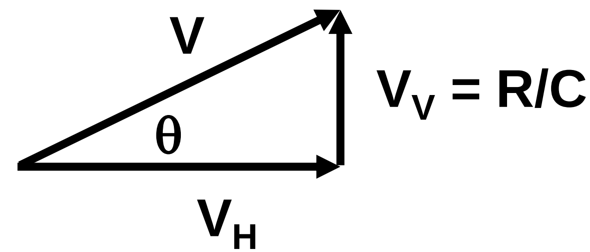
$$\sin\theta = \frac{T-D}{W} \longrightarrow V\sin\theta = \frac{(T-D)\,V}{W} = R/C$$

for R/C > 0 $\boxed{T > D}$

$$\cos\theta = \frac{L}{W} \longrightarrow L = W\cos\theta \quad \boxed{L < W}$$

Steady Climbing Flight





$$V \sin \theta = \frac{(T - D)\, V}{W} = R/C$$

$$(T - D)\, V = T\, V - D\, V = \text{Excess Power}$$

$$\frac{(T - D)\, V}{W} = \text{Specific Excess Power} = R/C$$

Specific Excess Power

$$\boxed{\frac{(T-D)\,V}{W} = \frac{dh}{dt} + \frac{V}{g}\frac{dV}{dt} = P_s}$$

$$\frac{(T-D)\,V}{W} = \frac{dh}{dt} + \frac{V}{g}\cancelto{0}{\frac{dV}{dt}}$$

Rate of Climb

Climbing Flight

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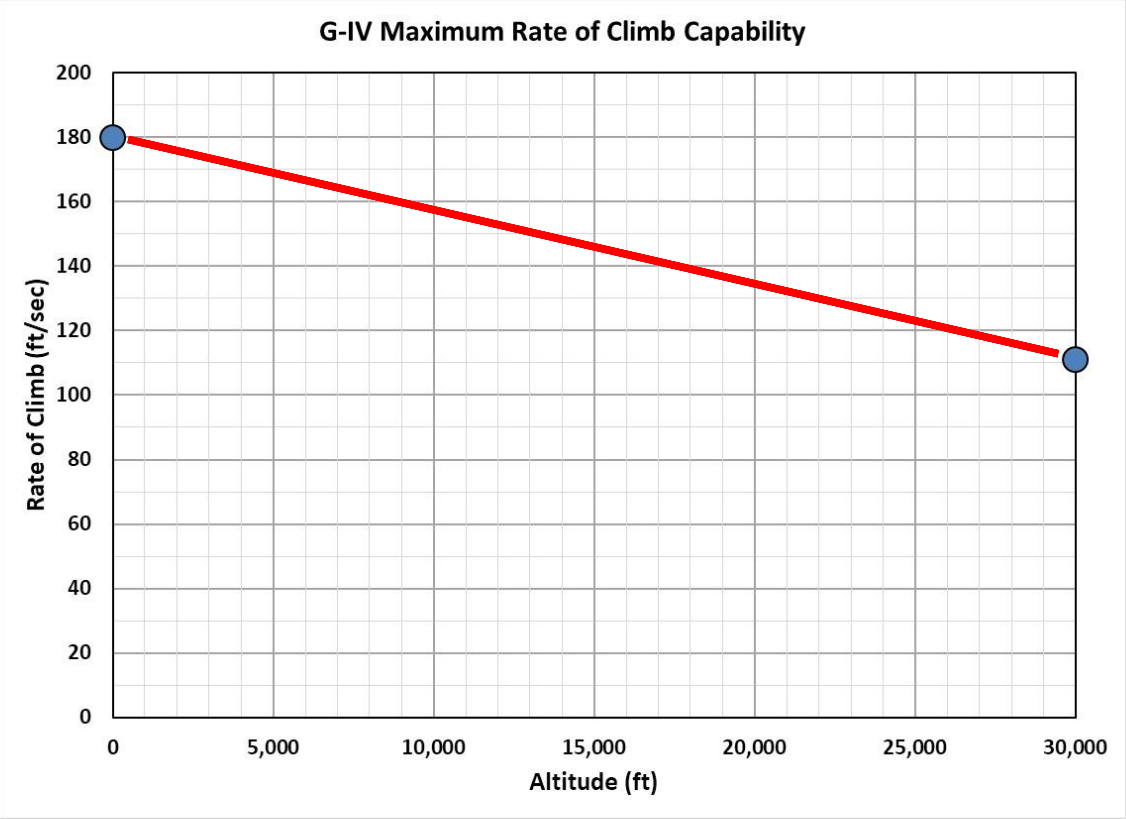
Minimum Time to Climb

Easier Method – assume linear R/C_{max} vs Altitude

Calculate the maximum Rate of Climb at Sea Level
Calculate the maximum Rate of Climb at 30,000 ft
Calculate the average Rate of Climb



Minimum Time to Climb

Easier Method

$$t_{min} = \frac{\Delta h}{(R/C)_{avg}}$$

At Sea Level: $(R/C)_{max} = 179.8$ ft/sec
At 30,000 ft: $(R/C)_{max} = 111.0$ ft/sec

$$t_{min} = \frac{(30,000 - 0)}{(179.8 + 111.0)/2}$$

$$\boxed{t_{min} = 206.3 \text{ sec} = 3.44 \text{ min}}$$

What about fuel and distance?

Fuel to Climb

Easier Method

$$\mathbf{w_{fuel}} = \dot{\mathbf{w}}_{\mathbf{avg}}\ \Delta\,\mathbf{t}$$

At Sea Level: $\dot{w}$ **= 10.0028 lb/sec**
At 30,000 ft: $\dot{w}$ **= 5.5454 lb/sec**

$$\mathbf{w_{fuel}} = \frac{(\mathbf{10.0028 + 5.5454})}{\mathbf{2}}\ \mathbf{206.3}$$

$$\boxed{\mathbf{w_{fuel} = 1{,}603.8\ lb}}$$

Distance to Climb

Easier Method

$$s = V_{avg}\ \Delta t$$

At Sea Level: V = 747.3 ft/sec
At 30,000 ft: V = 932.2 ft/sec

$$s = \frac{(747.3+932.2)}{2}\ 206.3$$

$$\boxed{s = 173{,}240\ \mathrm{ft} = 28.51\ \mathrm{NM}}$$

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Example 5.18

Climb Summary

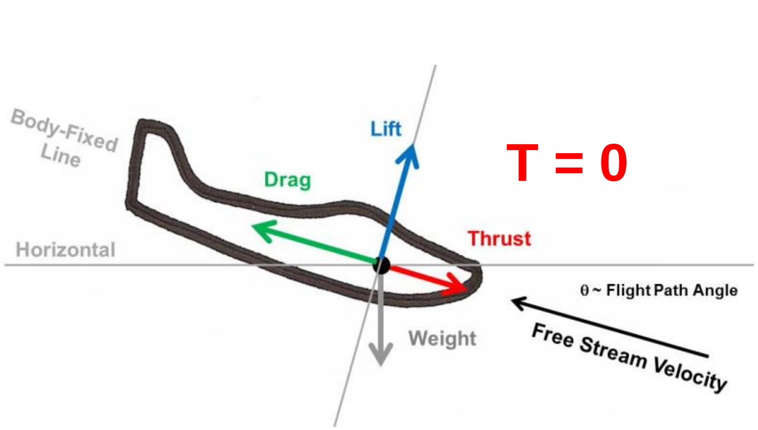
Easier Method

$$\mathbf{t_{min}} = \frac{\Delta\, \mathbf{h}}{(\mathbf{R/C})_{\mathbf{avg}}} \qquad \mathbf{w_{fuel}} = \dot{\mathbf{w}}_{\mathbf{avg}}\ \Delta\, \mathbf{t} \qquad \boldsymbol{s} = \mathbf{V_{avg}}\ \Delta\, \mathbf{t}$$

