Improved Climb

Performance Engineer Operations

Flight Operations Engineering

Tom Ruckman

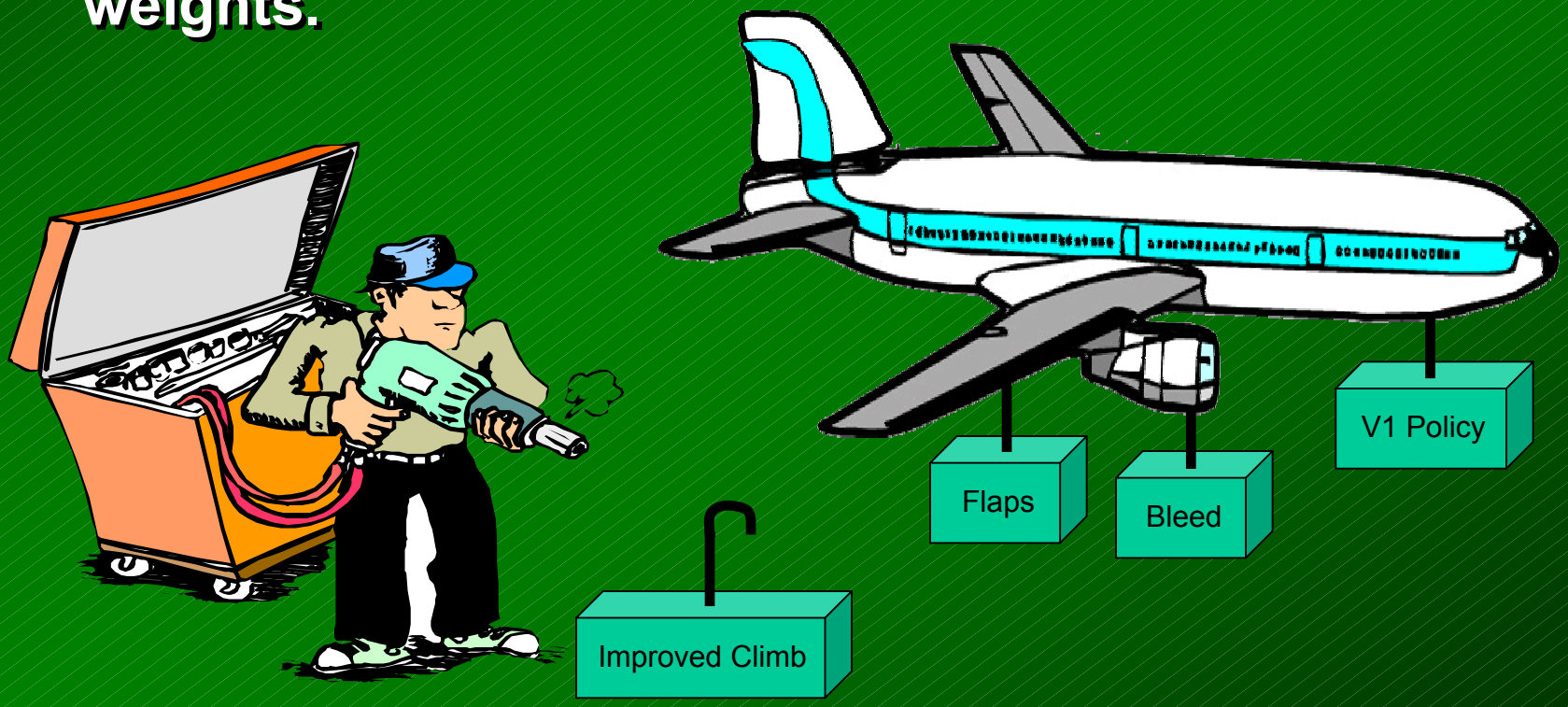
November 2001

Improved Climb

- What is Improved Climb?
- How is Improved Climb Used?
  - Airplane Flight Manual (AFM)
  - Operations Manual (OM) / Flight Planning & Performance Manual (FPPM)
- Operational Considerations
- Other Methods of “Improving” Climb Performance

What is Improved Climb?

- **Improved Climb is a tool available to the Performance Engineer to optimize the aircraft takeoff performance resulting in increased takeoff weights.**



5 Factors Determining Performance Limited Takeoff Gross Weight

1. Field Length
2. Climb
3. Tire Speed
4. Brake Energy
5. Obstacle

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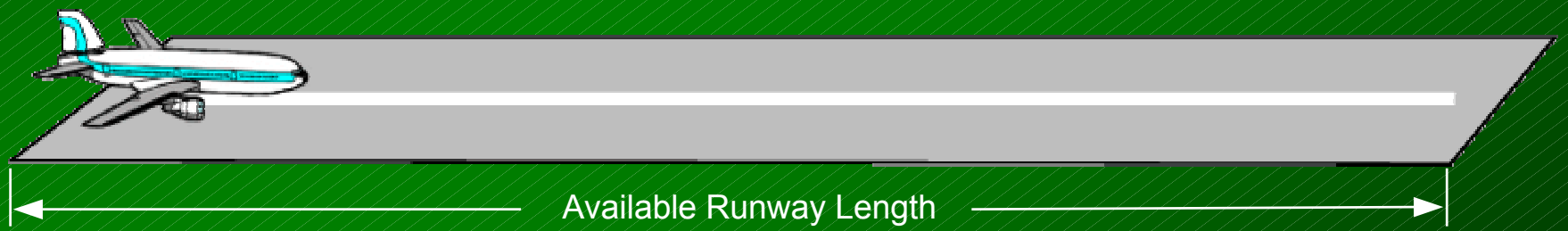
Field Length Limited Weight

- **Weight at which following an engine failure just prior to V1 the aircraft continues accelerating, with one engine inoperative, and reaches a height of 35 feet at the end of the runway.**



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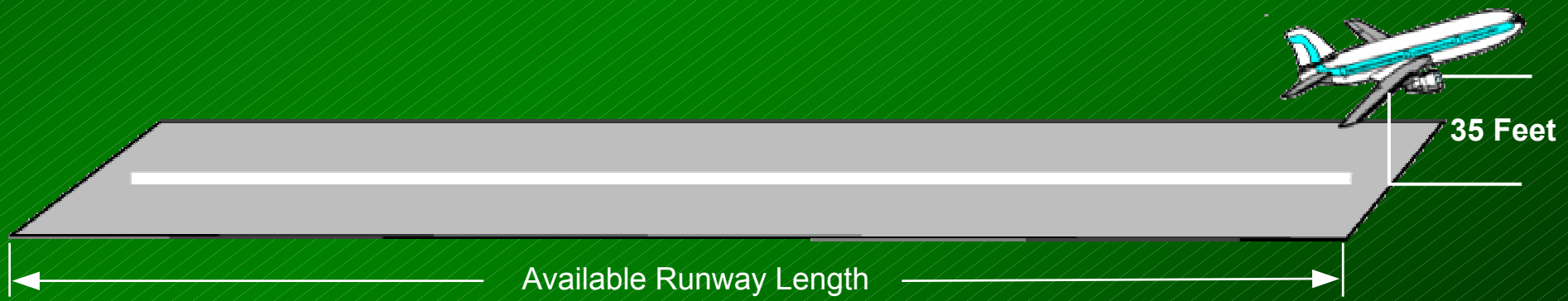
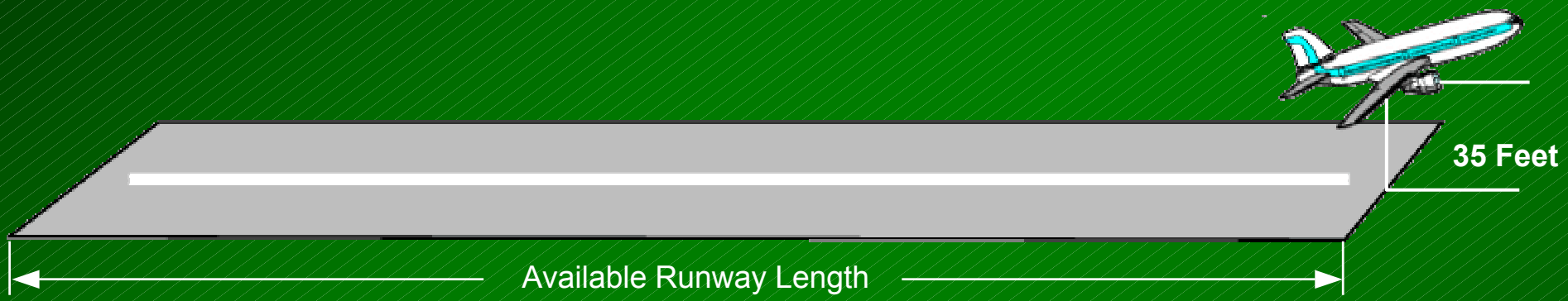
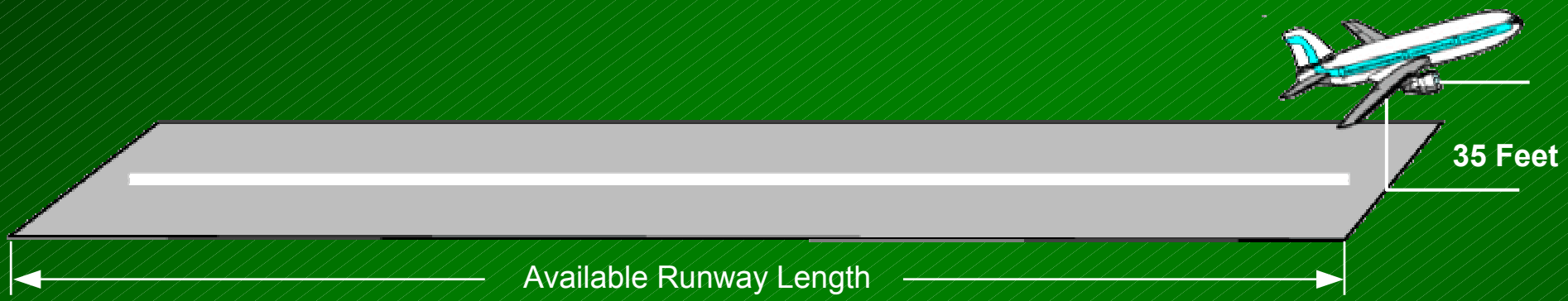


Field Length Limited Weight



- **FAR Part 25.107 defines the minimum speed required at the 35 foot height as highest of:**
  - **1.13*Vs1g**
  - **1.10*Vmca**
  - **Vr + acceleration to 35 feet**

Field Length Limited Weight



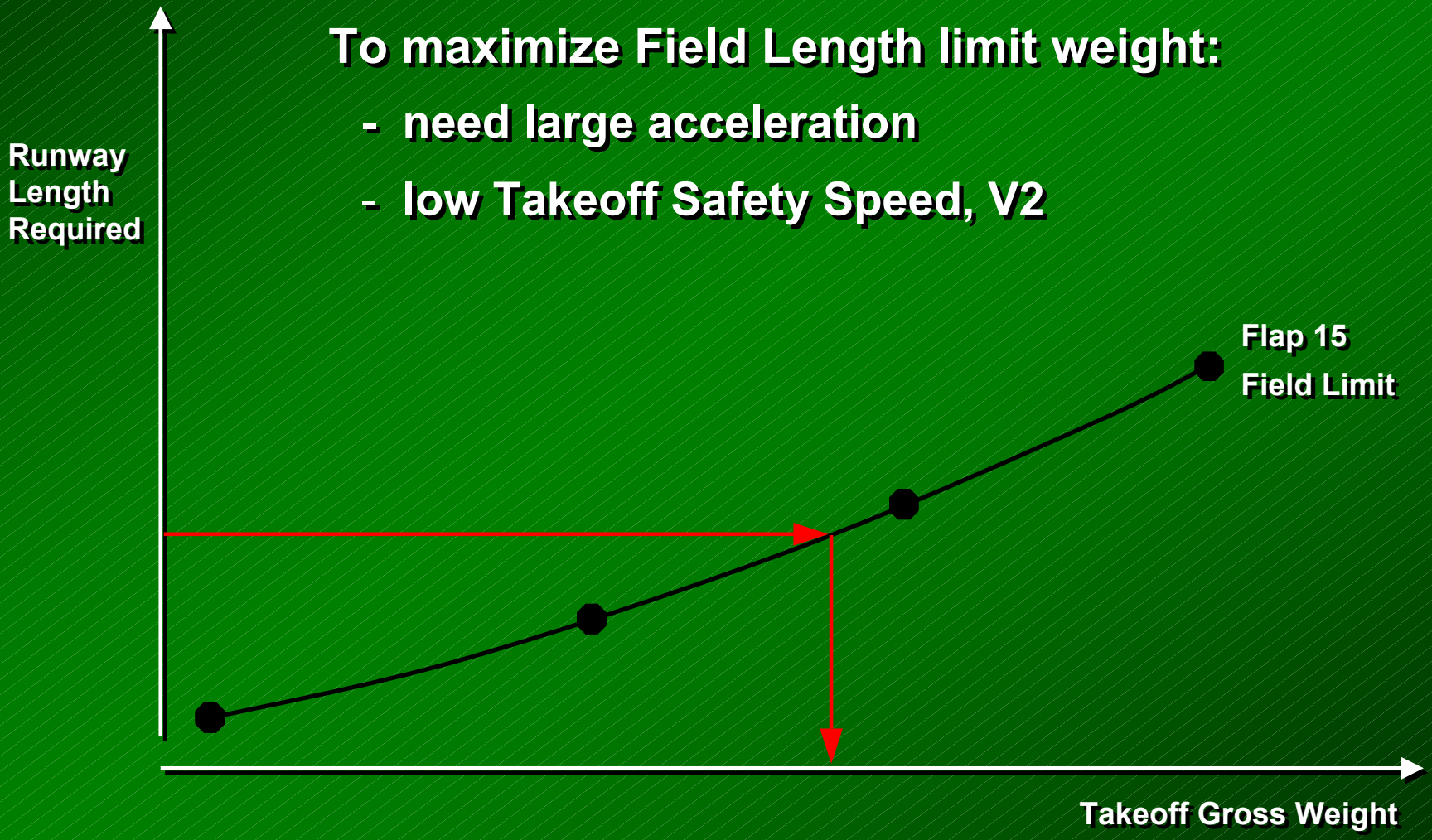
Distance (S) = f{ a, V }

- **Takeoff Distance is f{ Thrust, Config, Weight }:**
  - **sets acceleration**
  - **sets V2 speed**

Takeoff Weight Capability

To maximize Field Length limit weight:

- need large acceleration
- low Takeoff Safety Speed, V2



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1. Field Length
2. **Climb**
3. Tire Speed
4. Brake Energy
5. Obstacle

Climb Limited Weight

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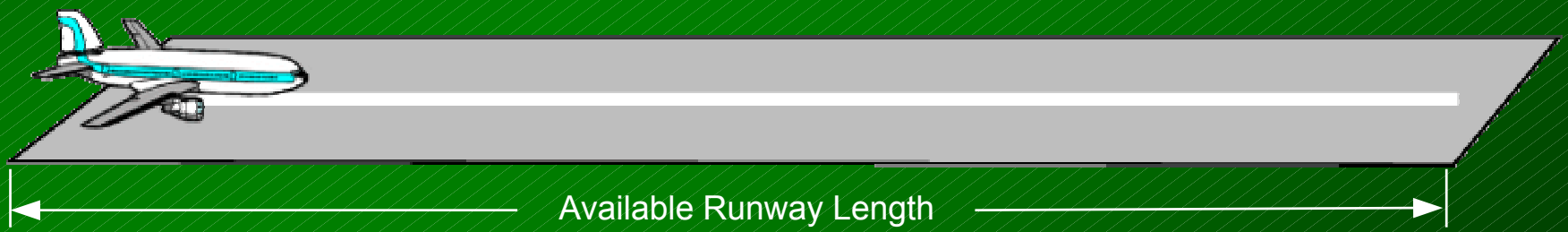

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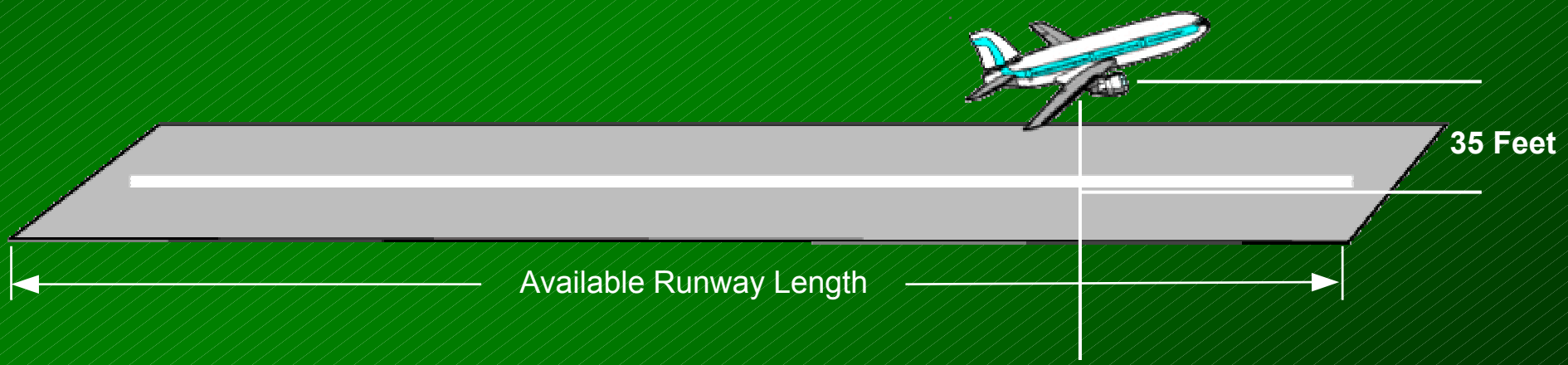
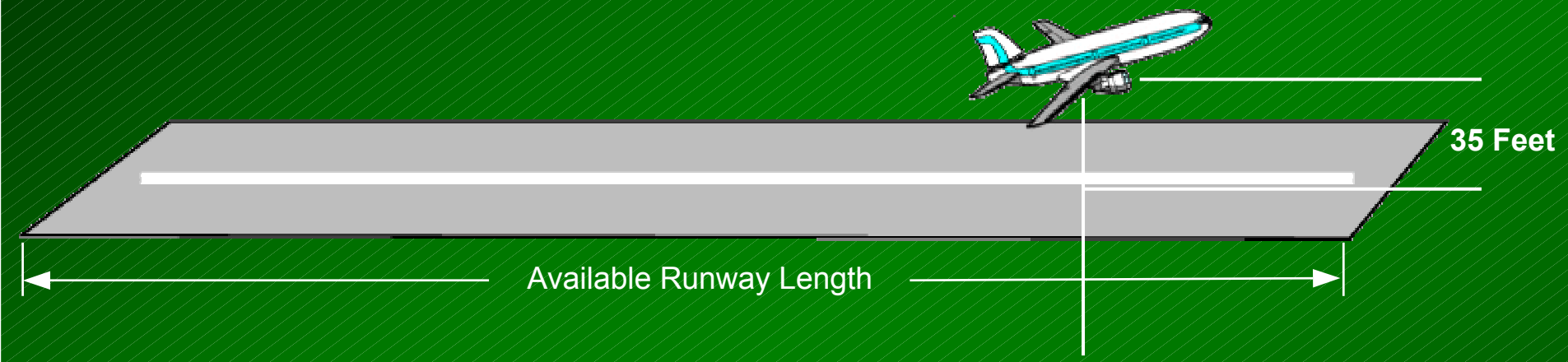