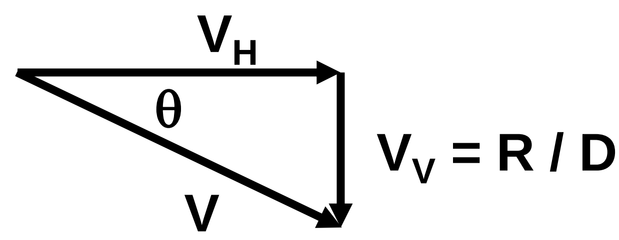
Sea Level			30,000 ft		
R/C	**FFR**	**Velocity**	**R/C**	**FFR**	**Velocity**
(ft/sec)	(lb/sec)	(ft/sec)	(ft/sec)	(lb/sec)	(ft/sec)
179.8	10.0028	747.3	111.0	5.5454	932.2

Time	Fuel	Distance
3.44 min	1,603.8 lb	28.51 NM

Steady Gliding Flight



T = 0



$$\sin\theta = \frac{D - \cancel{T}^{\,0}}{W} \longrightarrow V\sin\theta = \frac{D\,V}{W} = R/D$$

$$\cos\theta = \frac{L}{W} \longrightarrow L = W\cos\theta$$

$$\tan\theta = \frac{D - \cancel{T}^{\,0}}{L} = \frac{1 - \cancel{\left(T/D\right)}^{\,0}}{\left(L/D\right)} = \frac{1}{\left(L/D\right)}$$

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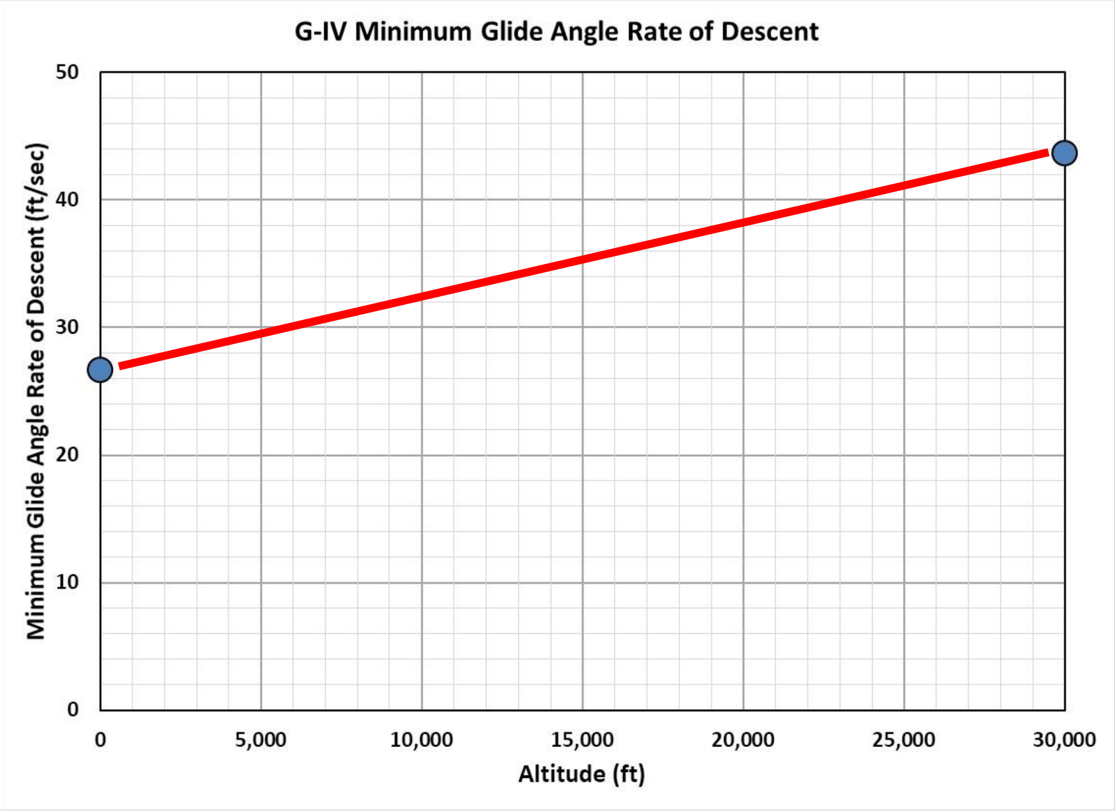
Time to Descend

<u>Easier Method</u> – assume linear Minimum Glide Angle vs Altitude

Calculate the Minimum Glide Angle and Velocity at Sea Level
Calculate the Minimum Glide Angle and Velocity at 30,000 ft
Calculate the average Glide Angle, average Velocity, and R/D



Example 5.18

Time to Descend

Easier Method

$$t_{\theta min} = \frac{\Delta h}{(R/D)_{avg}}$$

At Sea Level: $\theta_{min} = 3.96°$ $V_{\theta min} = 385.1$ ft/sec R/D = 26.7 ft/sec

At 30,000 ft: $\theta_{min} = 3.96°$ $V_{\theta min} = 631.0$ ft/sec R/D = 43.6 ft/sec

$$t_{\theta min} = \frac{(30,000 - 0)}{(43.6 + 26.7)/2}$$

$$\boxed{t_{\theta min} = 853.5 \text{ sec} = 14.22 \text{ min}}$$

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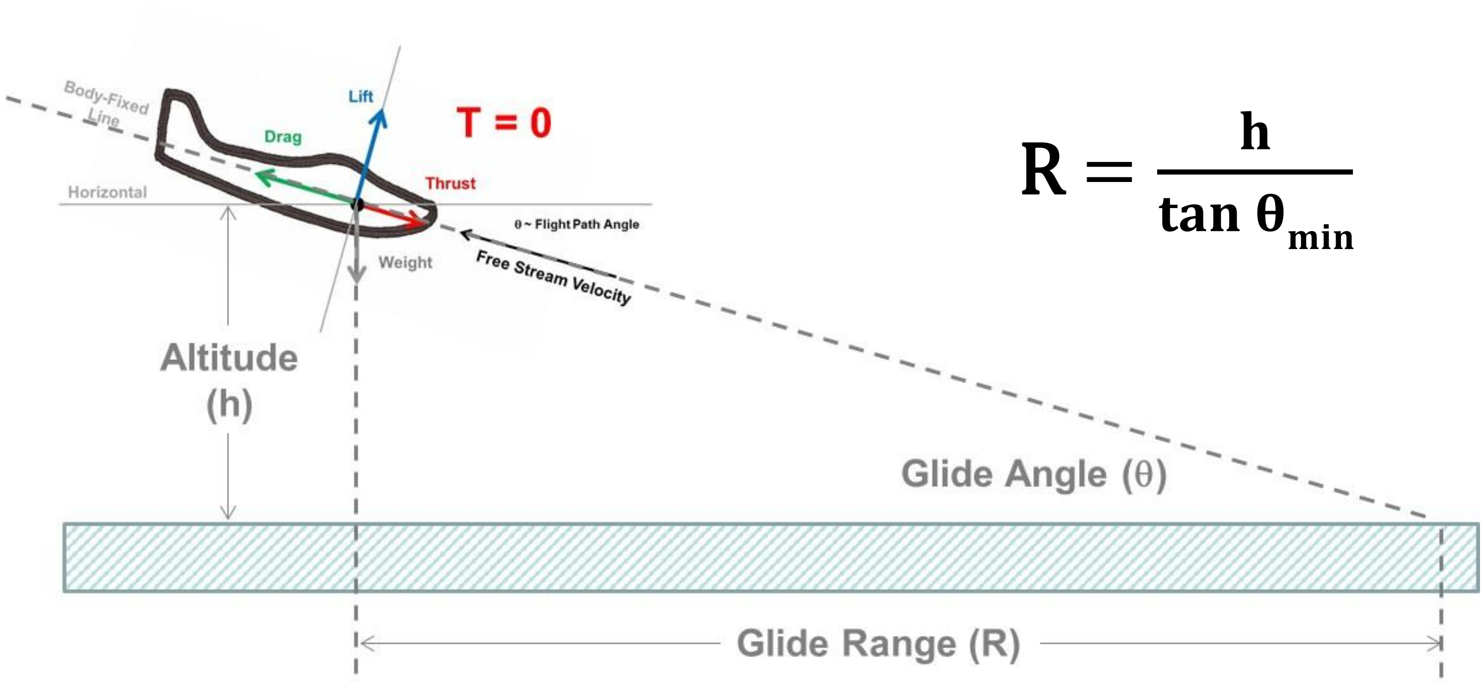
Fuel to Descend