Climb Limited Weight



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Takeoff Weight Capability

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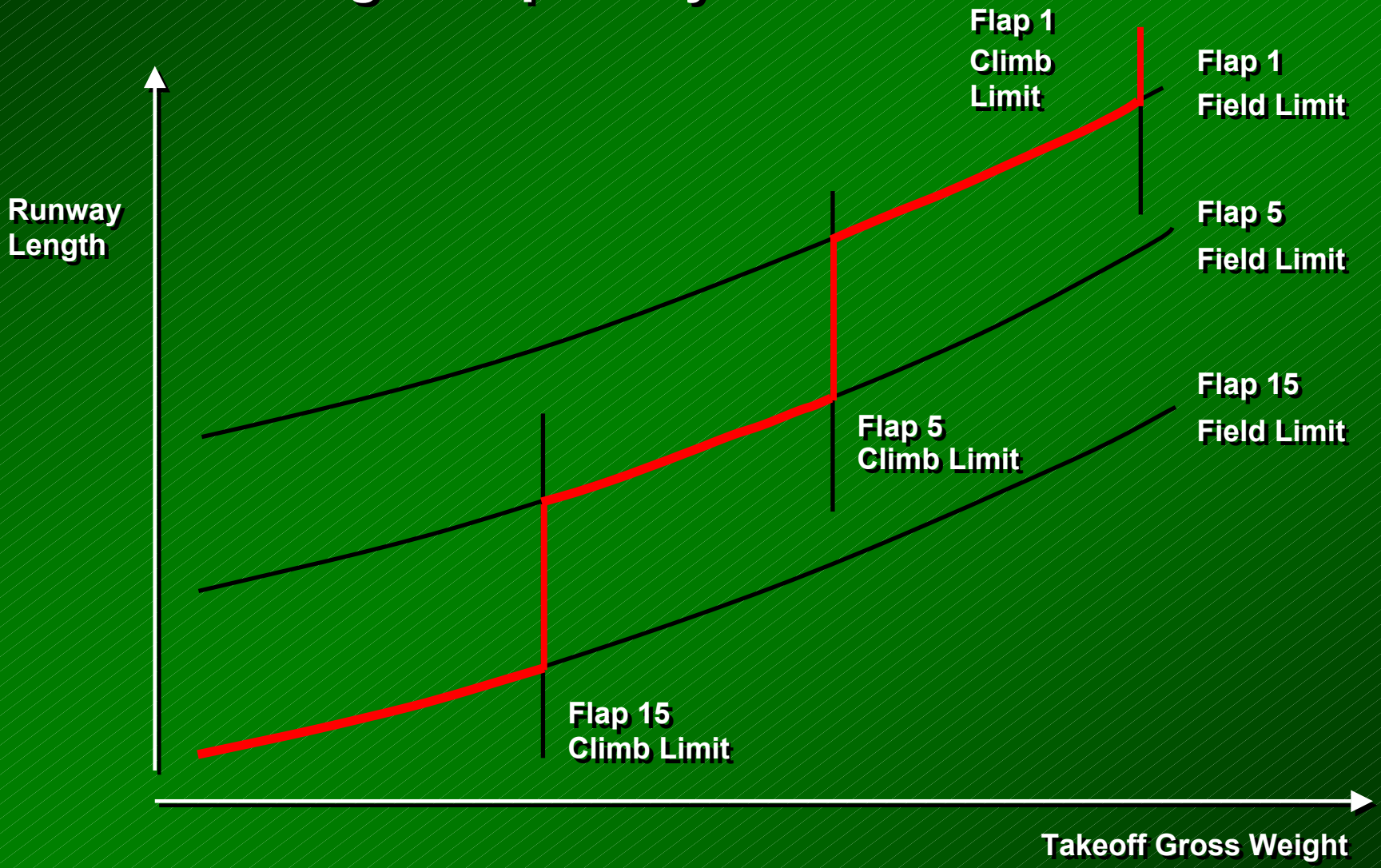
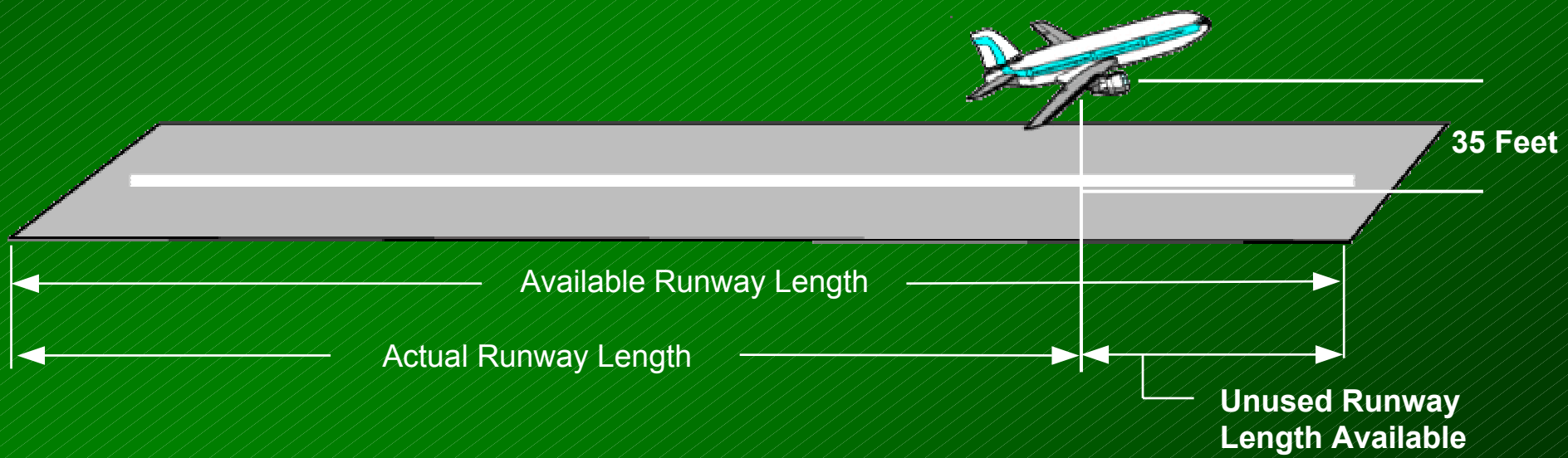
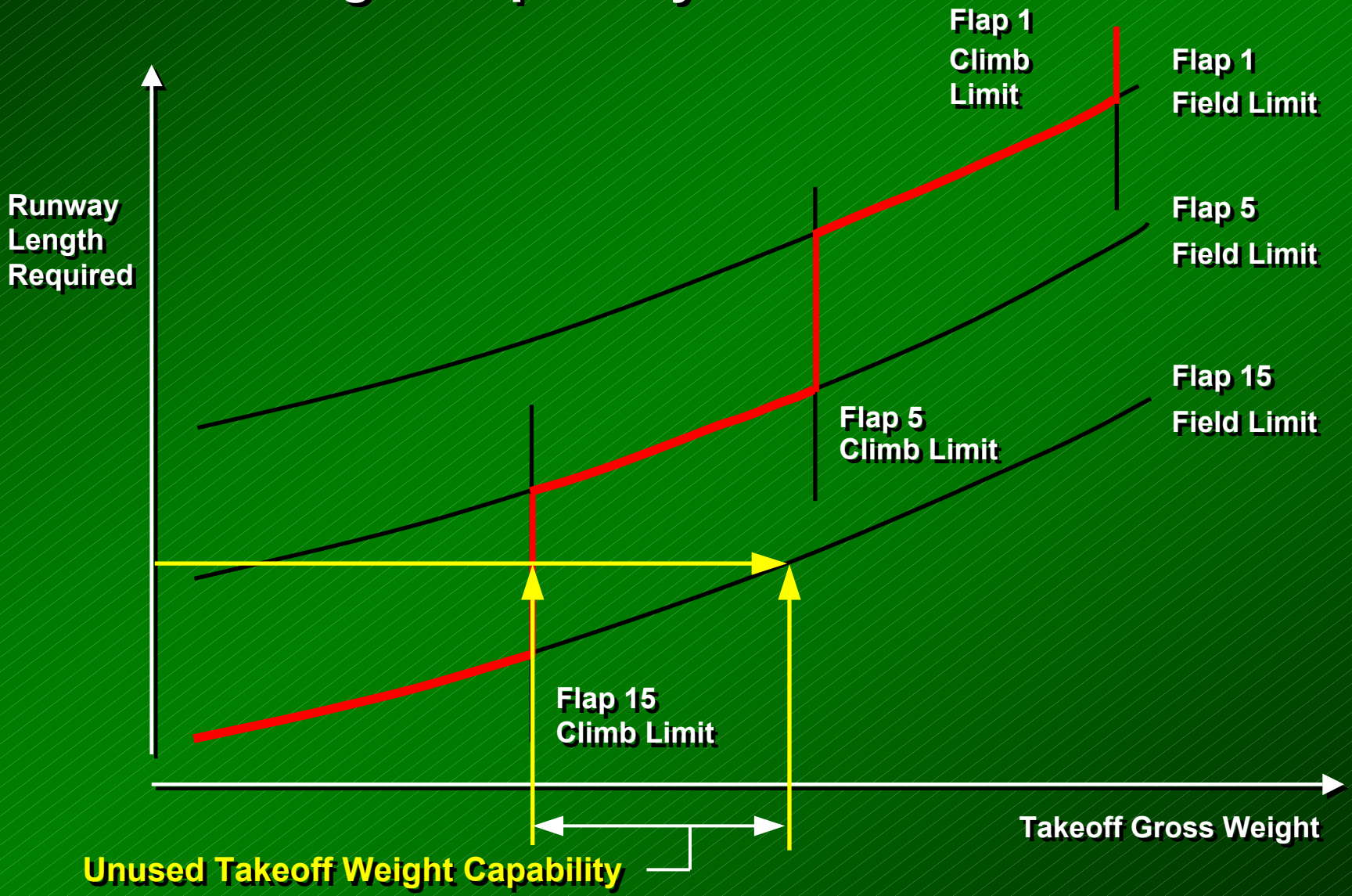


Climb Limited Weight

- **A Climb Limited Takeoff Weight results in not using all the Available Runway Length**



Takeoff Weight Capability



Definition of Climb Gradient

$$\text{Climb Gradient (Grad)} = \frac{\left[\frac{\text{Thrust}}{\text{Weight}} - \frac{\text{Drag}}{\text{Lift}}\right]}{1 + \text{Accel Factor}}$$

Where: Thrust is How Much Push We Have

Drag is How Much We Have to Push

Lift is How Much We Can Carry

Weight is How Much We Have to Carry

Definition of Climb Gradient

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Thrust (Fn) is f{ Alt, Temp, Speed }

Drag is f{ Alt, Temp, Config, Speed }

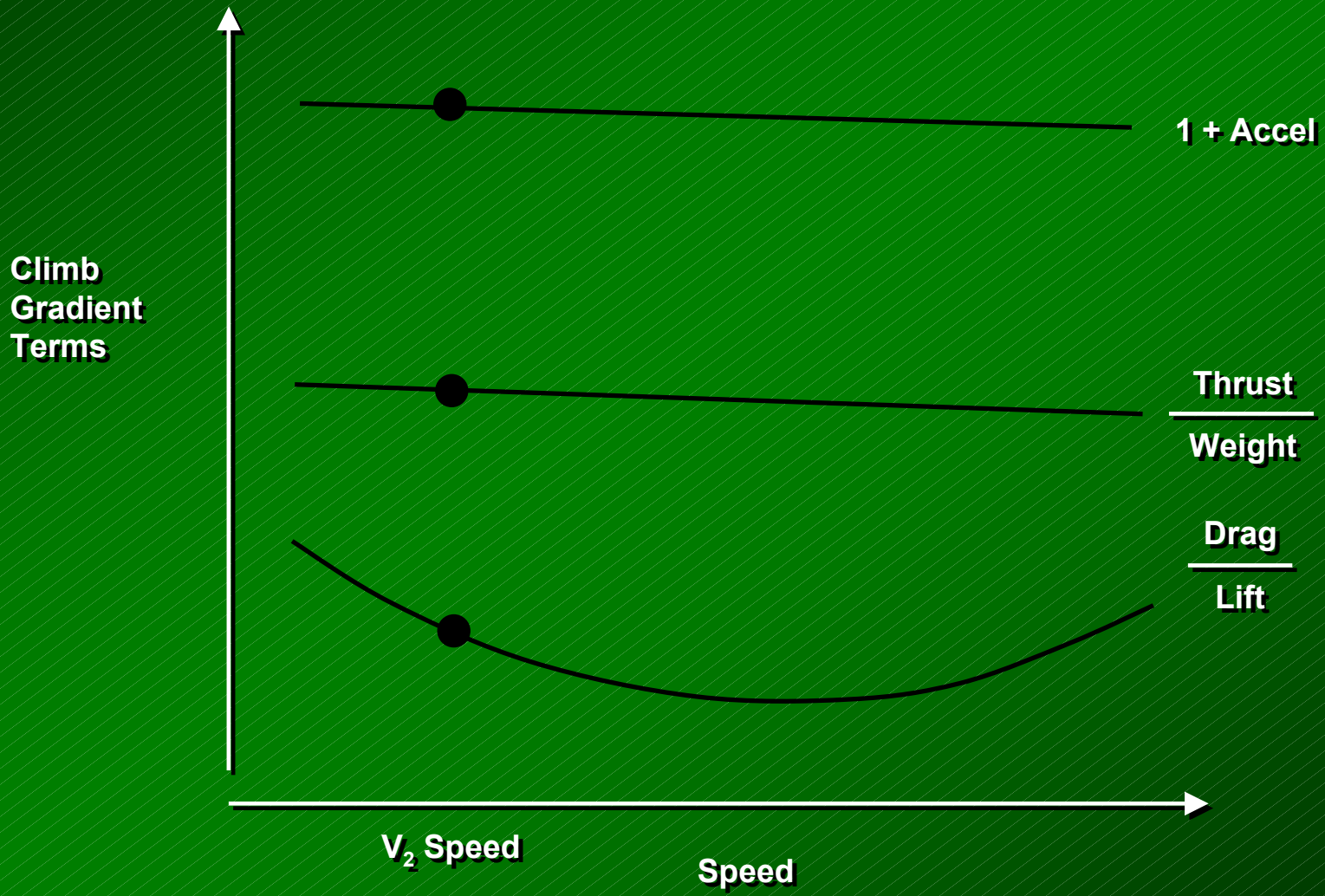
Weight (Wgt) is a constant

Lift is f{ Wgt }

Accel Factor is f{ Alt, Temp, Speed }

For a given condition, Grad will vary as a function of Speed

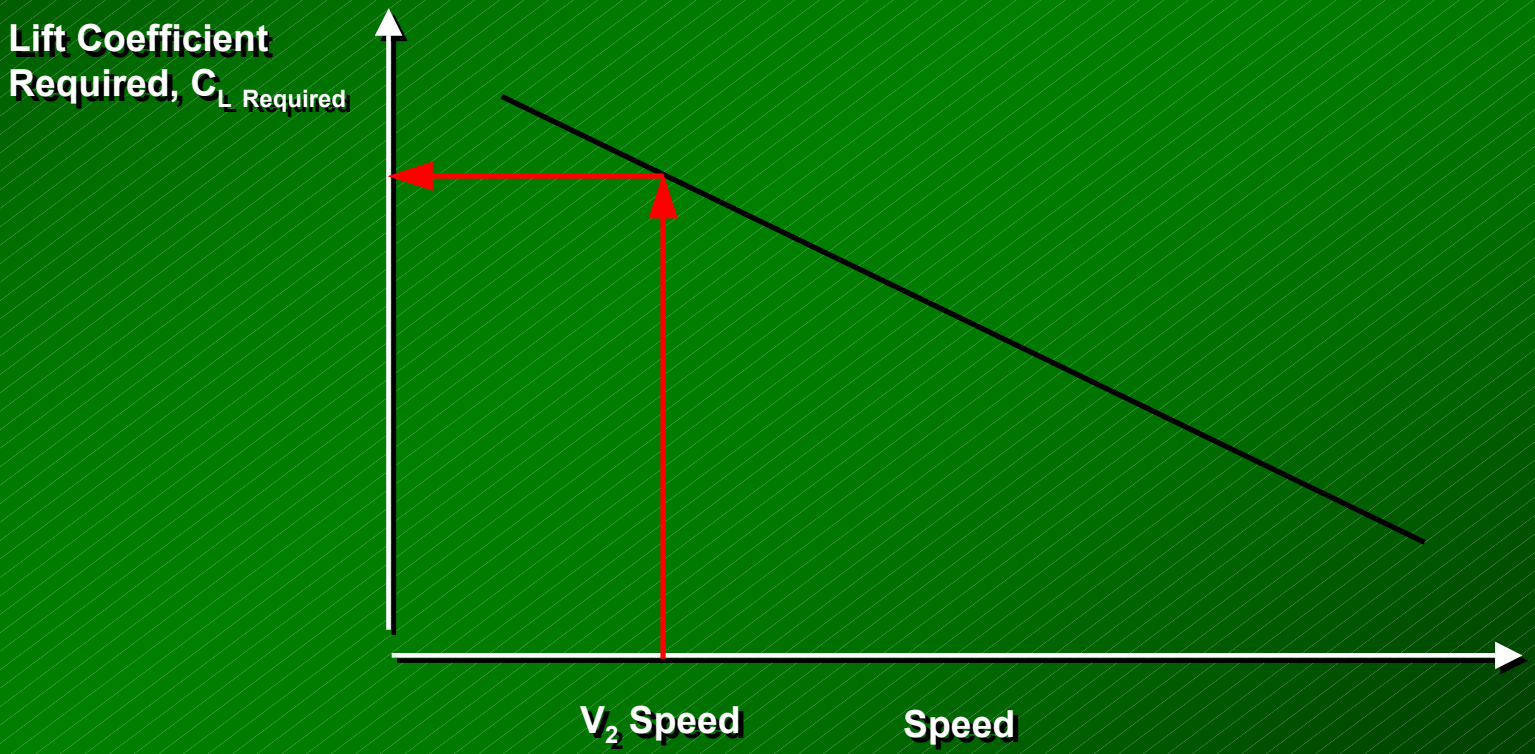
Climb Gradient Terms versus Speed



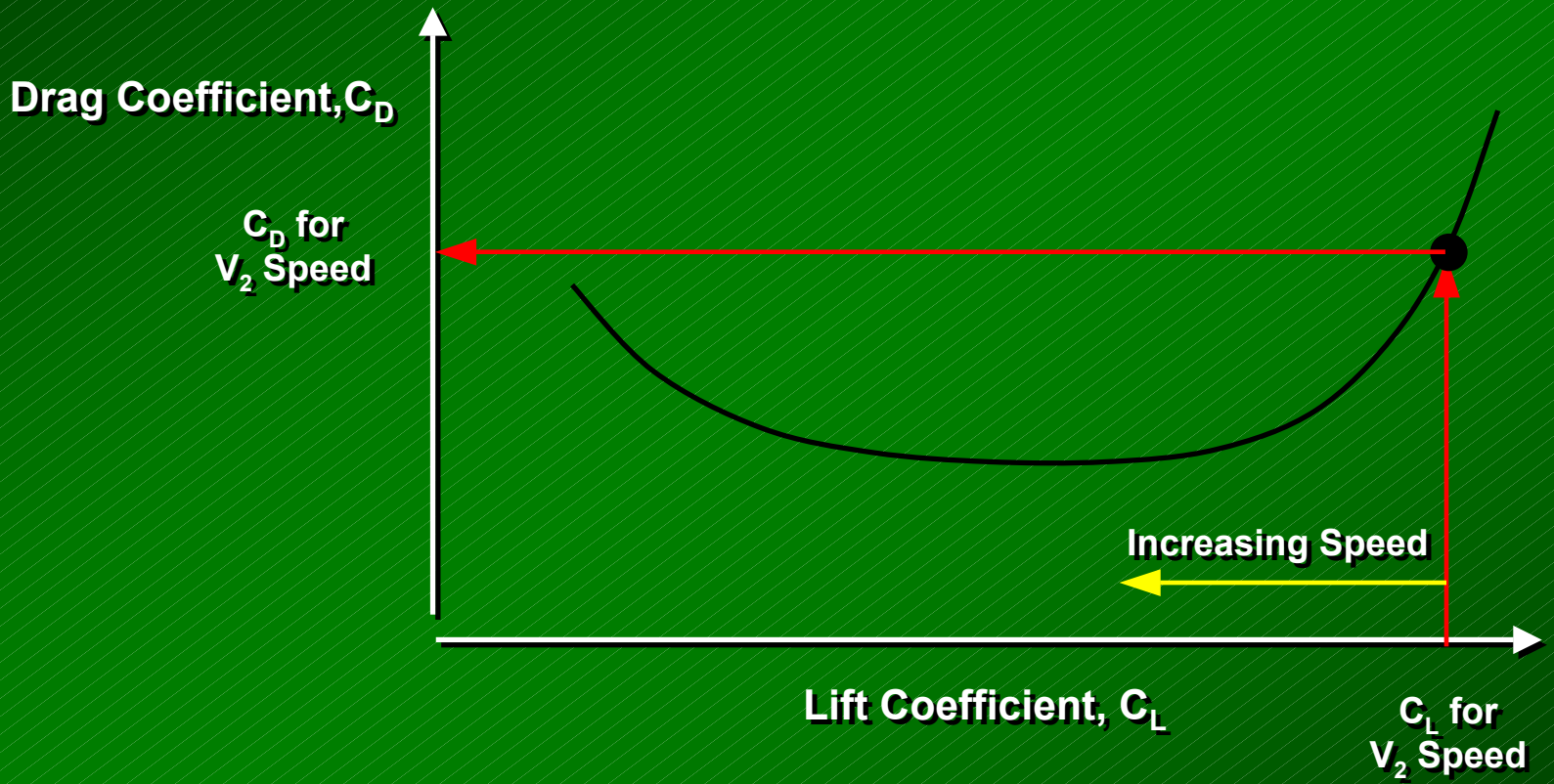
Lift Coefficient Required versus Speed

$$\text{Lift} = CL_{\text{Required}} * 0.5 * \rho * \text{Speed}^2$$

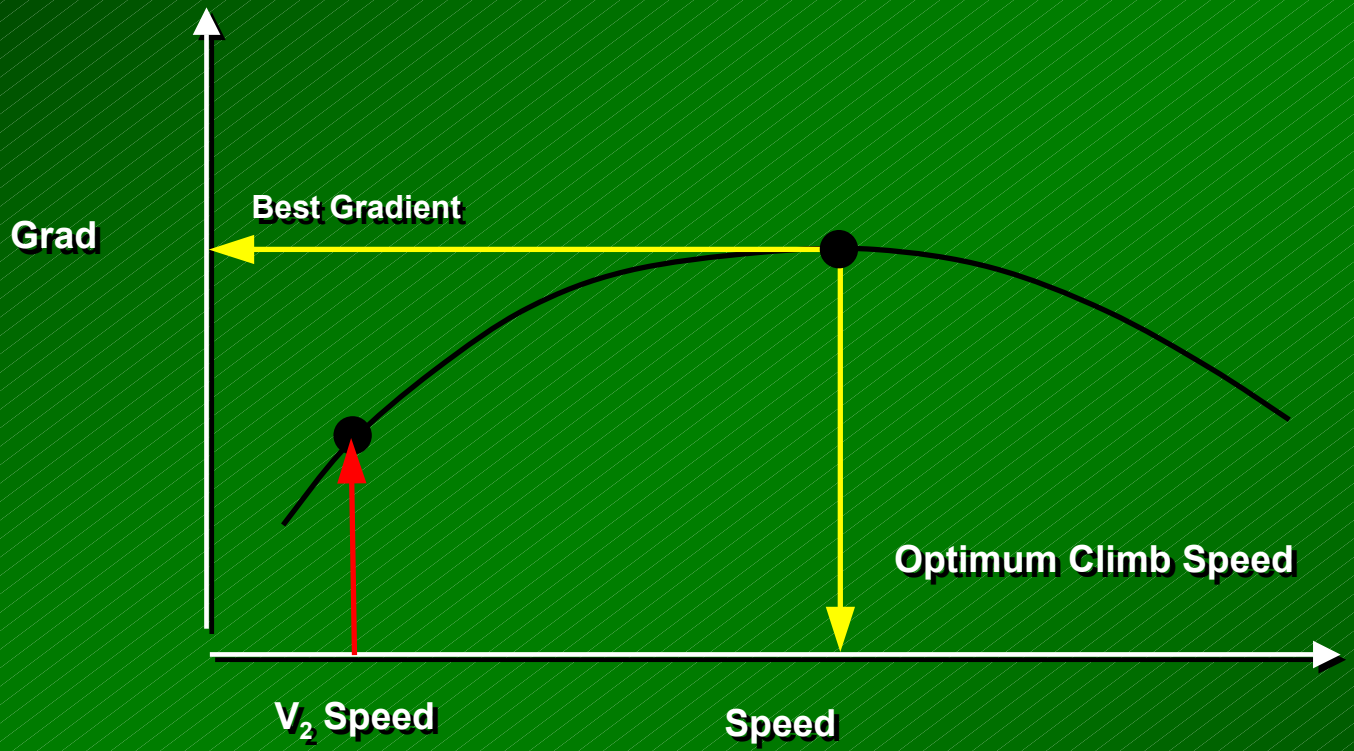
$$CL_{\text{Required}} = \frac{\text{Lift}}{0.5 * \rho * \text{Speed}^2}$$



Lift-Drag Relationship

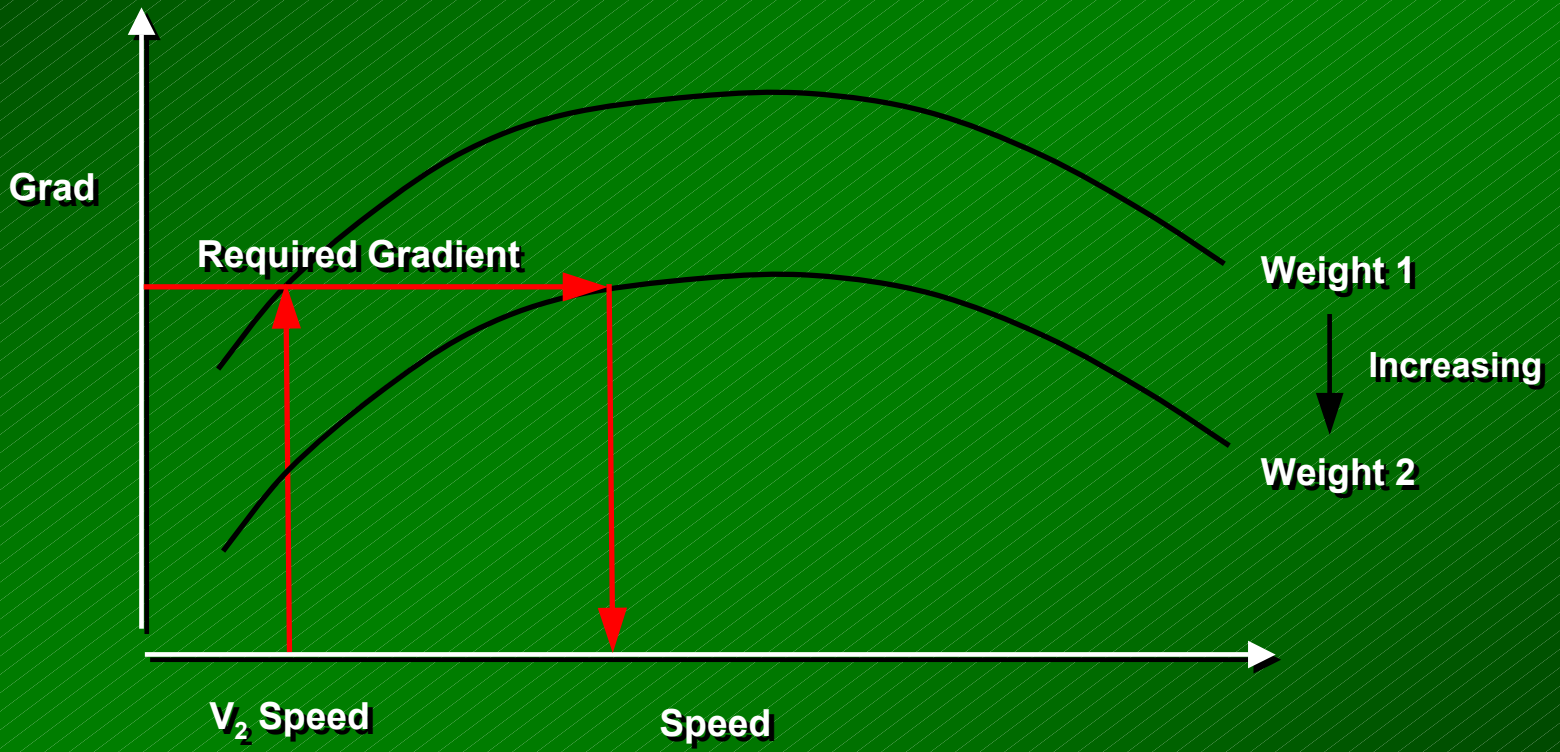


Climb Gradient Versus Speed



Increasing Climb Speed may improve climb gradient capability

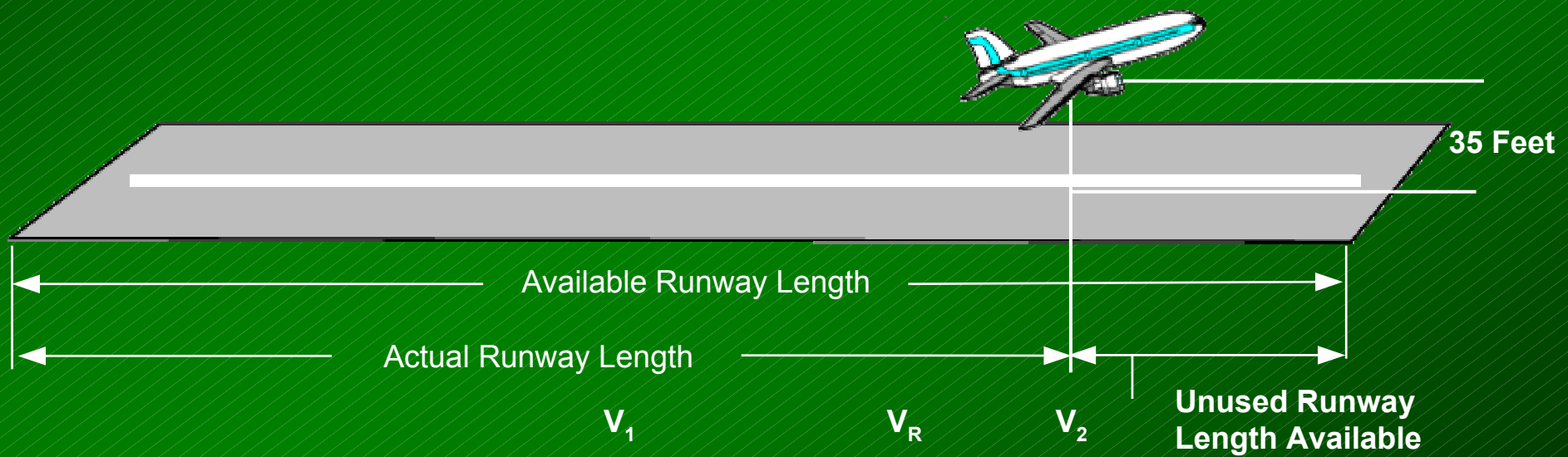
Climb Gradient Versus Speed



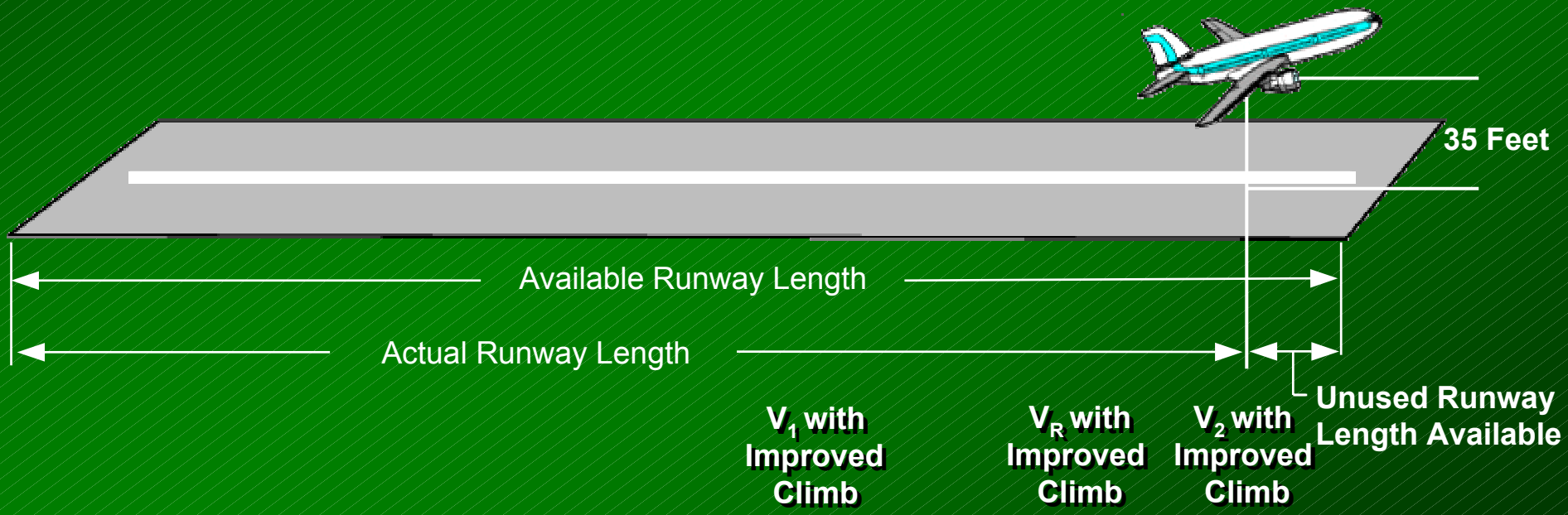
Increasing Climb Speed may:

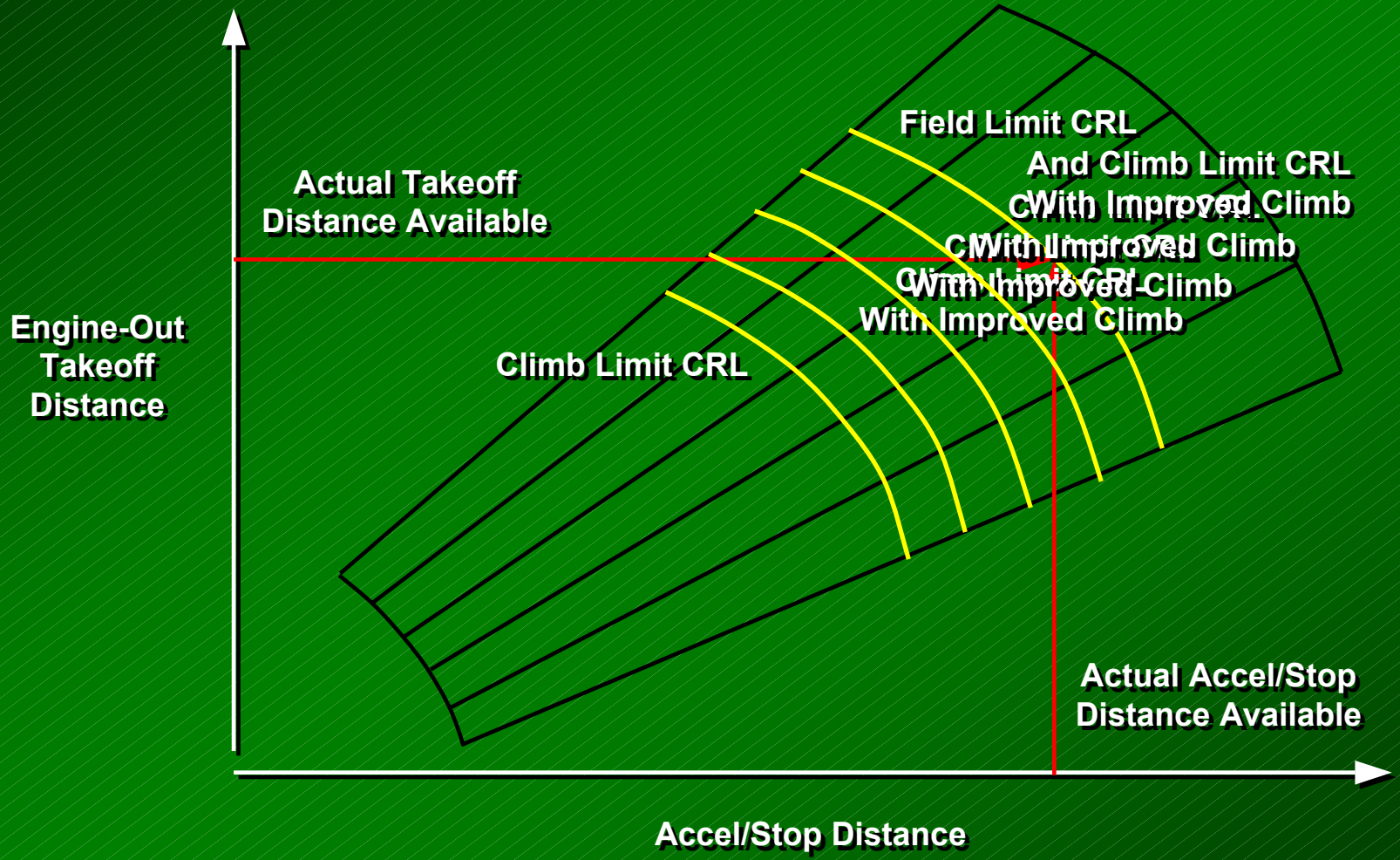
- improve climb gradient capability for given weight , or
- allow higher weight for fixed gradient

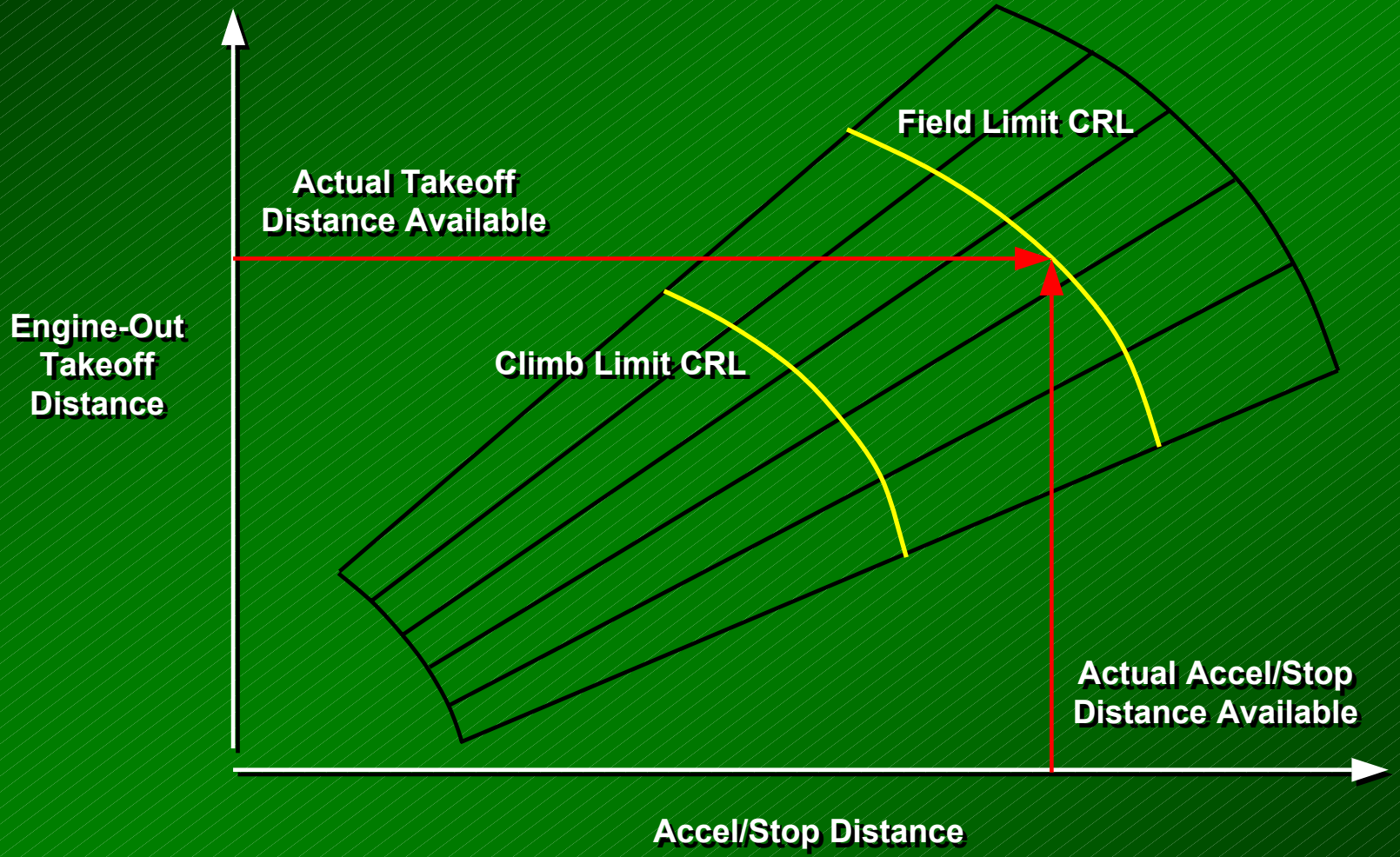
Climb Limited Weight Without Improved Climb