<u>Easier Method</u> – assume linear Fuel Flow vs Altitude

Since this is "gliding flight" T = 0 and FFR = 0

Distance to Descend

<u>Easier Method</u> – assume linear Glide Angle vs Altitude



$$R = \frac{h}{\tan \theta_{min}}$$

$$R = \frac{h}{\tan \theta_{min}} = \frac{(30{,}000 - 0)}{\tan 3.96°}$$

$$\boxed{R = 433{,}013 \text{ ft} = 71.26 \text{ NM}}$$

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Descent Summary

Easier Method

$$\mathbf{t}_{\theta\mathbf{min}} = \frac{\Delta\,\mathbf{h}}{(\mathbf{R}/\mathbf{D})_{\mathbf{avg}}} \qquad \mathbf{w}_{\mathbf{fuel}} = \mathbf{0} \qquad \mathbf{R} = \frac{\mathbf{h}}{\tan\theta_{\mathbf{min}}}$$

Sea Level			30,000 ft		
θ_{min}	Velocity	R/D	θ_{min}	Velocity	R/D
(deg)	(ft/sec)	(ft/sec)	(deg)	(ft/sec)	(ft/sec)
3.96	385.1	26.7	3.96	631.0	43.6

Time	Fuel	Distance
14.22 min	0.0 lb	71.26 NM

Specific Excess Power

$$\boxed{\frac{(T-D)\,V}{W} = \frac{dh}{dt} + \frac{V}{g}\frac{dV}{dt} = P_s}$$

$$\frac{(T-D)\,V}{W} = \underbrace{\cancel{\frac{dh}{dt}}}_{0} + \underbrace{\frac{V}{g}\frac{dV}{dt}}_{\text{Acceleration capability}}$$

0

Acceleration capability

Level Acceleration

Time to Accelerate

Easier Method

$$t_{accel} = \frac{\Delta V}{(\dot{V})_{avg}}$$

At 20,000 ft & 518.4 ft/sec: $\dot{V}$ **= 6.1366 ft/sec^2**
At 20,000 ft & 829.5 ft/sec: $\dot{V}$ **= 5.1774 ft/sec^2**

$$t_{accel} = \frac{(829.5 - 518.4)}{(5.1774 + 6.1366)/2}$$

$$\boxed{t_{accel} = 55.0\ \mathrm{sec} = 0.92\ \mathrm{min}}$$

What about fuel and distance?

Fuel to Accelerate

Easier Method

$$\mathbf{w_{fuel} = \dot{w}_{avg}\ \Delta\, t}$$

At V_1 (518.4 ft/sec): **$\dot{w}$ = 6.8559 lb/sec**
At V_2 (829.5 ft/sec): **$\dot{w}$ = 6.8559 lb/sec**

$$\mathbf{w_{fuel} = \frac{(6.8559 + 6.8559)}{2}\ 55.0}$$

$$\boxed{\mathbf{w_{fuel} = 377.1\ lb}}$$

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Distance to Accelerate

Easier Method

$$s = V_{avg} \; \Delta t$$

$$s = \frac{(518.4 + 829.5)}{2} \; 55.0$$

$$\boxed{s = 37,067 \text{ ft} = 6.10 \text{ NM}}$$

Example 5.18

Acceleration Summary

Easier Method

$$\mathbf{t_{accel}} = \frac{\Delta \mathbf{V}}{(\dot{\mathbf{V}})_{\mathbf{avg}}} \qquad \mathbf{w_{fuel}} = \dot{\mathbf{w}}_{\mathbf{avg}}\ \Delta\,\mathbf{t} \qquad \boldsymbol{s} = \mathbf{V_{avg}}\ \Delta\,\mathbf{t}$$

0.50 M / 20,000 ft			0.80 M / 20,000 ft		
$\dot{V}$	FFR	Velocity	$\dot{V}$	FFR	Velocity
(ft/sec^2)	(lb/sec)	(ft/sec)	(ft/sec^2)	(lb/sec)	(ft/sec)
6.1366	6.8559	518.4	5.1811	6.8559	829.5

Time	Fuel	Distance
55.0 sec	377.1 lb	6.10 NM

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Specific Excess Power

$$\boxed{\frac{(T-D)\,V}{W} = \frac{dh}{dt} + \frac{V}{g}\frac{dV}{dt} = P_s}$$

$$\frac{(T-D)\,V}{W} = \underbrace{\cancel{\frac{dh}{dt}}}_{0} + \frac{V}{g}\frac{dV}{dt}$$

Acceleration capability

Level Acceleration

Time to Accelerate

Easier Method

$$\mathbf{t_{accel}} = \frac{\Delta \mathbf{V}}{(\dot{\mathbf{V}})_{avg}}$$

At 20,000 ft & 518.4 ft/sec: $\dot{V}$ = 6.1366 ft/sec^2
At 20,000 ft & 829.5 ft/sec: $\dot{V}$ = 5.1774 ft/sec^2

$$\mathbf{t_{accel}} = \frac{(829.5 - 518.4)}{(5.1774 + 6.1366)/2}$$

$$\boxed{\mathbf{t_{accel}} = 55.0\ \mathbf{sec} = 0.92\ \mathbf{min}}$$

What about fuel and distance?

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Fuel to Accelerate

Easier Method

$$\mathbf{w_{fuel} = \dot{w}_{avg}\ \Delta\, t}$$

At V_1 (518.4 ft/sec): **$\dot{w}$ = 6.8559 lb/sec**
At V_2 (829.5 ft/sec): **$\dot{w}$ = 6.8559 lb/sec**

$$\mathbf{w_{fuel} = \frac{(6.8559 + 6.8559)}{2}\ 55.0}$$

$$\boxed{\mathbf{w_{fuel} = 377.1\ lb}}$$

Distance to Accelerate

Easier Method

$$s = V_{avg}\ \Delta t$$

$$s = \frac{(518.4 + 829.5)}{2}\ 55.0$$

$$\boxed{s = 37{,}067 \text{ ft} = 6.10 \text{ NM}}$$

Acceleration Summary

Easier Method

$$\mathbf{t_{accel}} = \frac{\Delta \mathbf{V}}{(\dot{\mathbf{V}})_{\mathbf{avg}}} \qquad \mathbf{w_{fuel}} = \dot{\mathbf{w}}_{\mathbf{avg}}\ \Delta\,\mathbf{t} \qquad \boldsymbol{s} = \mathbf{V_{avg}}\ \Delta\,\mathbf{t}$$

0.50 M / 20,000 ft			0.80 M / 20,000 ft		
$\dot{V}$	FFR	Velocity	$\dot{V}$	FFR	Velocity
(ft/sec^2)	(lb/sec)	(ft/sec)	(ft/sec^2)	(lb/sec)	(ft/sec)
6.1366	6.8559	518.4	5.1811	6.8559	829.5

Time	Fuel	Distance
55.0 sec	377.1 lb	6.10 NM

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Time to Decelerate

Easier Method

$$\mathbf{t_{decel}} = \frac{\Delta\,\mathbf{V}}{(\dot{\mathbf{V}})_{\mathbf{avg}}}$$

At 20,000 ft & 829.5 ft/sec: $\dot{V}$ **= -3.1902 ft/sec^2**
At 20,000 ft & 518.4 ft/sec: $\dot{V}$ **= -2.2310 ft/sec^2**

$$\mathbf{t_{decel}} = \frac{(\mathbf{518.4 - 829.5})}{(\mathbf{-3.1902 - 2.2310})/\mathbf{2}}$$

$$\boxed{\mathbf{t_{decel}} = \mathbf{114.8\ sec = 1.91\ min}}$$

What about fuel and distance?

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Fuel to Decelerate

<u>Easier Method</u> – assume linear Fuel Flow vs Velocity

Since this is "decelerating flight" T = 0 and FFR = 0

Distance to Decelerate

Easier Method

$$\mathbf{s = V_{avg}\ \Delta t}$$

$$\mathbf{s = \frac{(518.4 + 829.5)}{2}\ 114.8}$$

$$\boxed{\mathbf{s = 77,369\ ft = 12.73\ NM}}$$

Deceleration Summary

Easier Method

$$\mathbf{t_{accel}} = \frac{\Delta \mathbf{V}}{(\dot{\mathbf{V}})_{\mathbf{avg}}} \qquad \mathbf{w_{fuel}} = \mathbf{0} \qquad \boldsymbol{s} = \mathbf{V_{avg}}\ \Delta\,\mathbf{t}$$

0.80 M / 20,000 ft			0.50 M / 20,000 ft		
$\dot{V}$	FFR	Velocity	$\dot{V}$	FFR	Velocity
(ft/sec^2)	(lb/sec)	(ft/sec)	(ft/sec^2)	(lb/sec)	(ft/sec)
-3.1902	0.0	829.5	-2.2310	0.0	518.4

Time	Fuel	Distance
114.8 sec	0 lb	12.73 NM

Level Turning Flight

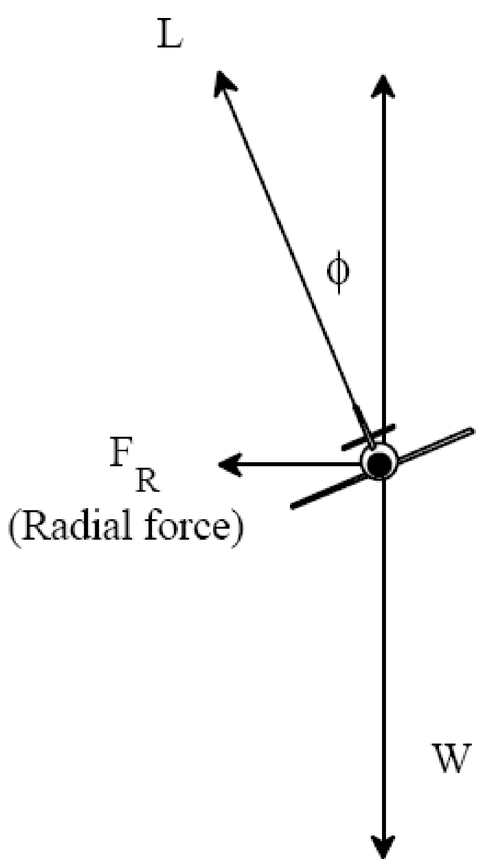

Figure 6.1
FORCES IN A STEADY LEVEL TURN

Lift acts perpendicular to the Free Stream Velocity
Lift acts perpendicular the wing surface
Drag acts parallel to the Free Stream Velocity
Weight acts vertically towards the ground
Thrust is fixed in the aircraft

Bank angle ϕ **Load factor n**

$$\Sigma F_z = L \cos\phi - W = 0$$

$$\cos\phi = \frac{W}{L} \qquad n = \frac{L}{W}$$

$$\phi = \arccos\left(\frac{1}{n}\right)$$

Level Turning Flight

Turn Radius: $$R = \frac{mV^2}{L \sin\phi} = \frac{V^2}{g\sqrt{n^2 - 1}}$$ (tightest turn)

Turn Rate: $$\omega = \frac{V}{R} = \frac{g\sqrt{n^2 - 1}}{V}$$ (quickest turn)

To minimize turn radius for tightest turn and to maximize turn rate for quickest turn:

Highest possible load factor
Lowest possible velocity

Level Turning Flight

Bank Angle ϕ

Load Factor n

Turn Radius R

Turn Angle ψ

Turn Rate $\omega = d\psi/dt$

Sustained Turn – turning while maintaining the same velocity and altitude $P_s = 0$

Sustained Corner Velocity – speed for highest turn rate while maintaining velocity and altitude

Instantaneous Turn – turning and not maintaining the same velocity and altitude $P_s \neq 0$

Corner Velocity – speed for highest turn rate

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Sustained Turn

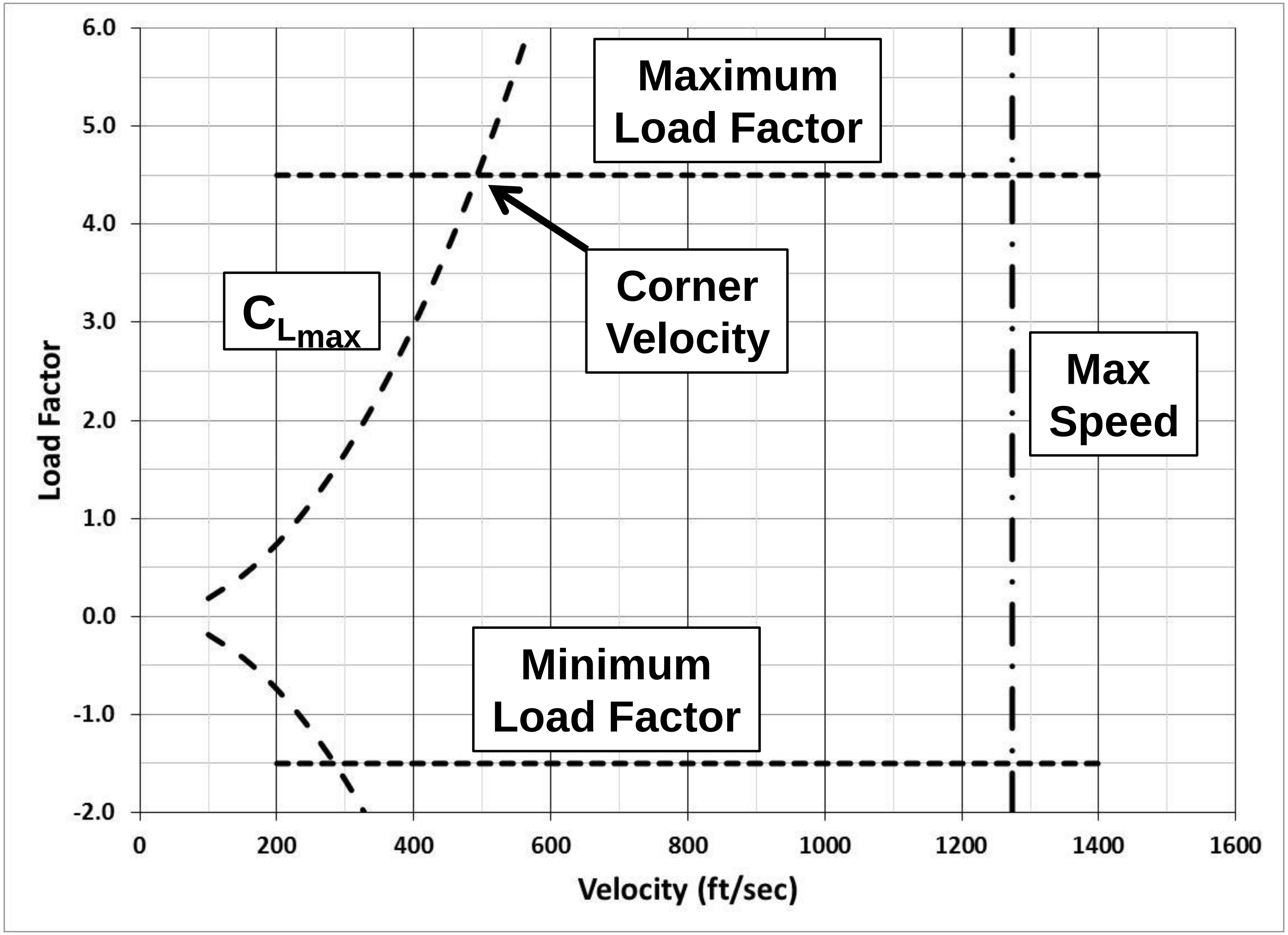
Sustained Turn – turning while maintaining the same velocity and altitude