Climb Limited Weight With Improved Climb




Actual Takeoff
Distance Available
Engine-Out
Takeoff
Distance
Climb Limit CRL
Field Limit CRL
And Climb Limit CRL
With Improved Climb
With Improved Climb
With Improved Climb
Actual Accel/Stop
Distance Available
Accel/Stop Distance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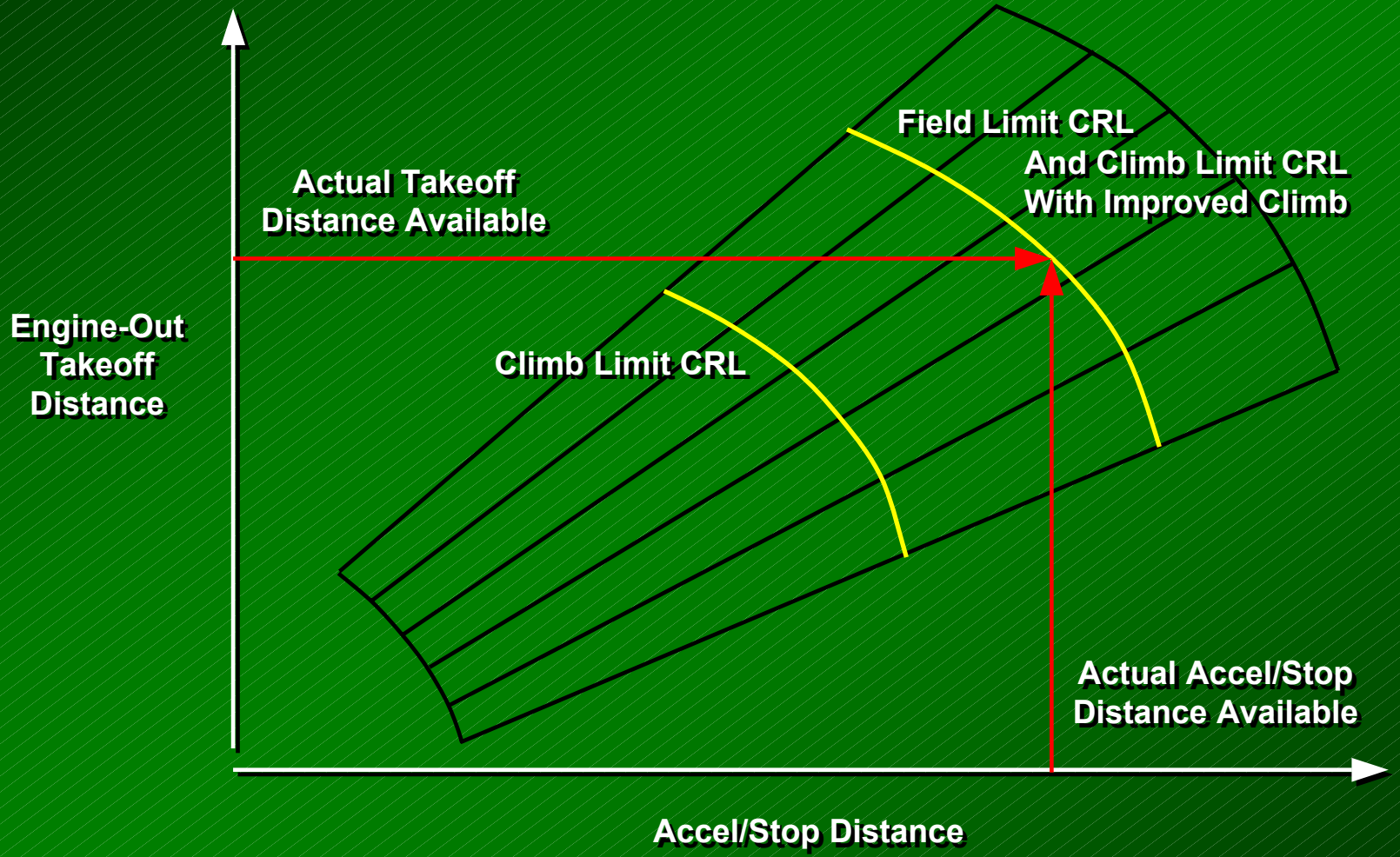
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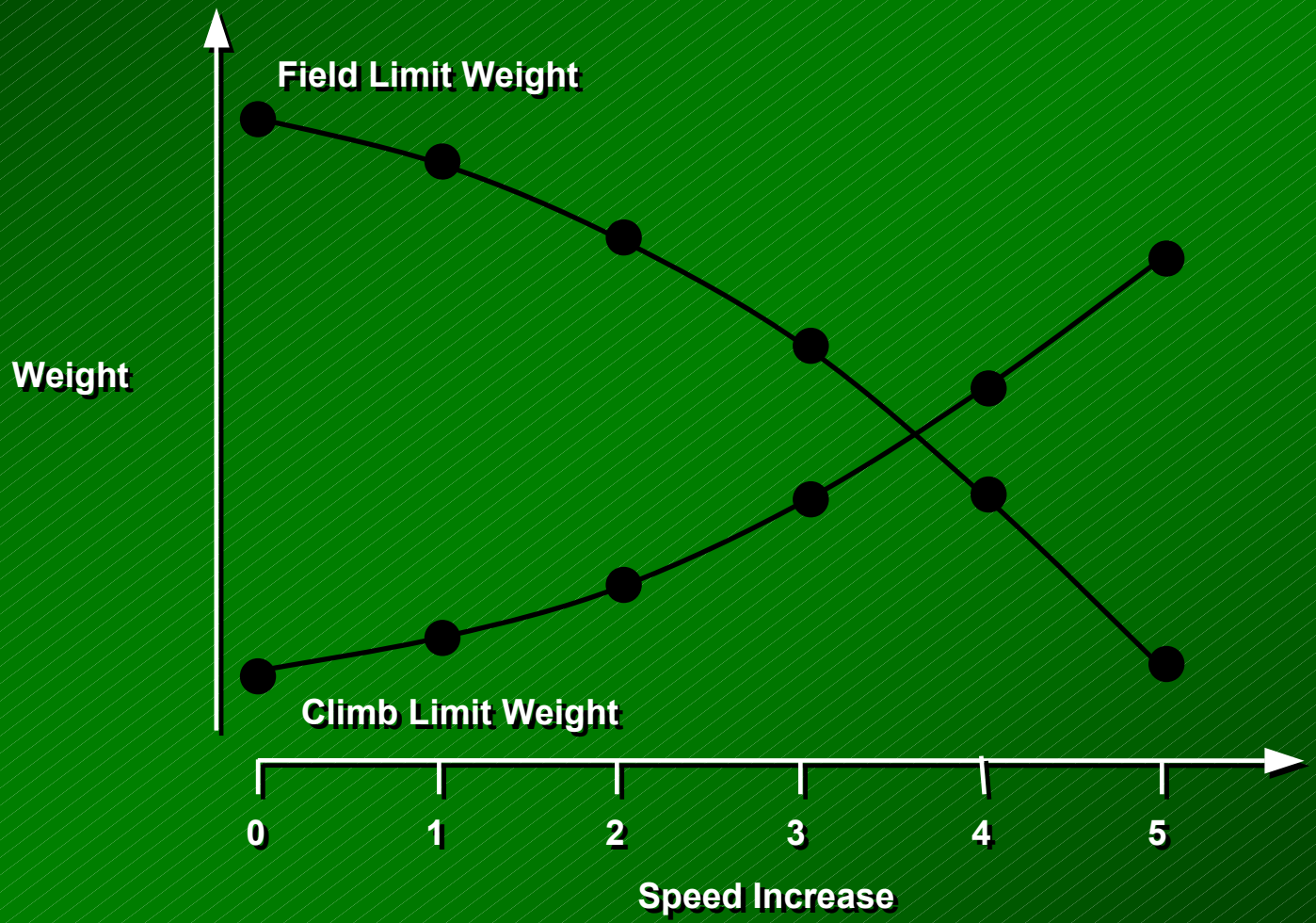
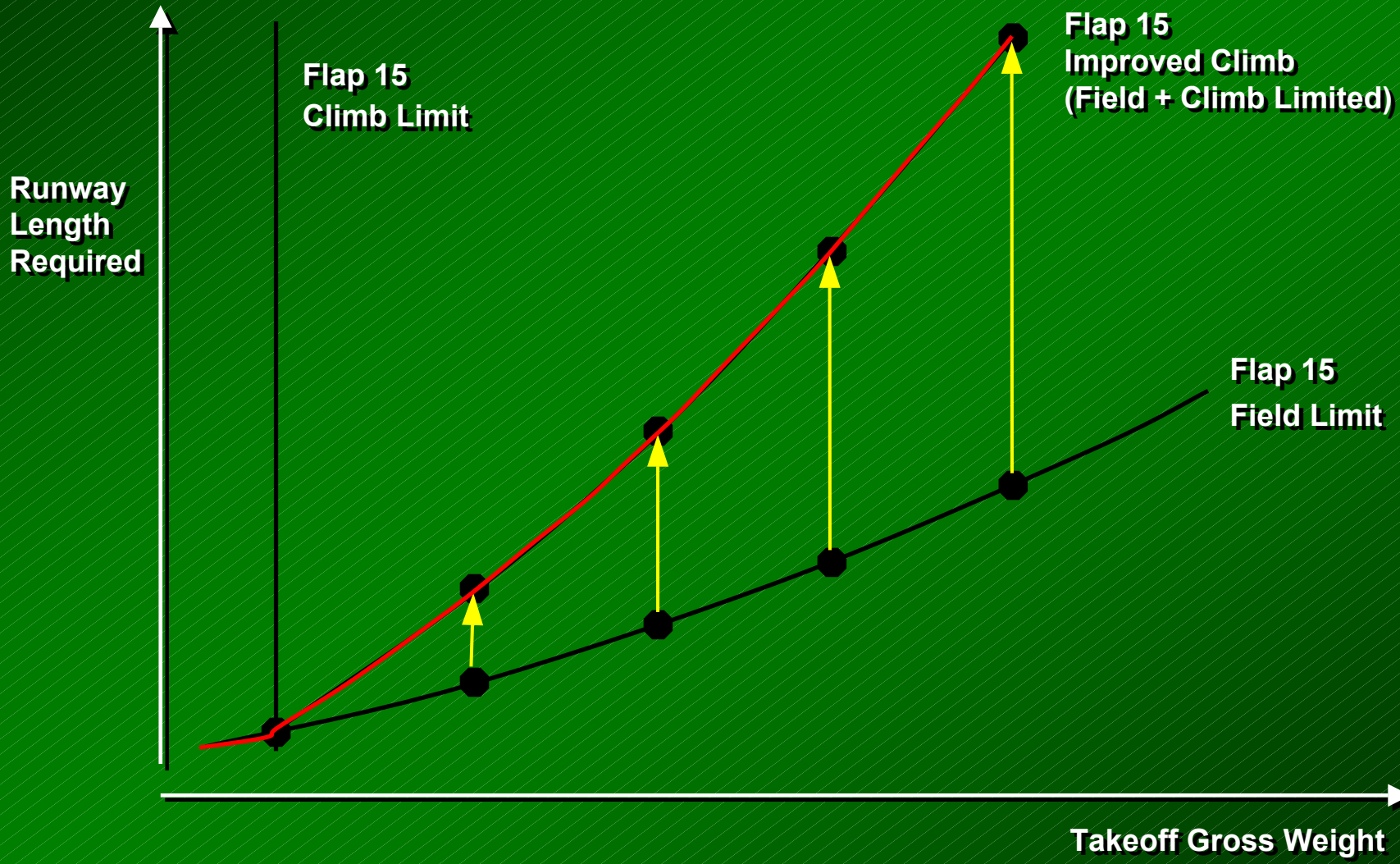
Determination of Improved Climb Limited Weight



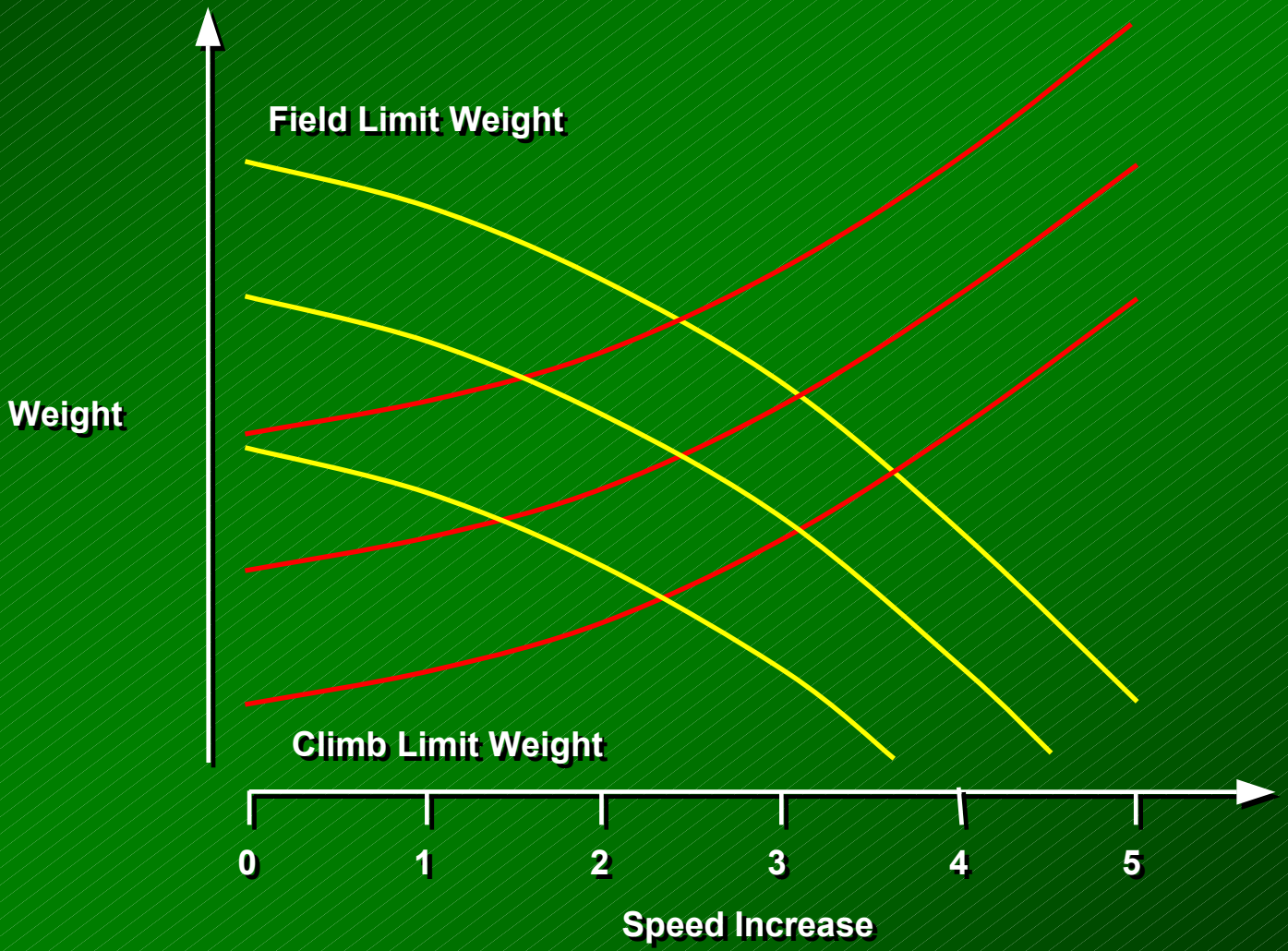
Determination of Improved Climb Limited Weight

Takeoff Weight Capability With Improved Climb

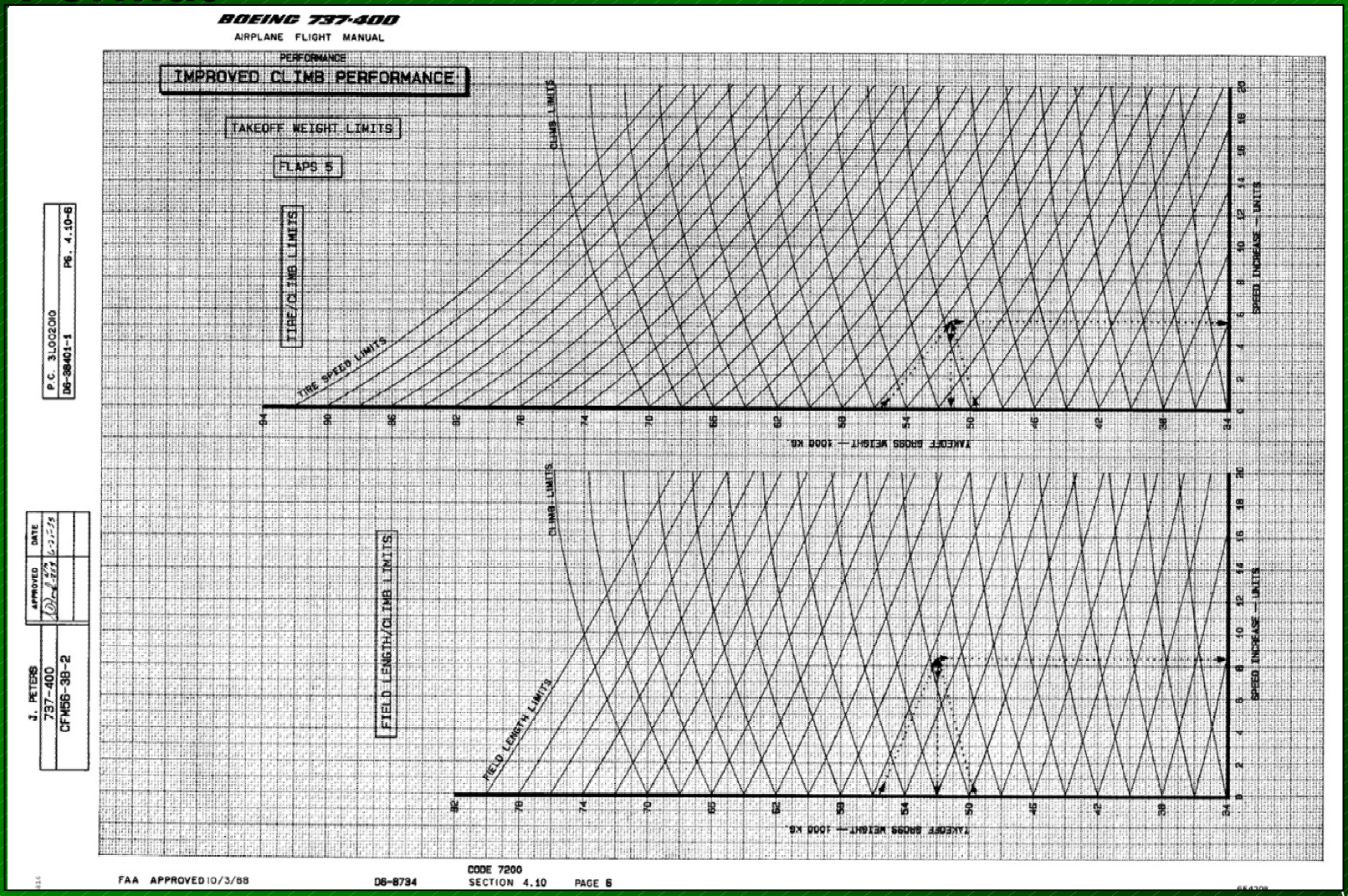


Takeoff Weight Capability With Improved Climb

Development of AFM Improved Climb Limit Weight Chart Format



AFM Improved Climb Limit Weight Chart Format



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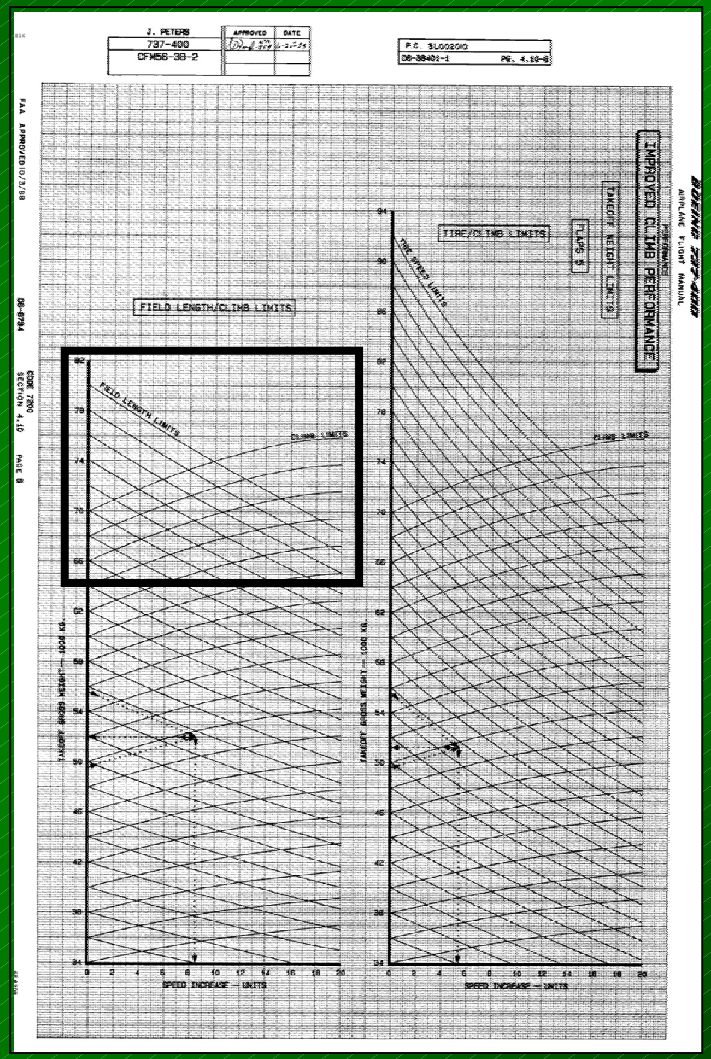