$P_s = 0$

$$(n_{max})_{sust} = \sqrt{\frac{q}{K\,(W/S)}\left[\frac{T}{W} - \frac{q\,C_{D_0}}{(W/S)}\right]} = \left(\frac{T}{W}\right)\left(\frac{L}{D}\right)_{max}$$

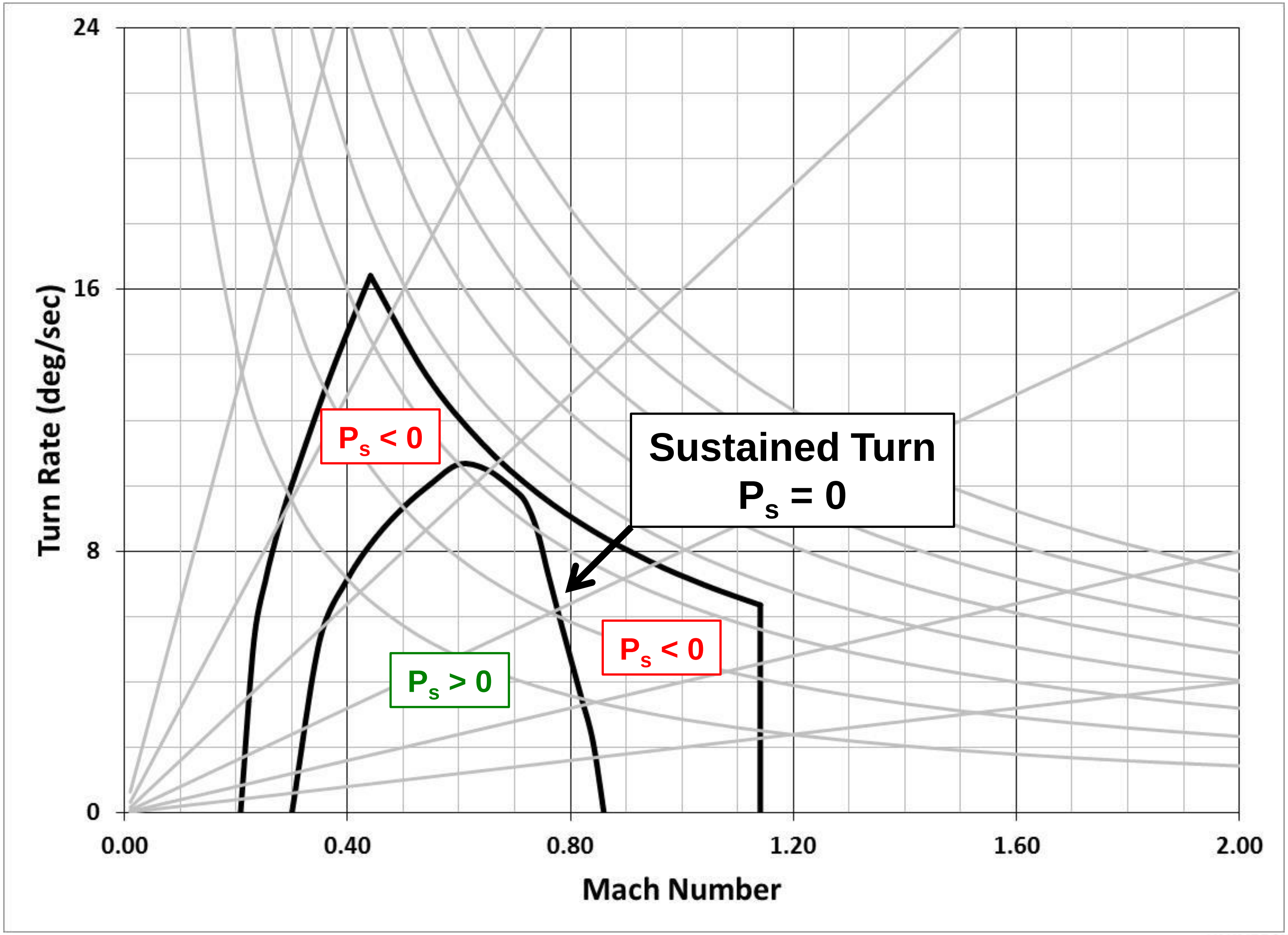
$$V_{(n_{max})_{sust}} = \left(\frac{2}{\rho}\sqrt{\frac{K}{C_{D_0}}}\,\frac{n\,W}{S}\right)^{1/2}$$

Instantaneous Turn



Maneuver Diagram

G-IV Example



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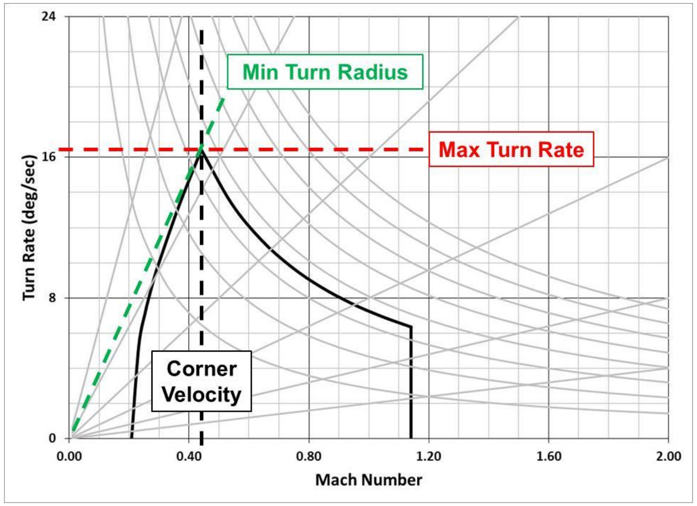
Maneuver Calculations



Corner Velocity

$$V_{corner} = \sqrt{\frac{2\, n_{max}\, (W/S)}{\rho\, C_{L_{max}}}}$$

CD0	0.0150	**Wt**	73,000	lb	**CLmax**	1.20	
K	0.08	**Alt**	0	ft	**Vmax**	1.14	Mach
Thrust	27,700	**QMS**	1481.4	lb/sqft	**Max g**	4.5	g's
W/S	76.84	**rho**	0.00237688	slugs/ft^3			
T/W	0.3795	**a**	1116.45	ft/sec			
		S	950	sq ft			
Maximum Turn Rate & Minimum Turn Radius							
Corner Velocity		492.4	ft/sec				
		0.4410	Mach				
Max Turn Rate		16.43	deg/sec				
Min Turn Radius		1718	ft				

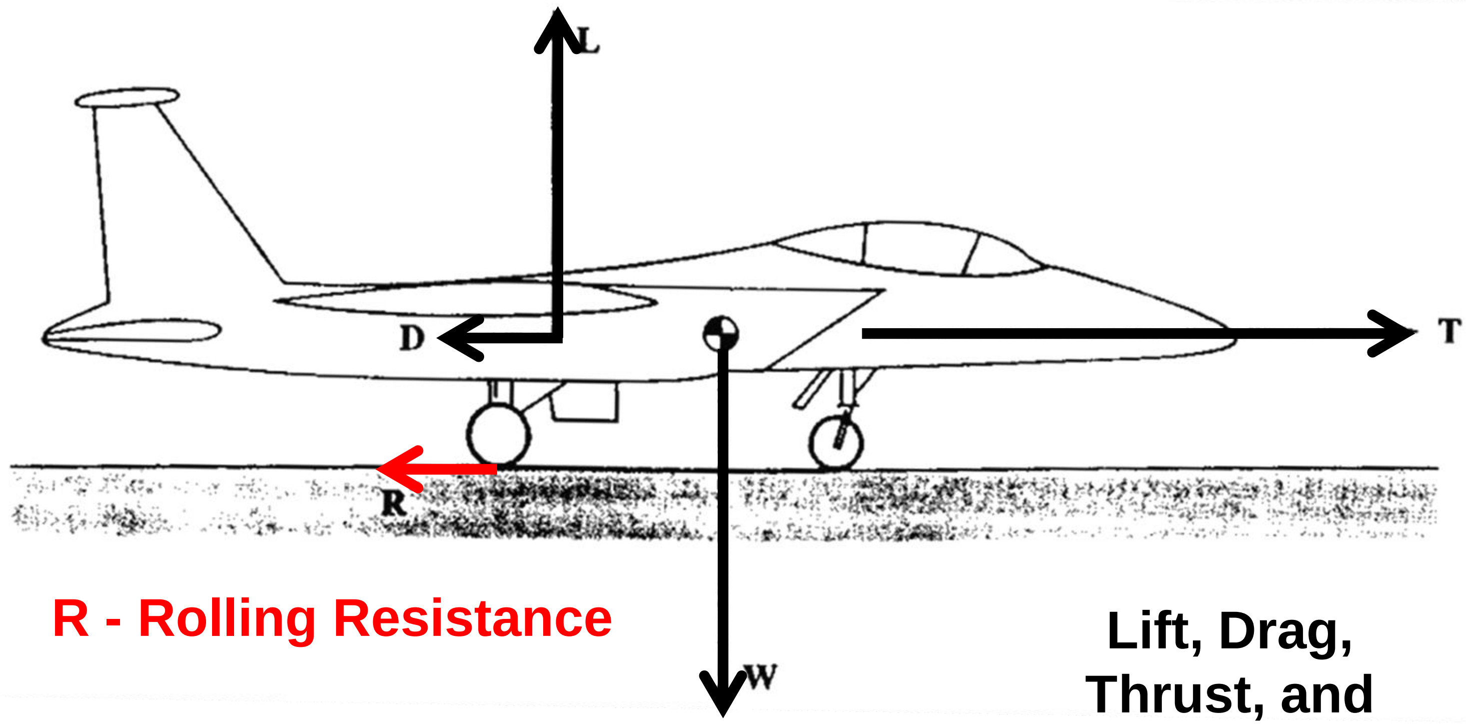
Turn Rate

$$\omega = \frac{g\sqrt{n^2 - 1}}{V}$$

Turn Radius

$$R = \frac{V^2}{g\sqrt{n^2 - 1}}$$

Takeoff



R - Rolling Resistance

Lift, Drag, Thrust, and Weight

$R = \mu_r (W - L)$

μ_r = coefficient of rolling friction

$0.02 < \mu_r < 0.08$

Takeoff

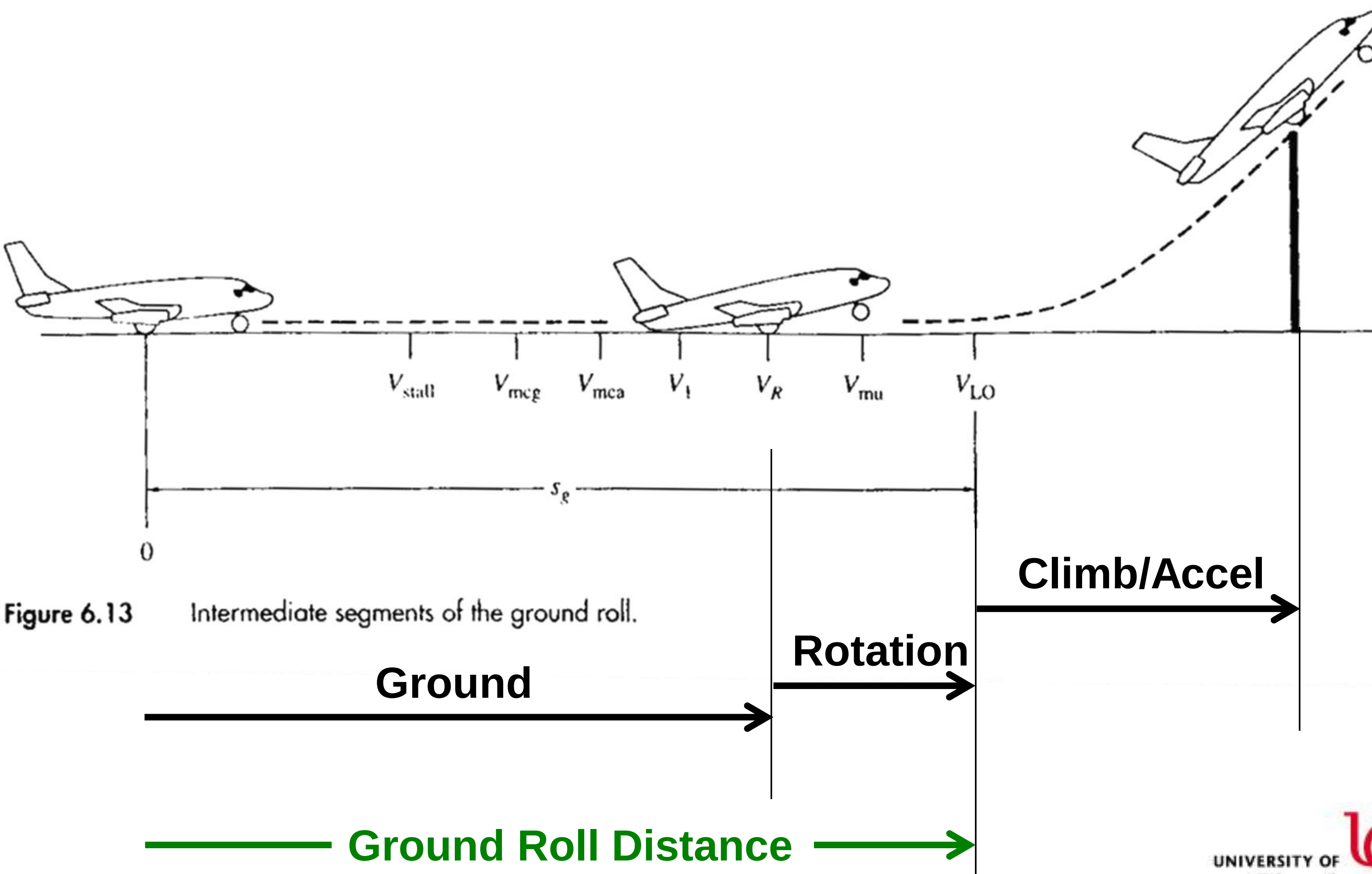
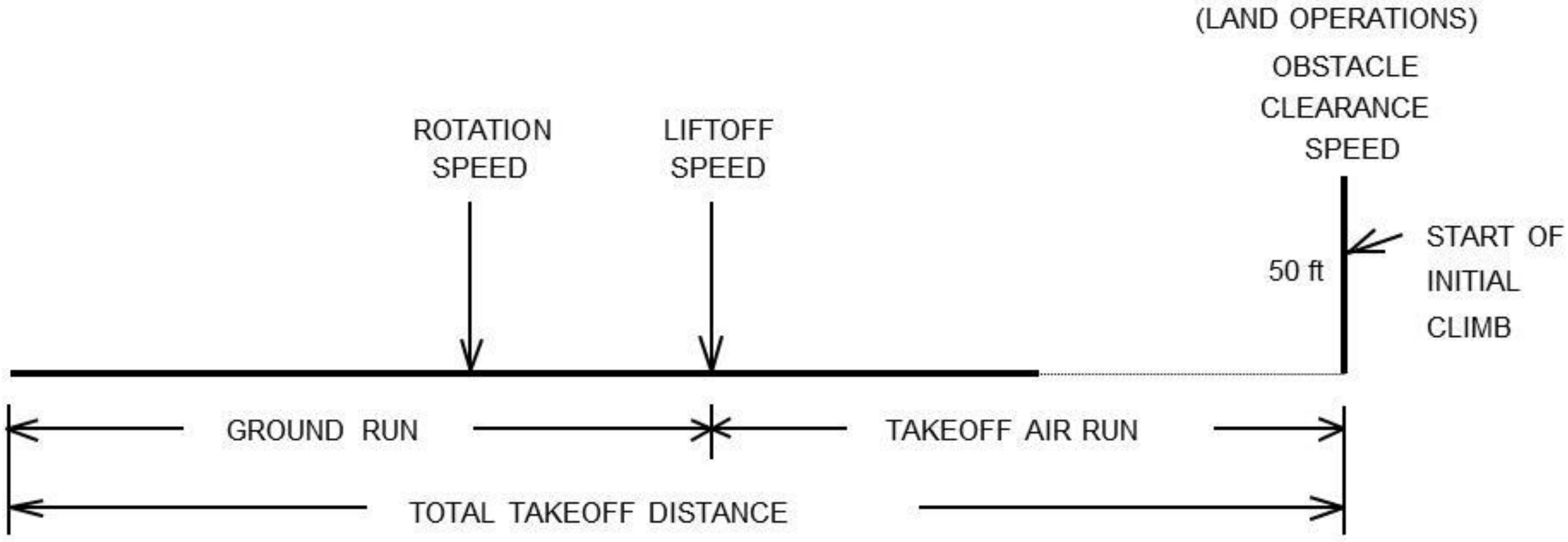