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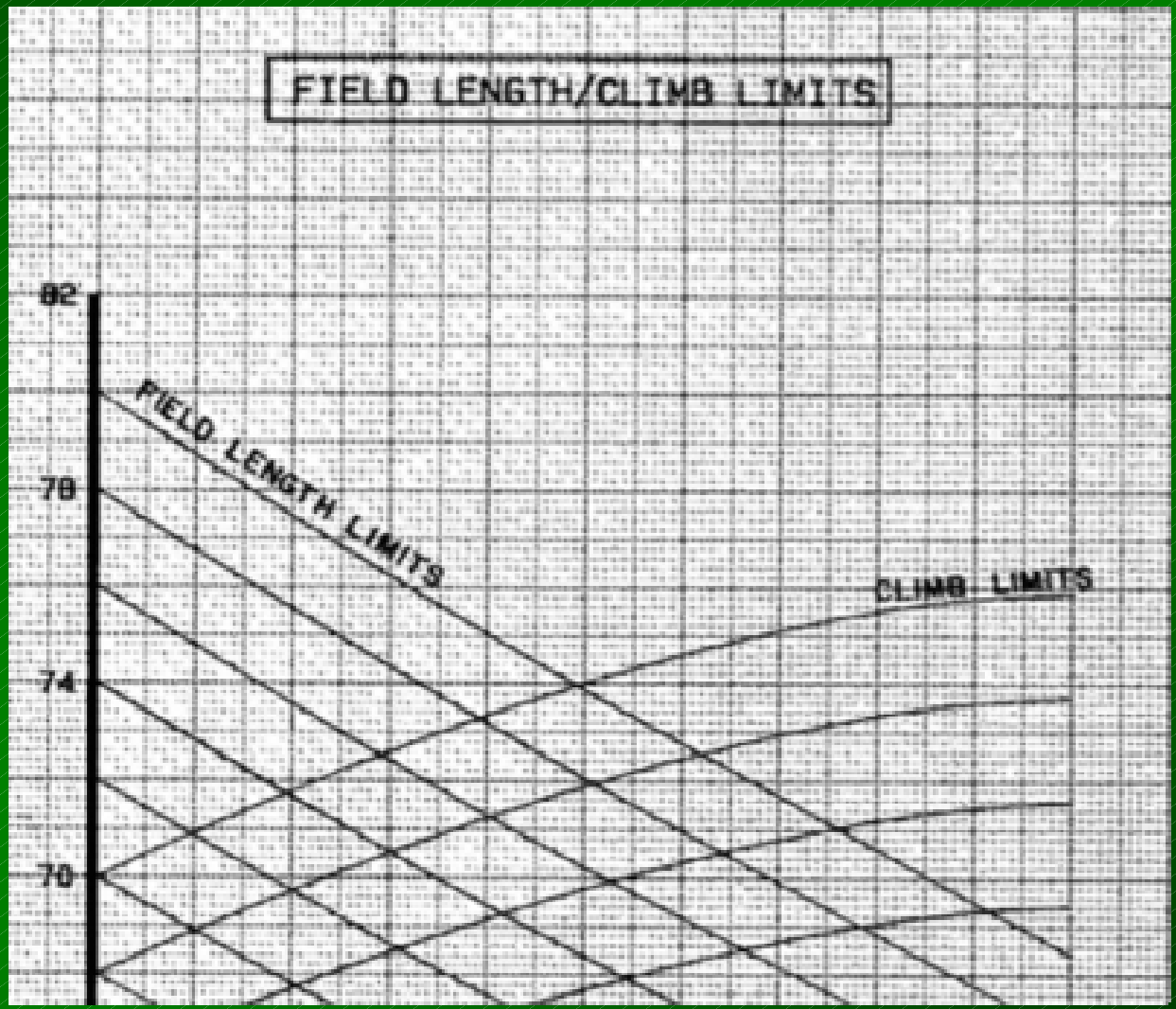
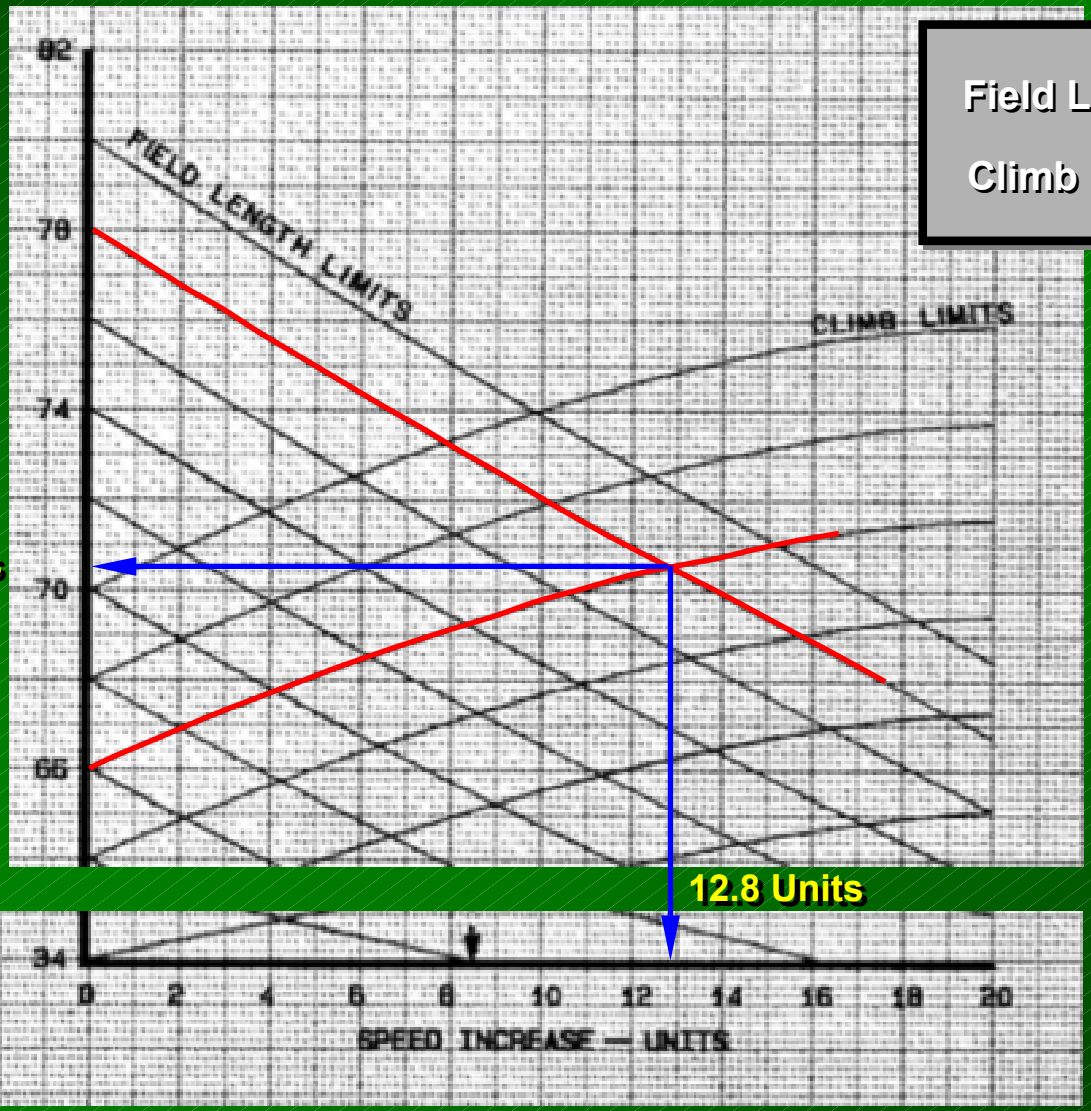


Use of AFM Improved Climb Limit Weight Chart



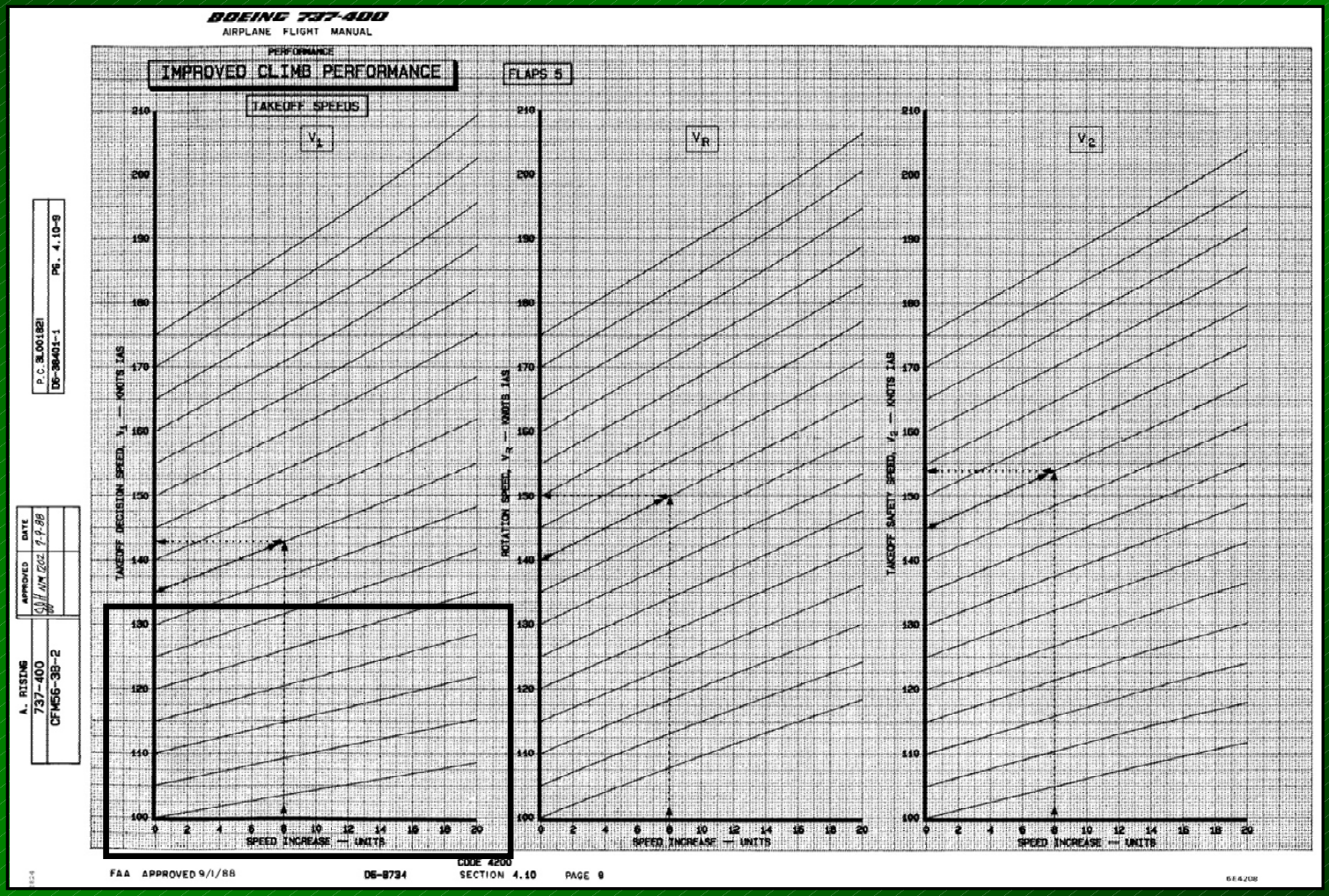
70,500 Kgs

12.8 Units

Field Length Limit = 78,000 Kgs

Climb Limit = 66,000 Kgs

AFM Improved Climb Speeds Chart Format



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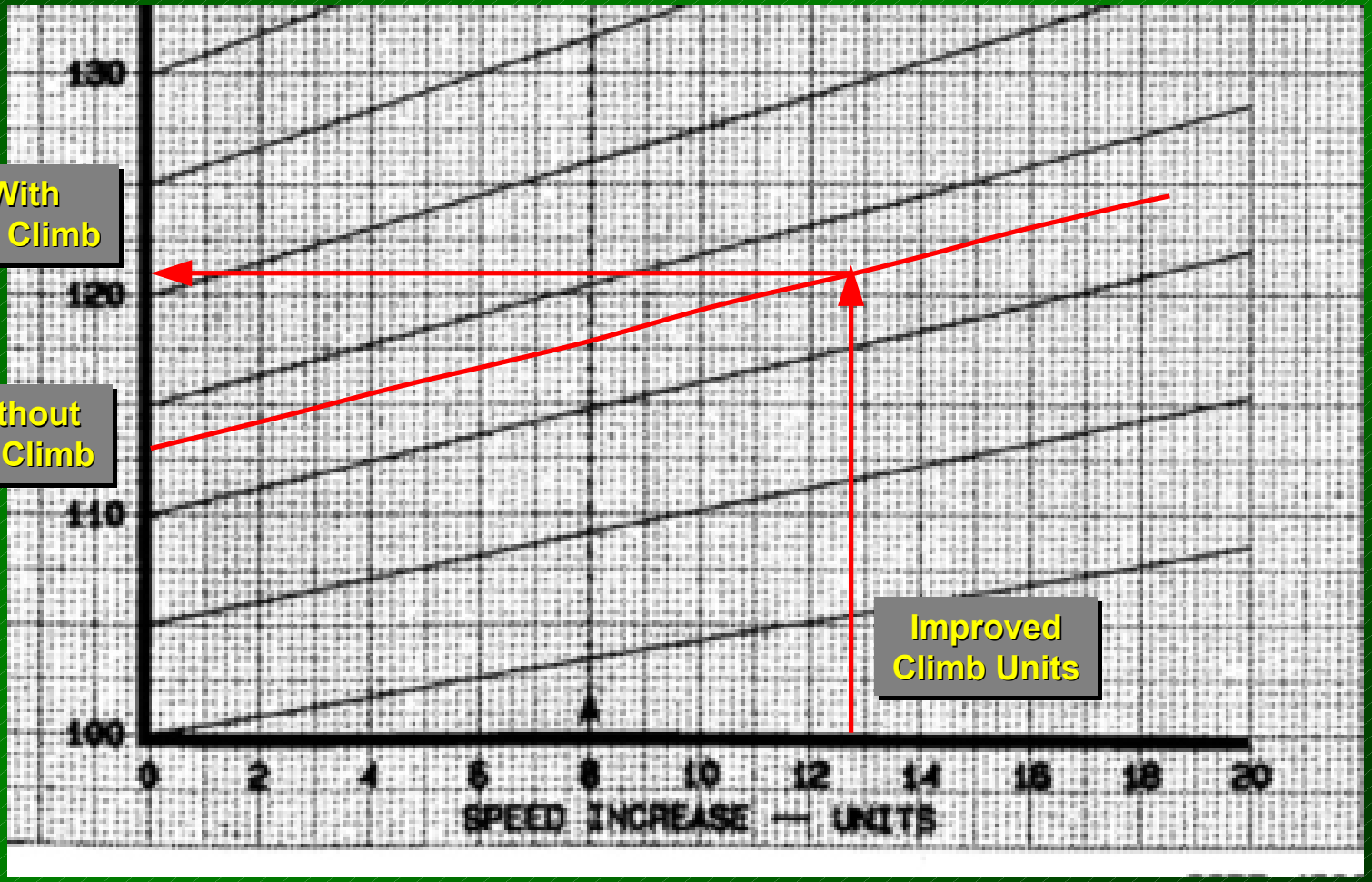
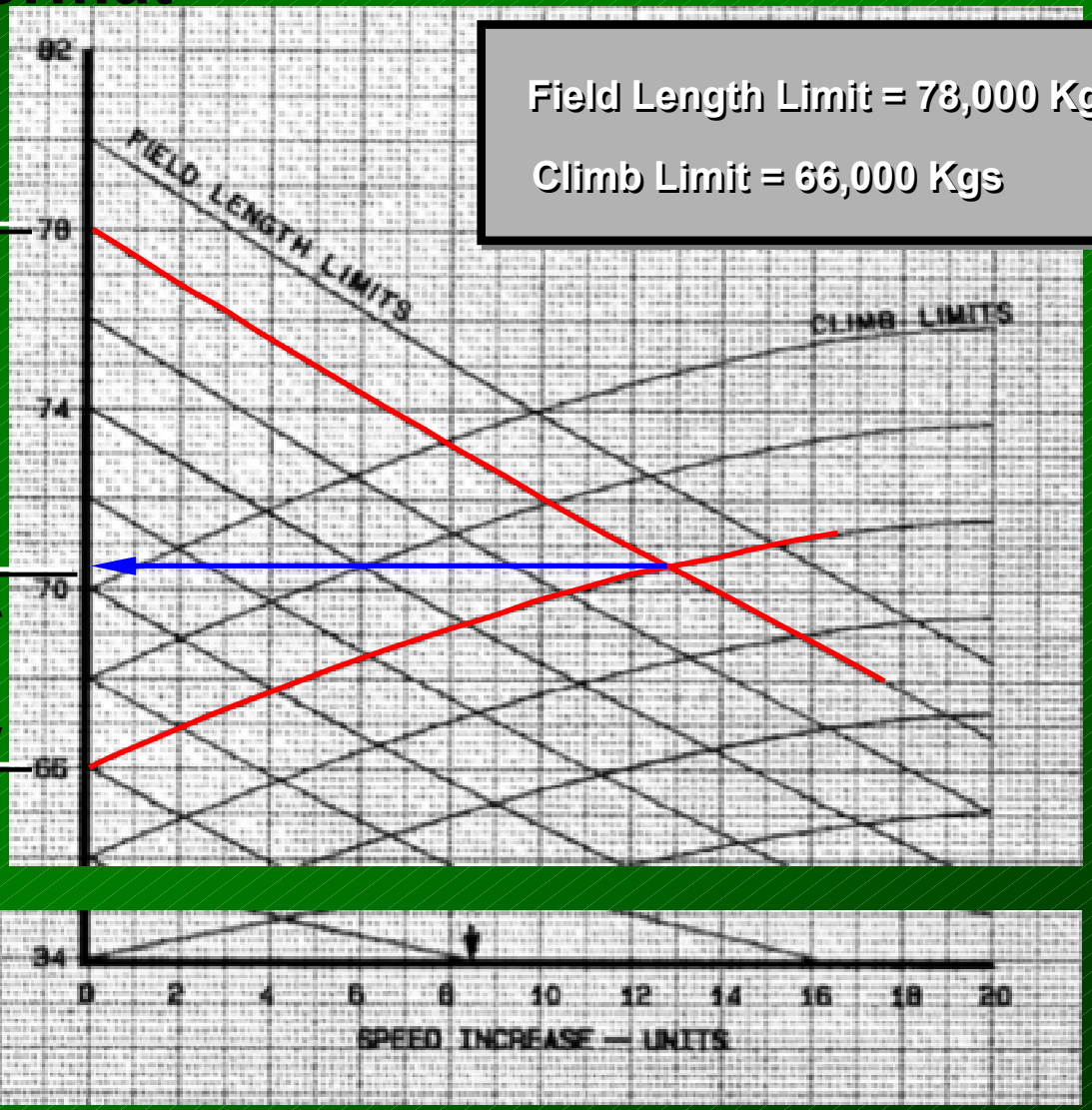


Development of Operations Manual Improved Climb Chart Format



Field Length Limit = 78,000 Kgs

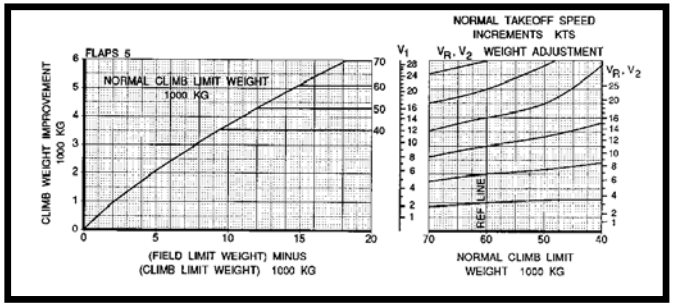
Climb Limit = 66,000 Kgs

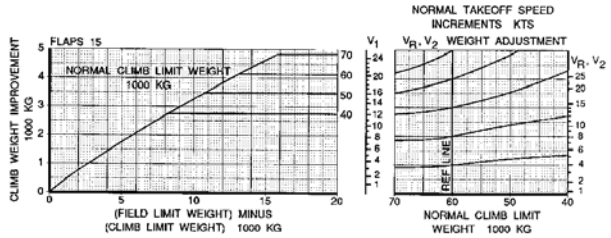
Field Length Limit Weight
Minus
Climb Limit Weight

Climb Weight Improvement

Operations Manual Improved Climb Chart Format

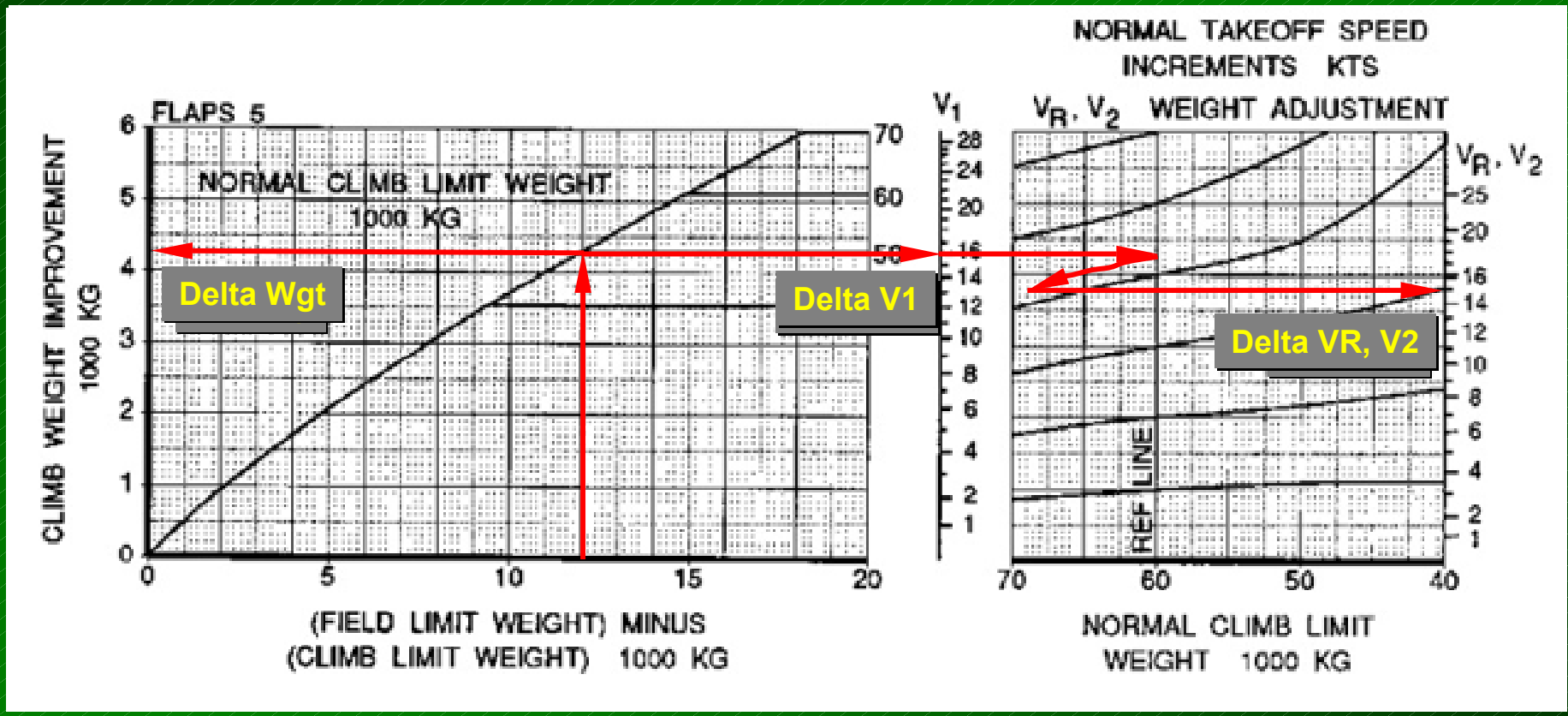
Improved Climb Field Length Limit





USE SMALLER OF IMPROVED CLIMB WT. (FIELD LENGTH LIMITS) OR (TIRE SPEED LIMITS).
APPLY SPEED INCREMENTS TO NORMAL V_1, V_R, V_2 FOR ACTUAL TAKEOFF WT.
CHECK BRAKE ENERGY LIMITS.