Figure 6.13 Intermediate segments of the ground roll.

Takeoff



Rotation Speed
> 1.05 V_{stall}

Liftoff Speed
> 1.10 V_{stall}

Obstacle Speed
> 1.20 V_{stall}

$$V_{stall} = \sqrt{\frac{2\,W}{\rho\,S\,C_{L_{max}}}}$$

$$V_{rot} = 1.05\,V_{stall}$$

Takeoff

$$\boxed{s_g = \frac{{V_{TO}}^2}{2\,a}}$$

where a is the average acceleration during the ground run

$$\Sigma\, F_x = T - D - R = m\frac{dV}{dt}$$

$$a = \frac{dV}{dt} = \frac{T - D - R}{W/g}$$

where T, D, and R are calculated at 0.7 V_{TO}

Takeoff

$$a = \frac{dV}{dt} = \frac{T - D - R}{W/g}$$

where T, D, and R are calculated at 0.7 V_{TO}

T = Thrust at 0.7 V_{TO} at takeoff altitude

D = Drag at 0.7 V_{TO} at takeoff altitude
= $(C_{D_0} + \Delta C_{D_0})\,(0.5\,\rho\,(0.7\,V_{TO})^2\,S)$

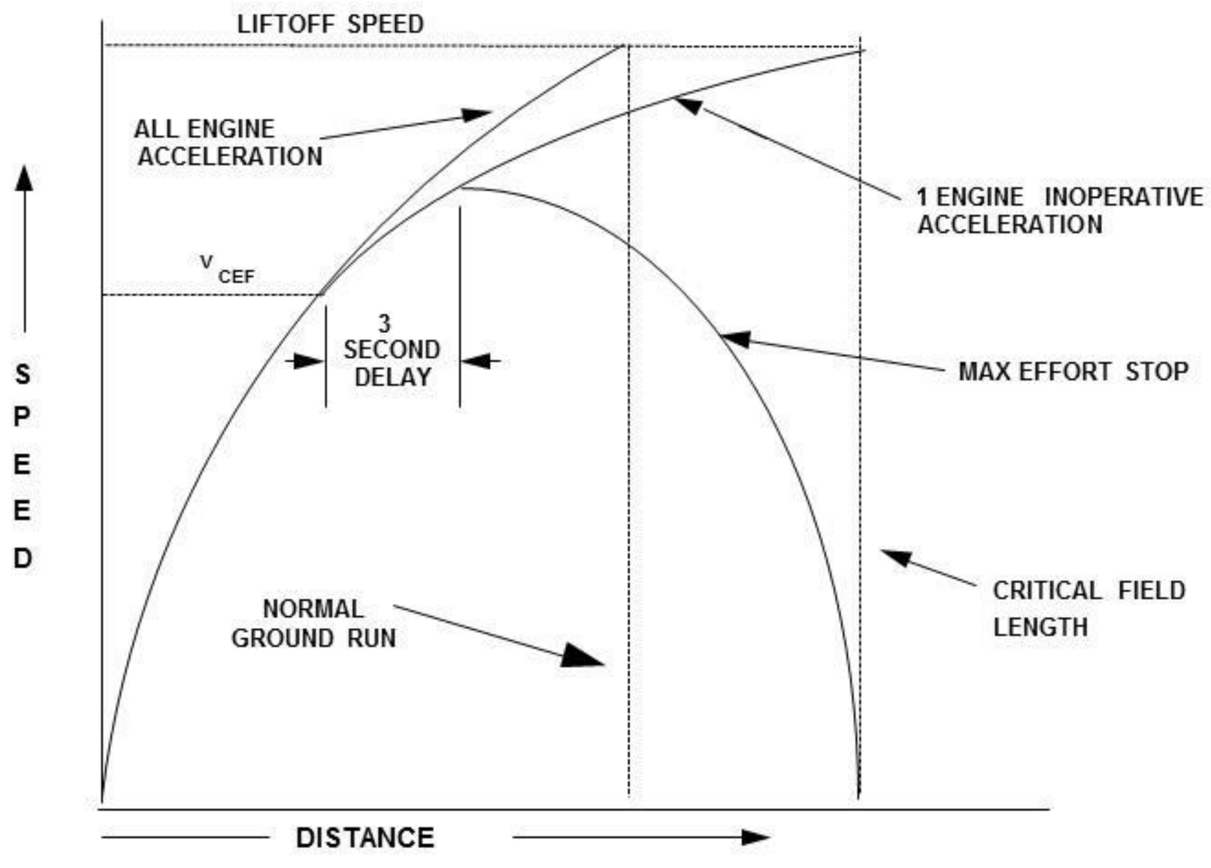
ΔC_{D_0} includes gear drag and flap drag

C_{D_L} and L are considered negligible

Chapter 6.7

Critical Field Length

In the event of the loss of an engine during ground roll
Decision point at Critical Engine Failure Speed
Decide whether to continue takeoff or abort takeoff