Use of Operations Manual Improved Climb Chart



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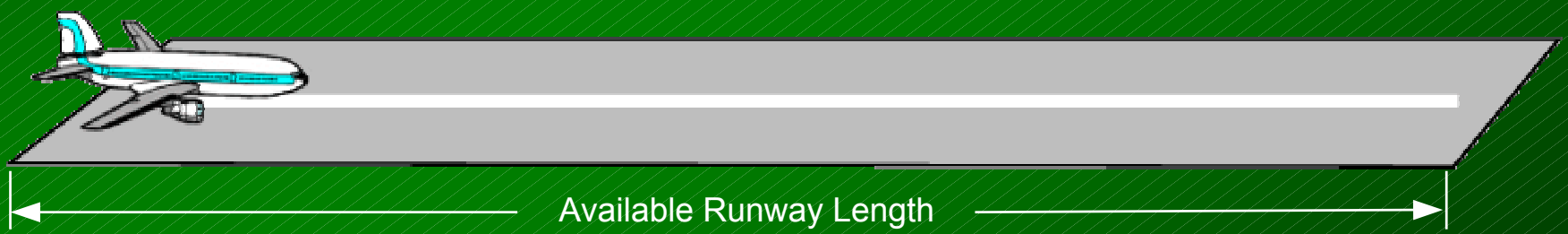
Tire Speed Limited Weight

- **Weight at which the maximum speed reached on the ground does not exceed the rated speed limit of the tire.**



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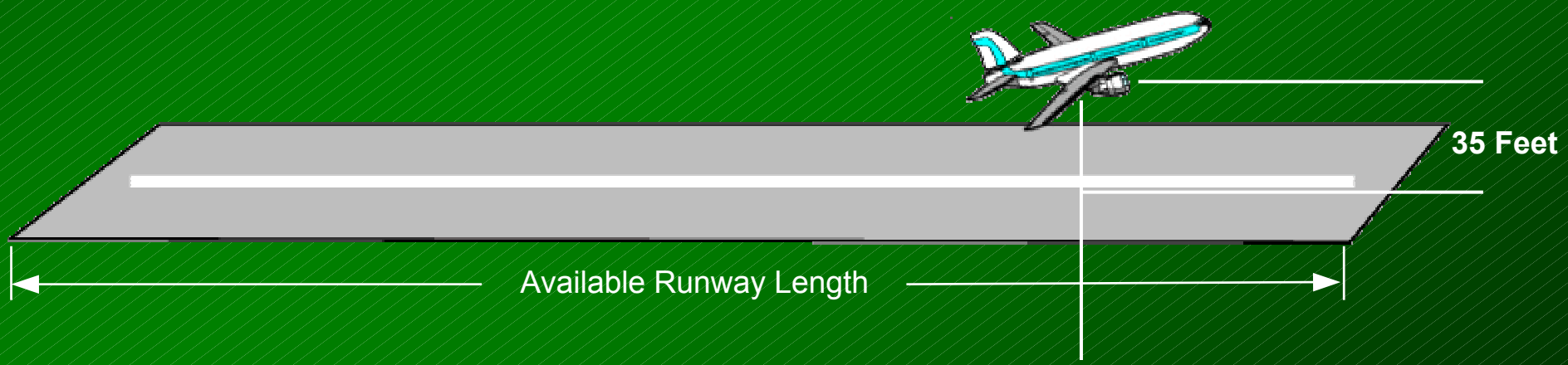
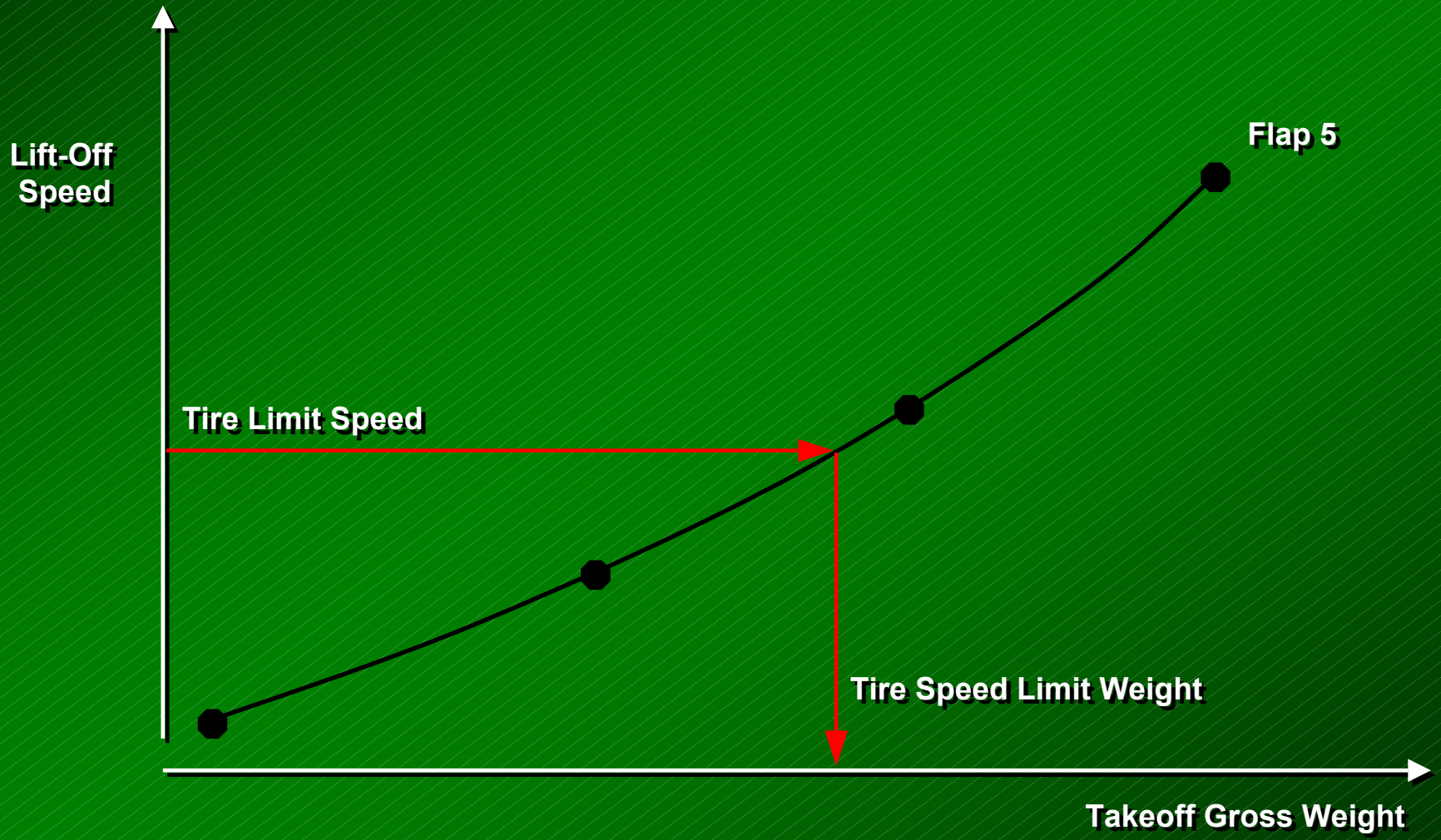
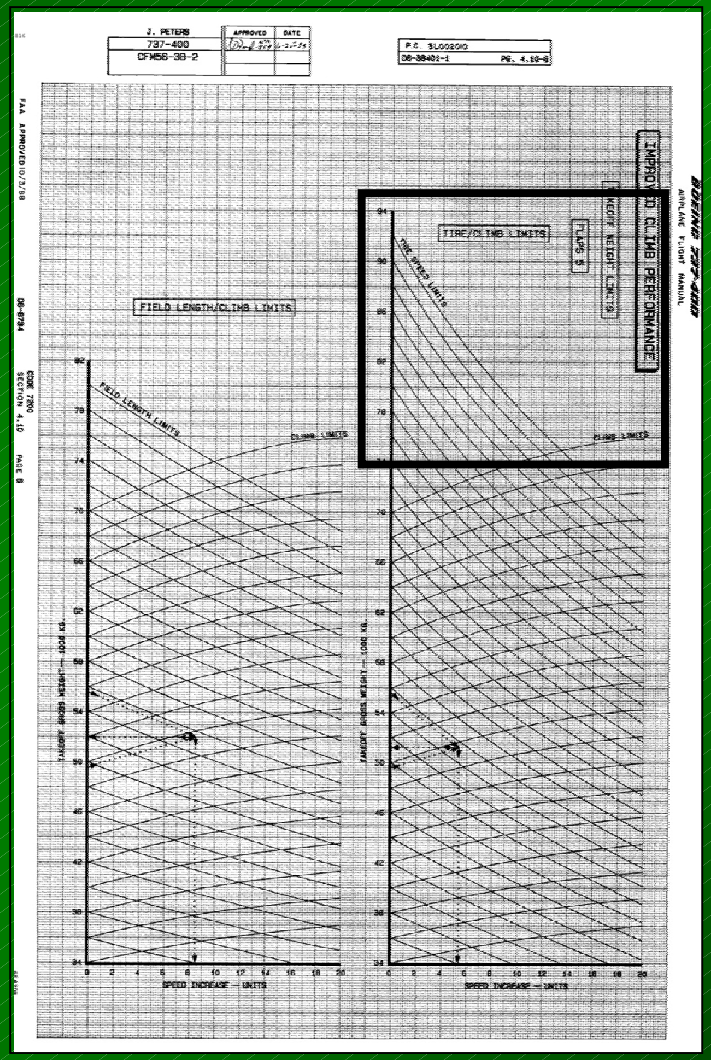


Determination of Tire Speed Limited Weight



AFM Improved Climb Limit Weight Chart Format



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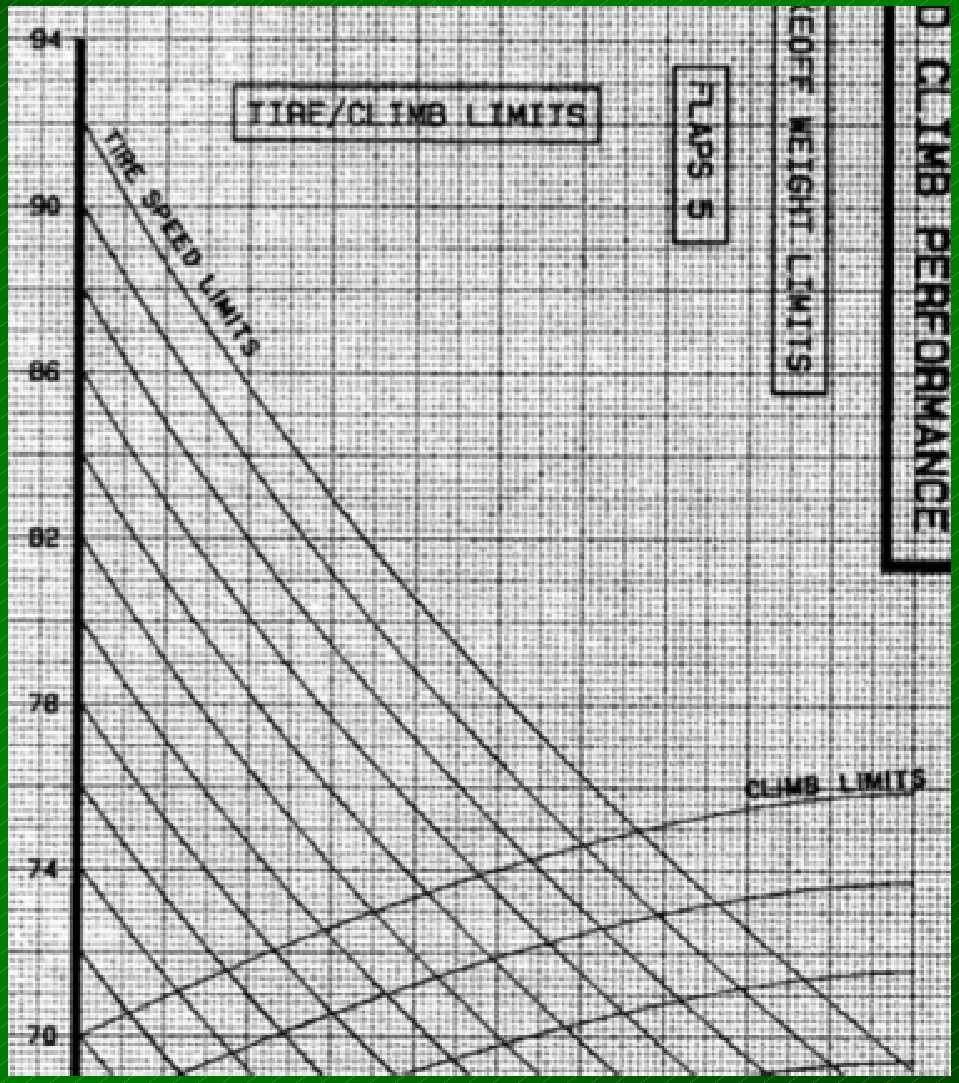

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Obstacle Limited Weight

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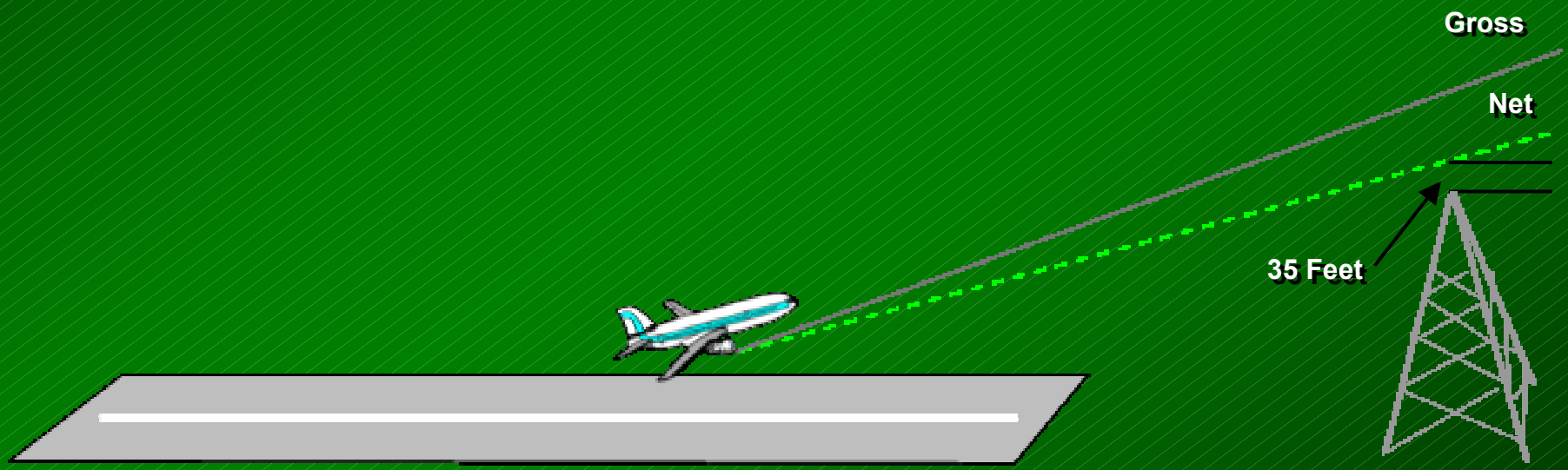
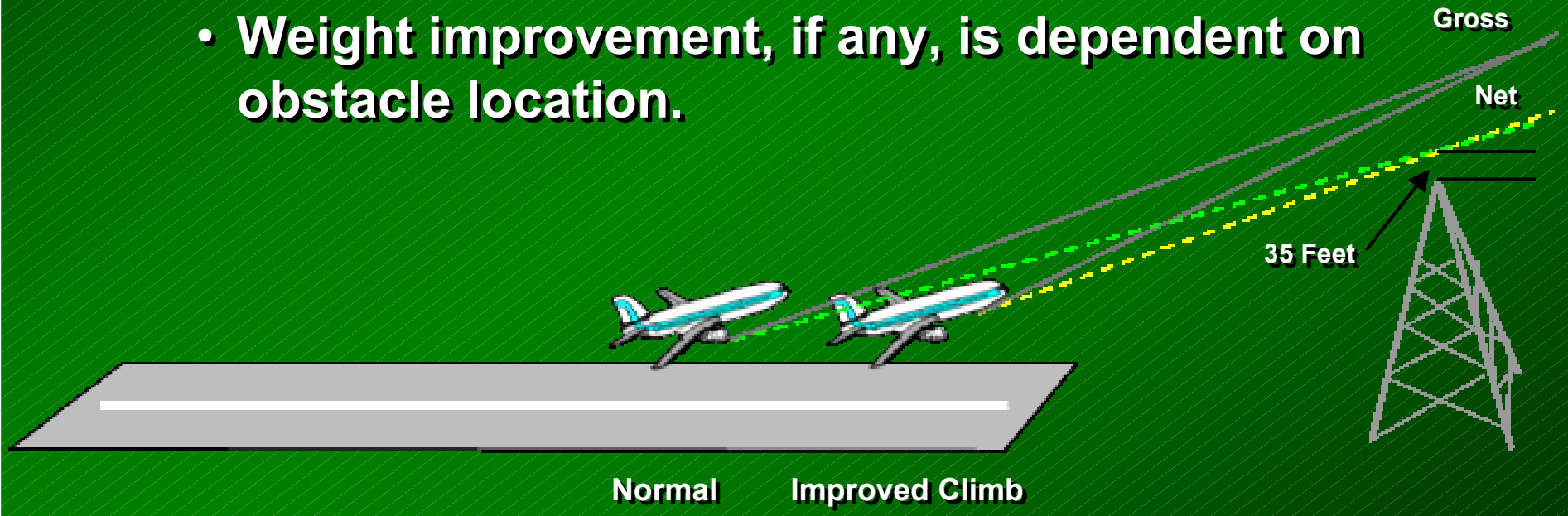


Obstacle Limited Weight

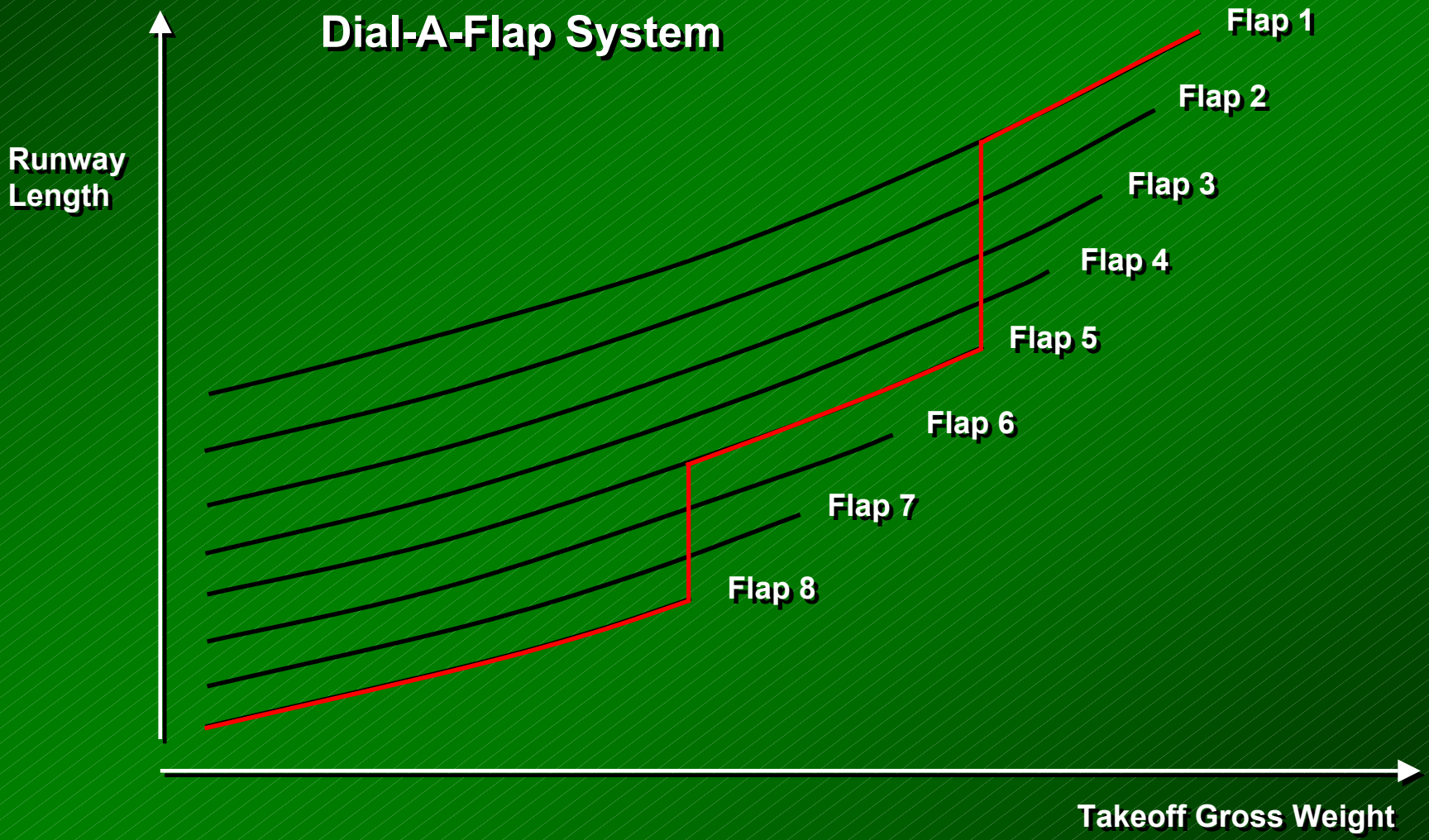
- Obstacle limited weight performance with Improved Climb is a trade between increased takeoff distance and improved climb gradient capability.
- Weight improvement, if any, is dependent on obstacle location.



Operational Considerations

- Anti-skid must be operative and ON
- FMS V-speeds are NOT valid
- Operations Manual V-speeds are not valid without making FPPM Improved Climb speed adjustments

Other Methods of Improved Climb Performance

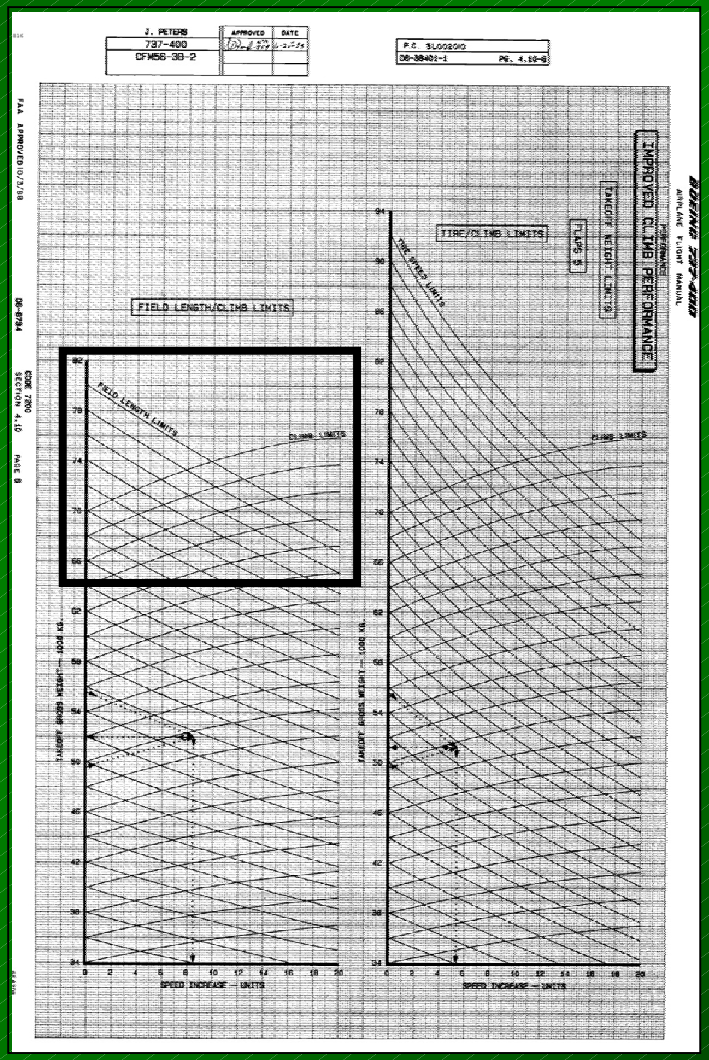


Example Problem

Airplane = 737-400
Engines = CFM56-3-B2
Flaps = 5
Slope = 0.5%
Airconditioning = Auto
Anti-Skid = ON
OAT = 30 Deg C
Wind = 0 Kts
Altitude = 3000 ft
Obstacles = None
V1/Vr Ratio
Climb Limit Weight = 57,000 kg
Field Limit Weight = 62,000 kg
Tire Speed Limit Weight = 69,000 kg

Improved Climb Weight	
Improved Climb V_1	
Improved Climb V_R	
Improved Climb V_2	

Example Problem (AFM Format)



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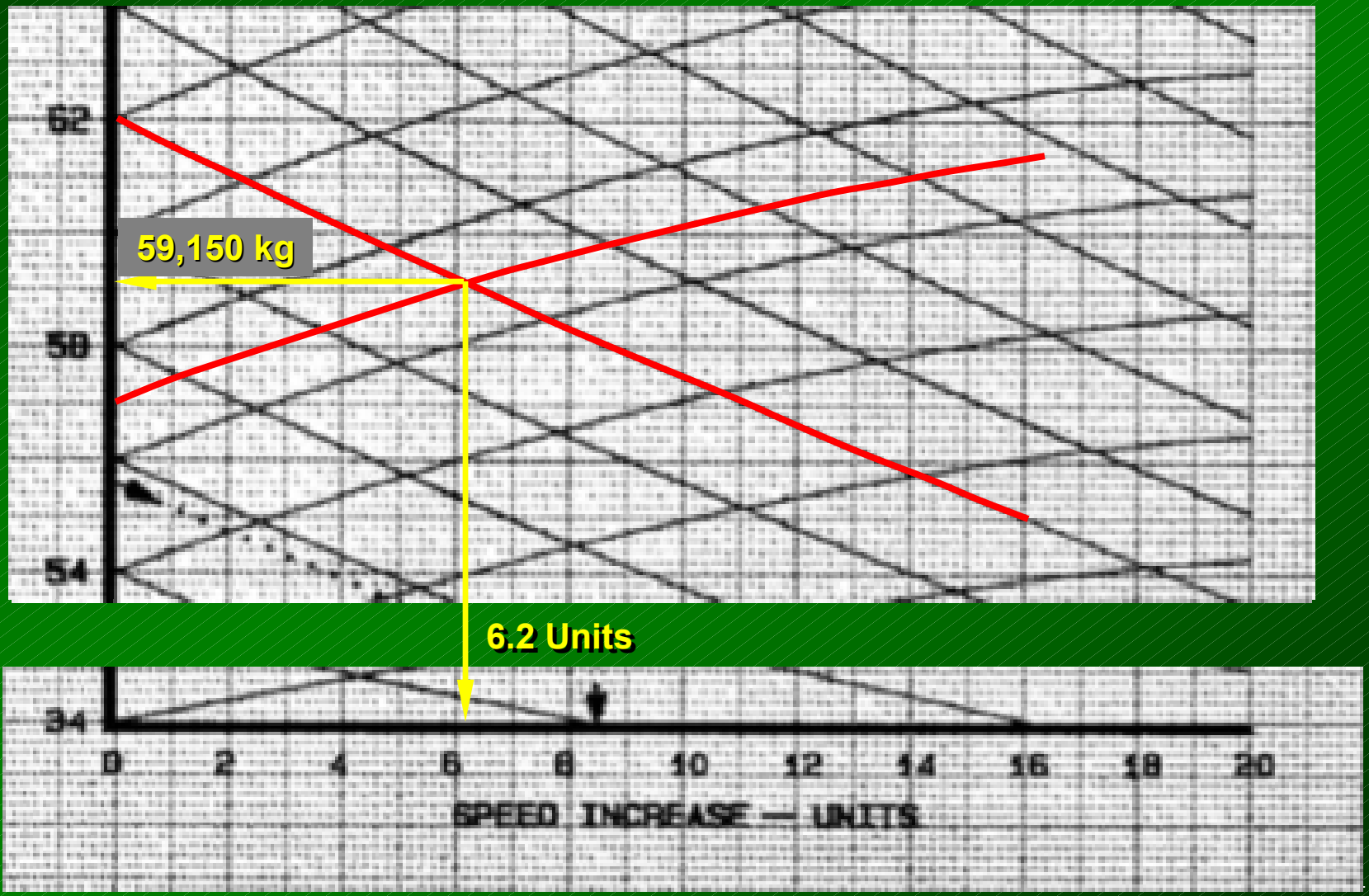
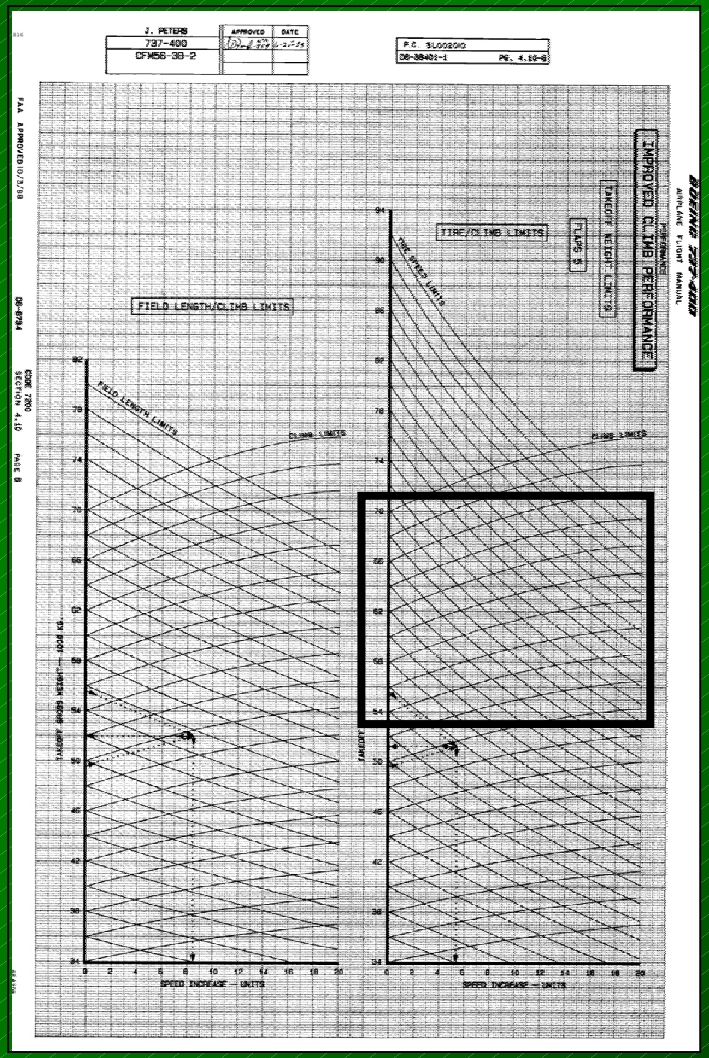
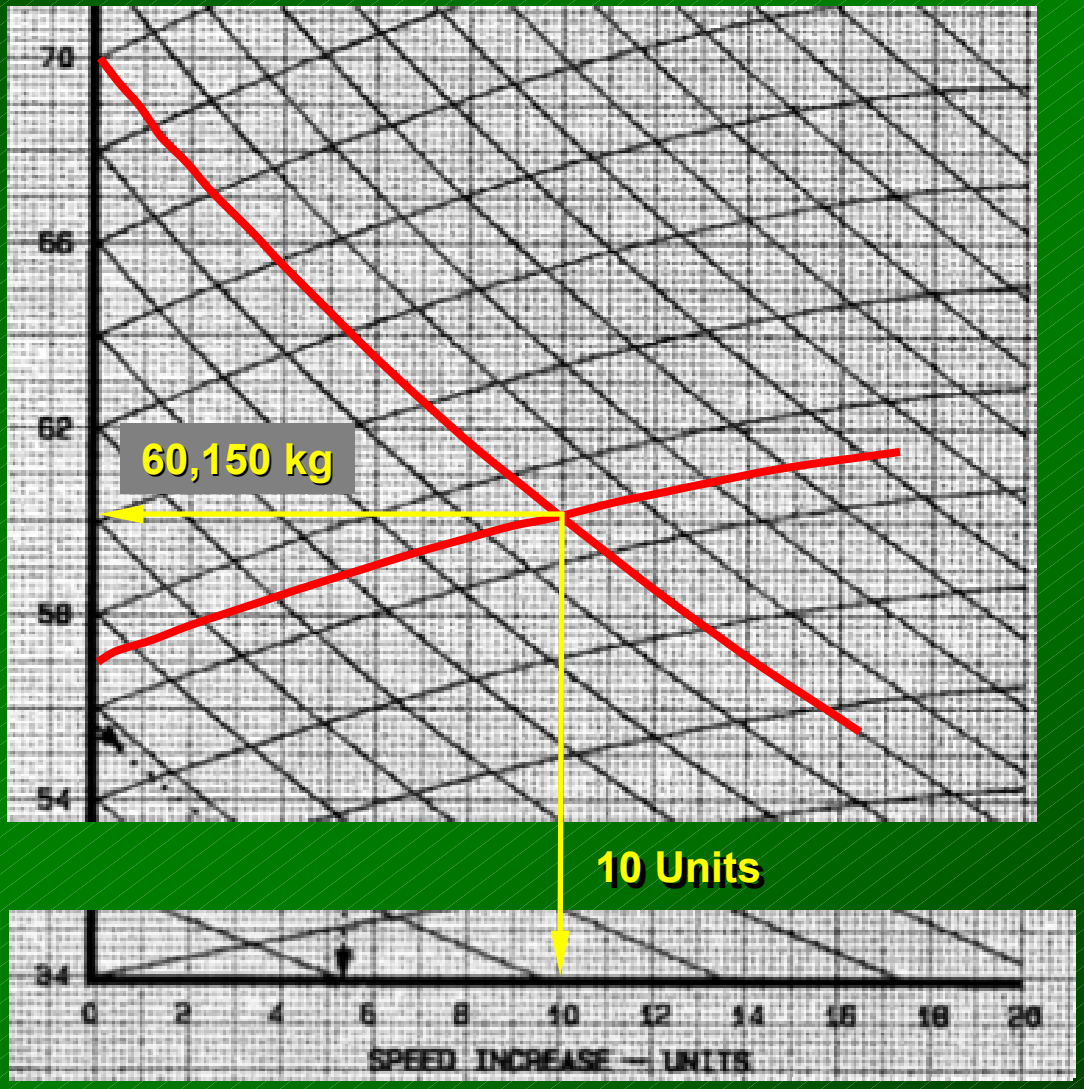


Example Problem (AFM Format)



Example Problem (AFM Format)

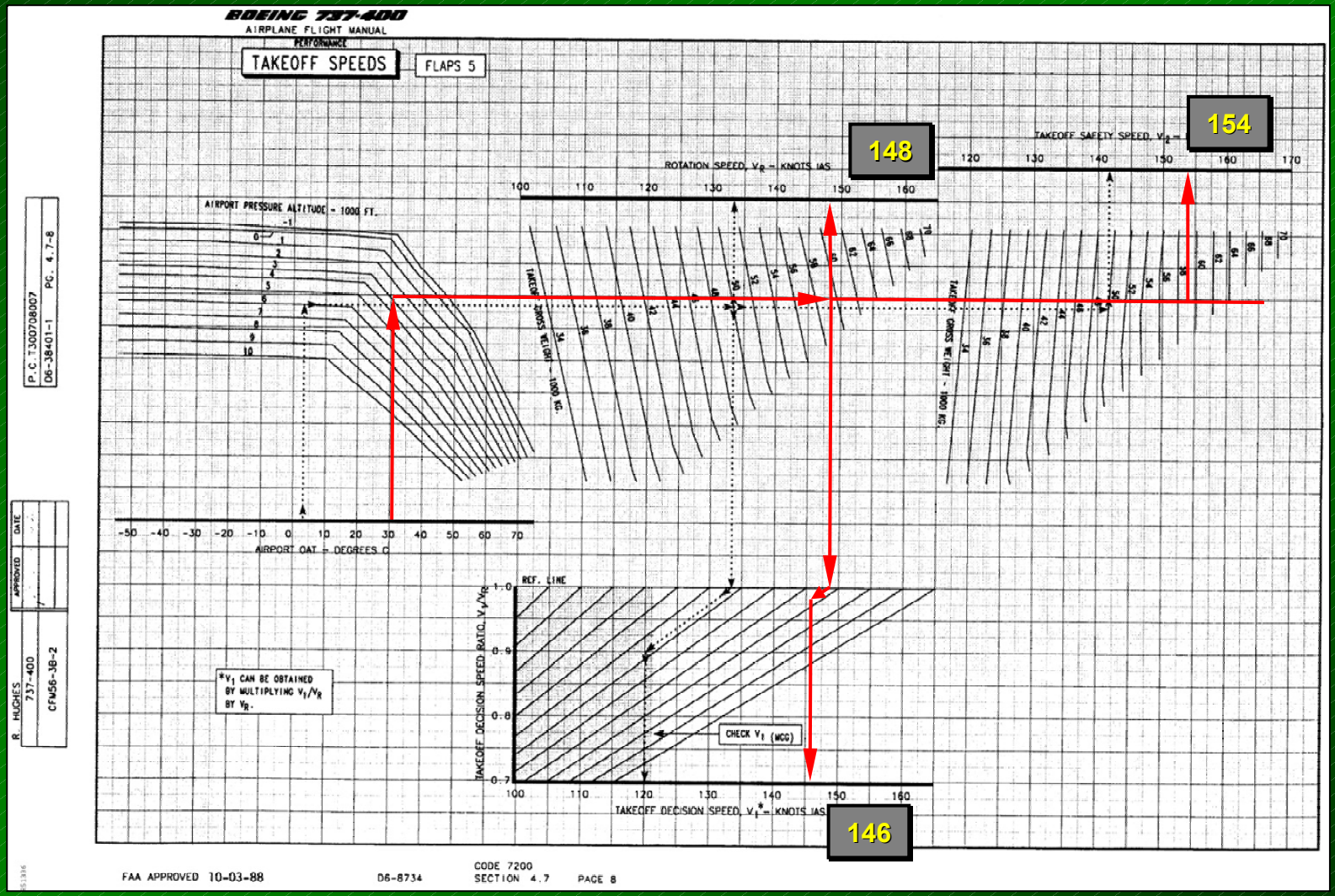


Example Problem (AFM Format)

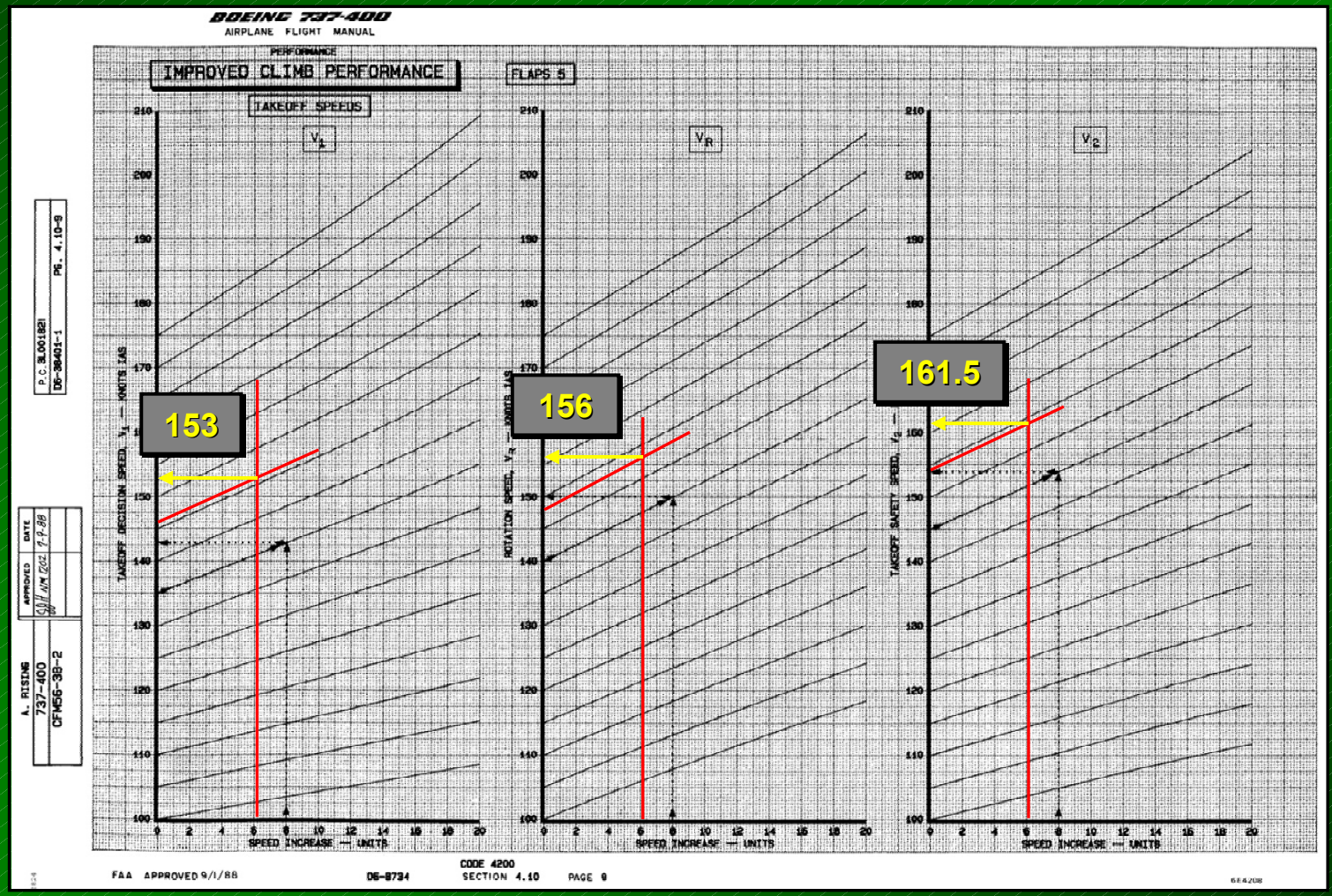
Airplane = 737-400
Engines = CFM56-3-B2
Flaps = 5
Slope = 0.5%
Airconditioning = Auto
Anti-Skid = ON
OAT = 30 Deg C
Wind = 0 Kts
Altitude = 3000 ft
Obstacles = None
V1/Vr Ratio
Climb Limit Weight = 57,000 kg
Field Limit Weight = 62,000 kg
Tire Speed Limit Weight = 69,000 kg