Only for multi-engine aircraft

Landing

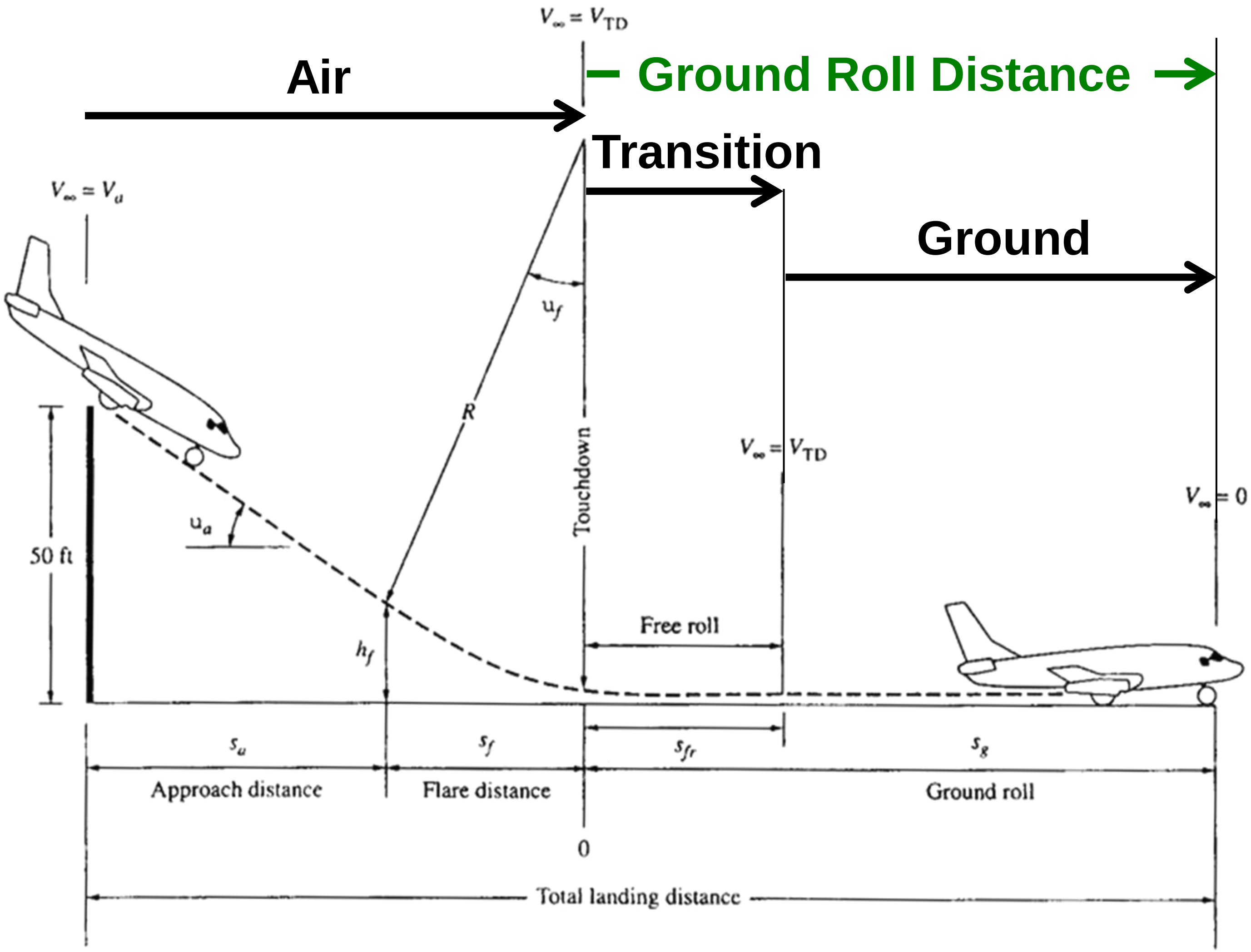
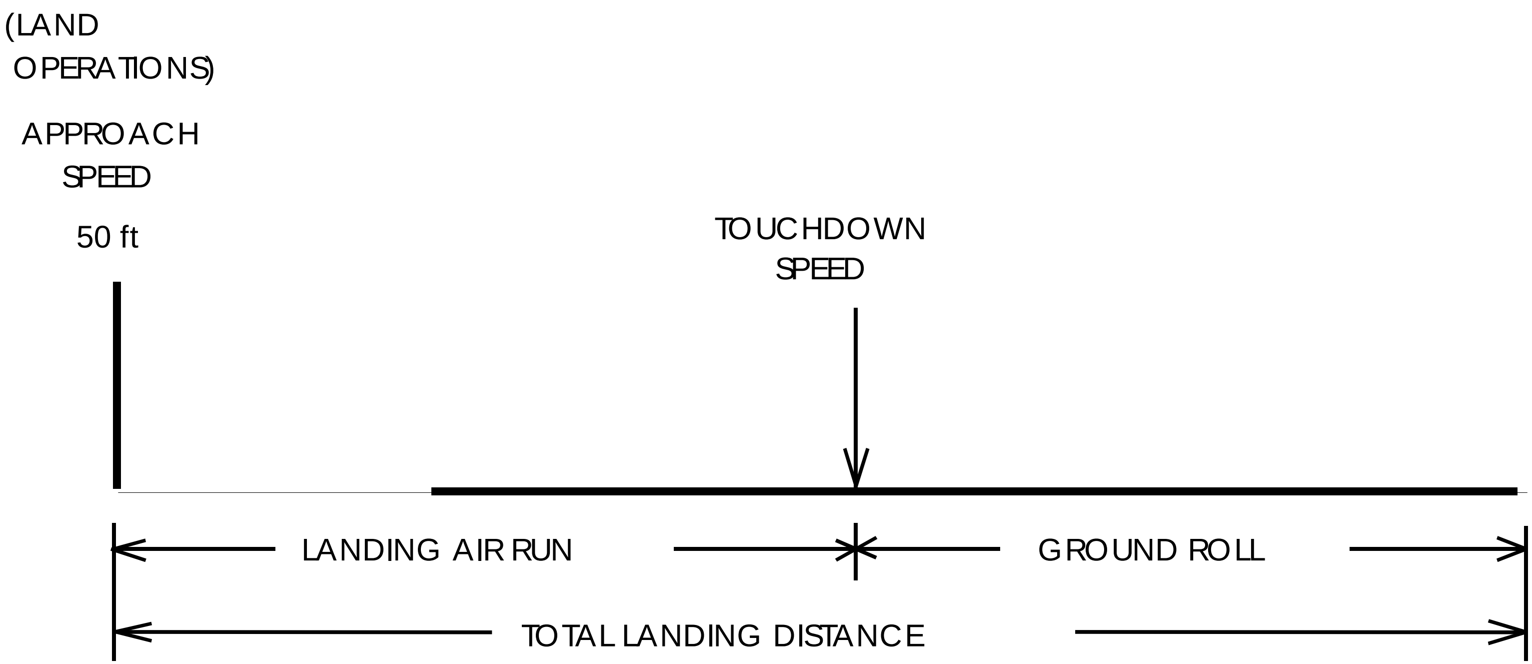


Figure 6.17 The landing path and landing distance.

Landing



Approach Speed V_{app} > 1.20 V_{stall}

Commercial > 1.30 V_{stall}

Touchdown Speed V_{TD} > 1.10 V_{stall}

Commercial > 1.15 V_{stall}

Landing – Transition

$$S_{TR} = \left[\left(\frac{V_{TD} + V_{TR}}{2}\right) - V_W\right] \Delta t_{TR}$$

Approximate by assuming 3 seconds to rotate the nose gear to the runway and deploy deceleration devices

$$S_{TR} = 3V_{TD}$$

V_{TD} – Touchdown Velocity
V_{TR} – Transition Velocity
V_W – Wind Velocity

Landing – Ground

$$s_{Brake} = -\frac{(V_{TD} - V_W)^2}{2g\left({}^{T}/_{W} - \mu\right)}$$

$0.12 < \mu_b < 0.38$

V_{TD} – Touchdown Velocity
V_W – Wind Velocity

For zero thrust and no wind

$$\mathbf{s_{brake} = \frac{V_{TD}{}^2}{2\ g\ \mu}}$$

$$\mathbf{s_g = s_{TR} + s_{brake}}$$

Course Exams

Will be done online via Canvas:

Exam #1 – Thursday, January 27 at 2:00 pm ET

Exam #2a – Tuesday, February 17 at 2:00 pm ET

Exam #2b – Thursday, March 10 at 2:00 pm ET

Start the exam between 2:00 and 2:15 pm ET

You will have **100 minutes** to complete the exam

Allowable resources include your notes, calculator, lecture slides, reference materials, spreadsheets

Academic Integrity = no help from other students!!

Questions are randomly selected

Exam will be graded automatically

Students will know their exam grade immediately after submitting

Questions during the exam should be e-mailed to the instructor

Course Exam Tips

Be ready to take this exam!

There are 15 questions to answer (~100 points each):

- True / False
- Multiple Choice
- Matching
- Numerical values

Answers do not depend on any previous calculations, which means that there is no partial credit

You can answer the questions in any order

You can review any of the questions at any time

Do not hit the “Submit” button until you have finished

Questions?

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