Improved Climb Weight	59,150 kg
Improved Climb V_1	
Improved Climb V_R	
Improved Climb V_2	

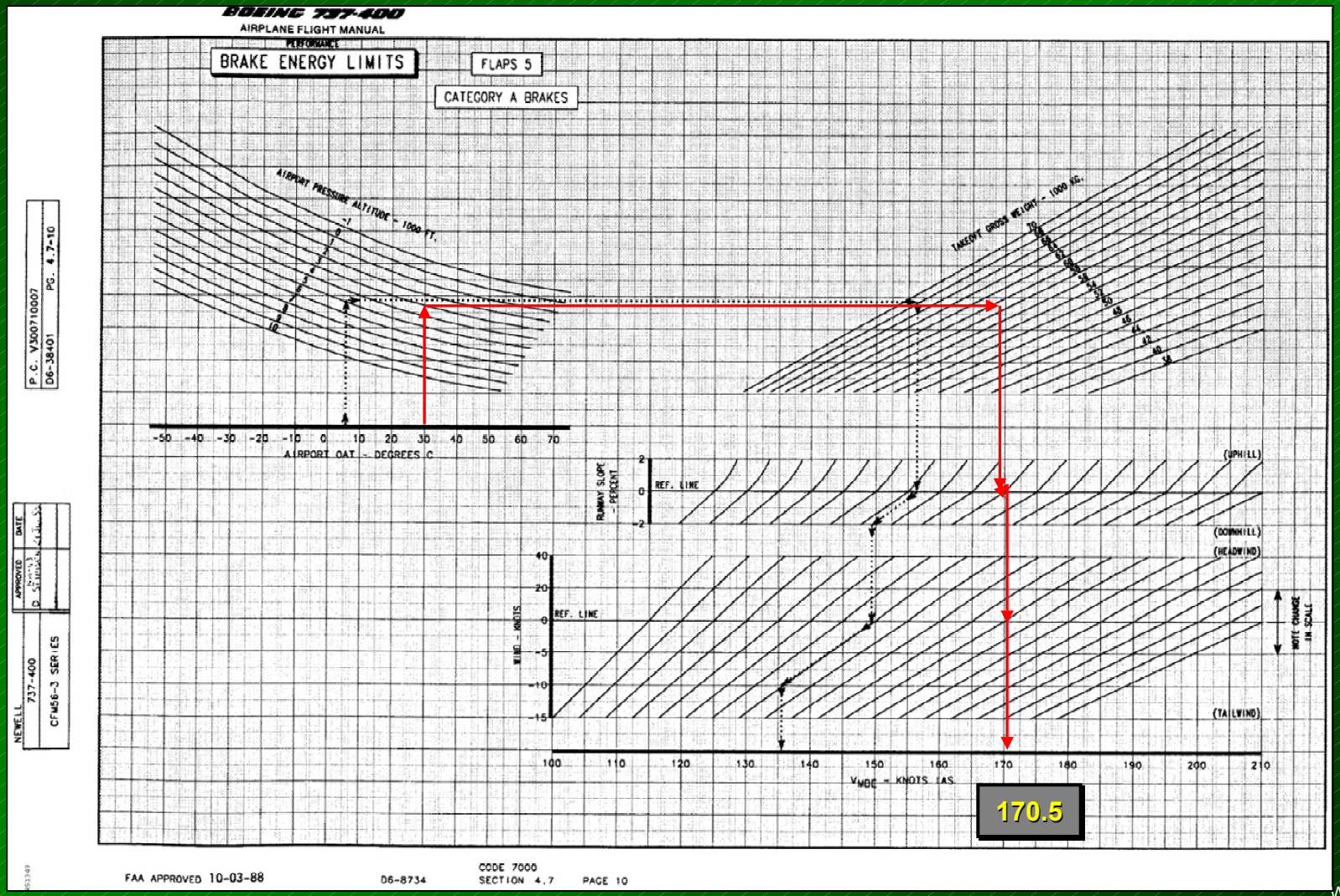
Example Problem (AFM Format)



Example Problem (AFM Format)



Example Problem (AFM Format)



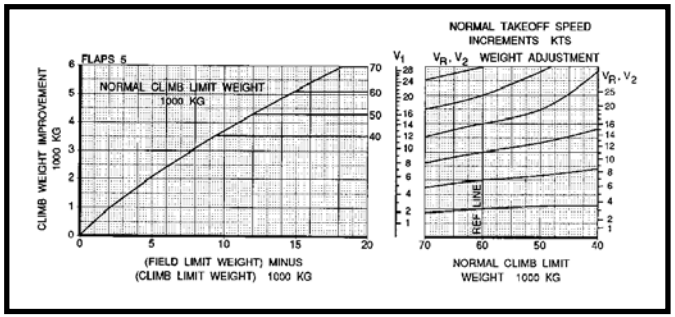
Example Problem (AFM Format)

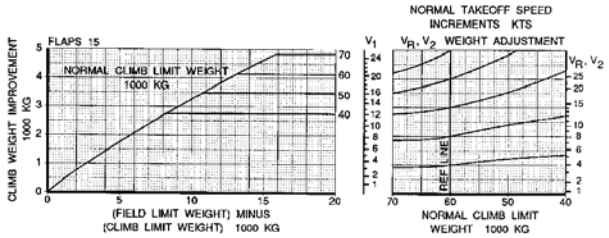
Airplane = 737-400
Engines = CFM56-3-B2
Flaps = 5
Slope = 0.5%
Airconditioning = Auto
Anti-Skid = ON
OAT = 30 Deg C
Wind = 0 Kts
Altitude = 3000 ft
Obstacles = None
V1/Vr Ratio
Climb Limit Weight = 57,000 kg
Field Limit Weight = 62,000 kg
Tire Speed Limit Weight = 69,000 kg

Improved Climb Weight	59,200 kg
Improved Climb V_1	153 Kt
Improved Climb V_R	156 Kt
Improved Climb V_2	161.5 Kt

Example Problem (FPPM Format)

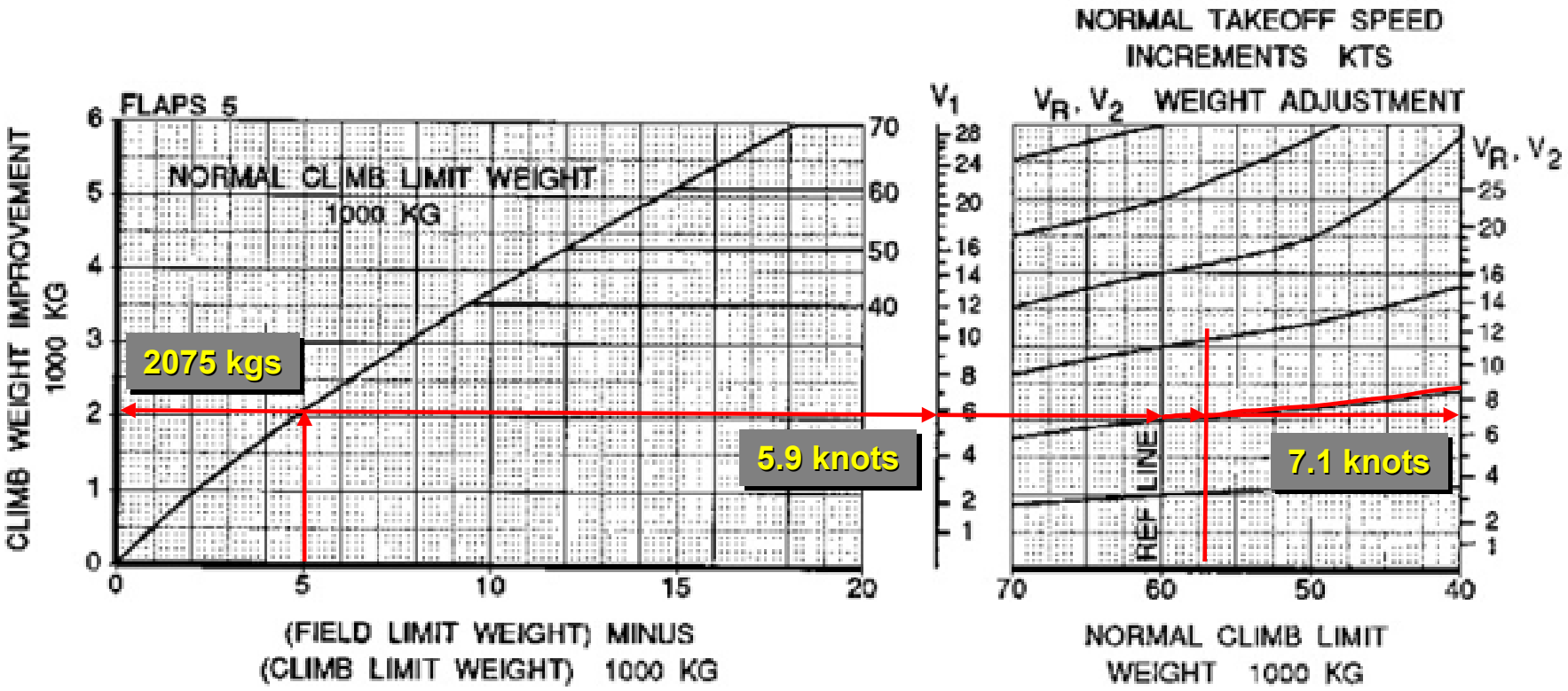
Improved Climb Field Length Limit





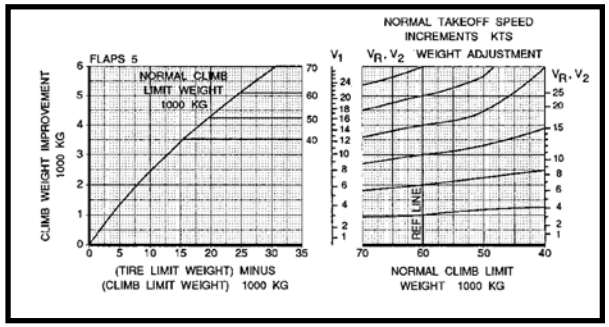
USE SMALLER OF IMPROVED CLIMB WT. (FIELD LENGTH LIMITS) OR (TIRE SPEED LIMITS).
APPLY SPEED INCREMENTS TO NORMAL V_1, V_R, V_2 FOR ACTUAL TAKEOFF WT.
CHECK BRAKE ENERGY LIMITS.

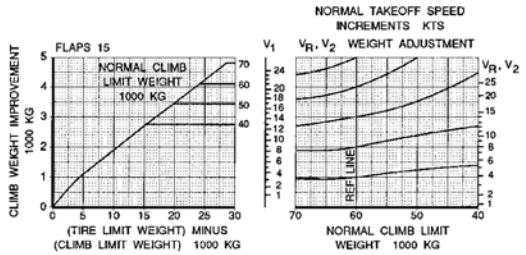
Example Problem (FPPM Format)



Example Problem (FPPM Format)

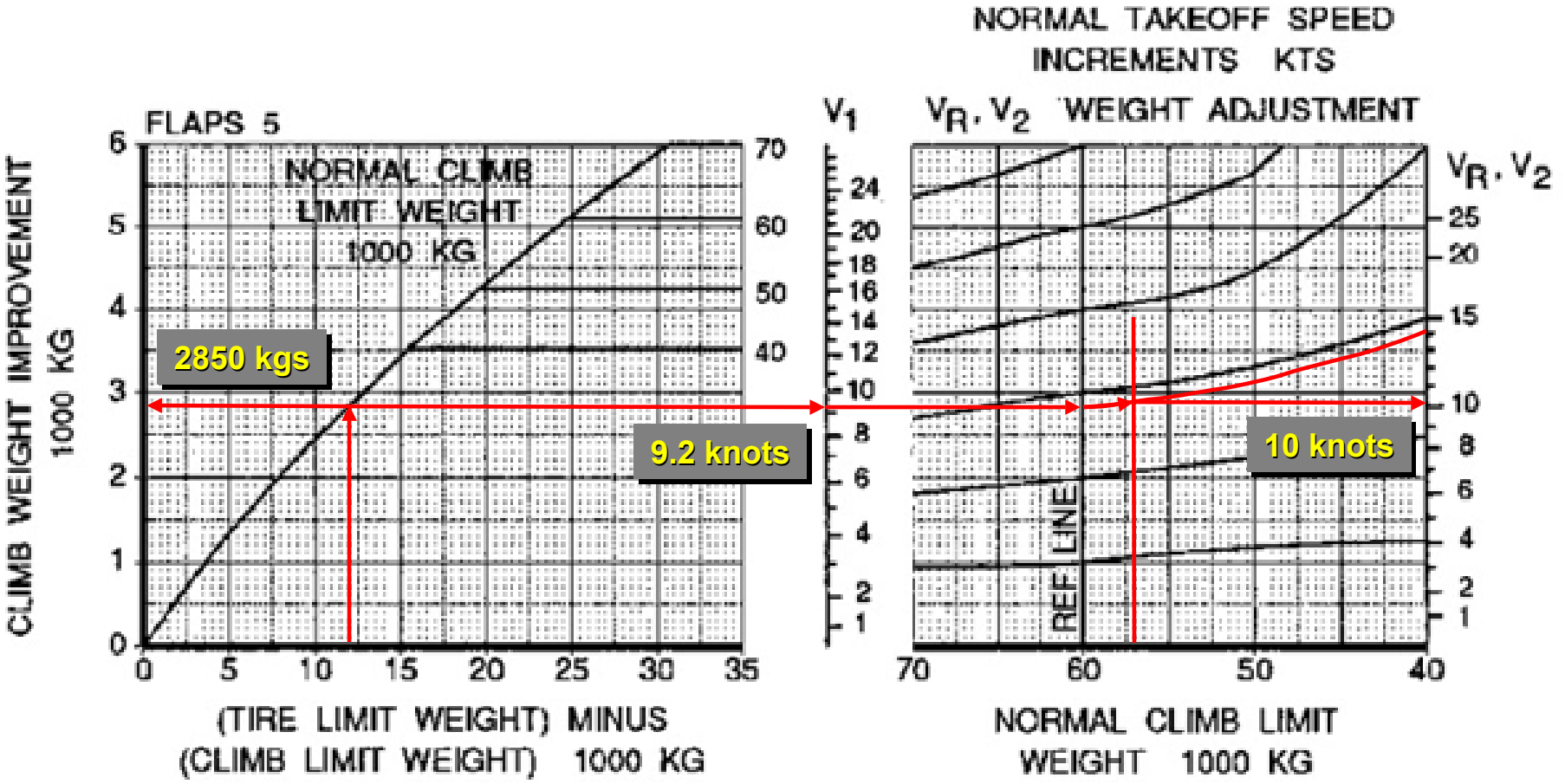
Improved Climb Tire Speed Limit





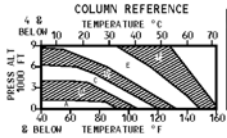
USE SMALLER OF IMPROVED CLIMB WT. (FIELD LENGTH LIMITS) OR (TIRE SPEED LIMITS).
APPLY SPEED INCREMENTS TO NORMAL V_1, V_R, V_2 FOR ACTUAL TAKEOFF WT.
CHECK BRAKE ENERGY LIMITS.

Example Problem (FPPM Format)



Example Problem (FPPM Format)

Takeoff Speeds
Flaps 5



SLOPE/WIND V_1 ADJUSTMENT*						
WEIGHT 1000 KG	SLOPE % DN		UP	WIND KTS TAIL		HEAD
	-2	0	2	-15	0	40
70	-3	0	4	-3	0	1
60	-2	0	2	-3	0	1
50	-2	0	1	-4	0	1
40	-2	0	1	-4	0	1

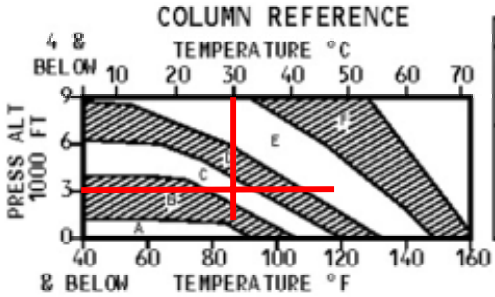
*V_1 NOT TO EXCEED V_R

WT 1000 KG	A			B			C		
	V_1	V_R	V_2	V_1	V_R	V_2	V_1	V_R	V_2
70	158	163	168	158	164	169			
65	151	155	161	152	156	162	153	157	162
60	144	148	155	145	148	155	146	149	155
55	137	139	149	138	140	149	138	141	148
50	129	131	142	130	132	142	131	133	142
45	121	123	136	122	124	135	122	125	135
40	113	114	130	113	116	129	113	116	128

WT 1000 KG	D			E			F		
	V_1	V_R	V_2	V_1	V_R	V_2	V_1	V_R	V_2
70									
65									
60									
55	140	143	148						
50	132	134	141	133	135	141			
45	124	126	135	125	127	134	128	128	134
40	115	117	128	116	118	127	119	120	126

IN BOXED AREA CHECK MINIMUM V_1 (MCG) FOR ACTUAL TEMP.

Example Problem (FPPM Format)



SLOPE/WIND V_1 ADJUSTMENT*						
WEIGHT 1000 KG	SLOPE % DN		UP	WIND KTS TAIL		HEAD
	-2	0	2	-15	0	40
70	-3	0	4	-3	0	1
60	-2	0	2	-3	0	1
50	-2	0	1	-4	0	1
40	-2	0	1	-4	0	1

*V_1 NOT TO EXCEED V_R

0.5 Knots

WT 1000 KG	A			B			C		
	V_1	V_R	V_2	V_1	V_R	V_2	V_1	V_R	V_2
70	158	163	168	158	164	169			
65	151	155	161	152	156	162	153	157	162
60	144	148					146	149	155
55	137	139					138	141	148
50	129	131					131	133	142
45	121	123	136	122	124	135	122	125	135
40	113	114	130	113	116	129	113	116	128

145 Knots

154 Knots

148 Knots

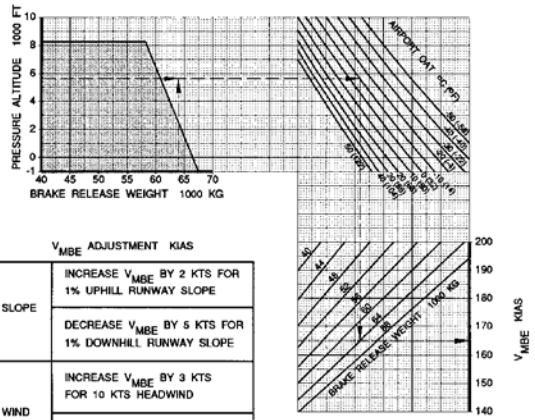
WT 1000 KG	D			E			F		
	V_1	V_R	V_2	V_1	V_R	V_2	V_1	V_R	V_2
70									
65									
60									
55	140	143	148						
50	132	134	141	133	135	141			
45	124	126	135	125	127	134	128	128	134
40	115	117	128	116	118	127	119	120	126

IN BOXED AREA CHECK MINIMUM V_1 (MCG) FOR ACTUAL TEMP.

Example Problem (FPPM Format)

Brake Energy Limit VMBE
Category "A" Brakes

CHECK V_{MBE} WHEN OUTSIDE SHADED AREA OR WHEN OPERATING WITH TAILWIND OR IMPROVED CLIMB.



	V_{MBE} ADJUSTMENT KIAS
SLOPE	INCREASE V_{MBE} BY 2 KTS FOR 1% UPHILL RUNWAY SLOPE
	DECREASE V_{MBE} BY 5 KTS FOR 1% DOWNHILL RUNWAY SLOPE
WIND	INCREASE V_{MBE} BY 3 KTS FOR 10 KTS HEADWIND
	DECREASE V_{MBE} BY 20 KTS FOR 10 KTS TAILWIND

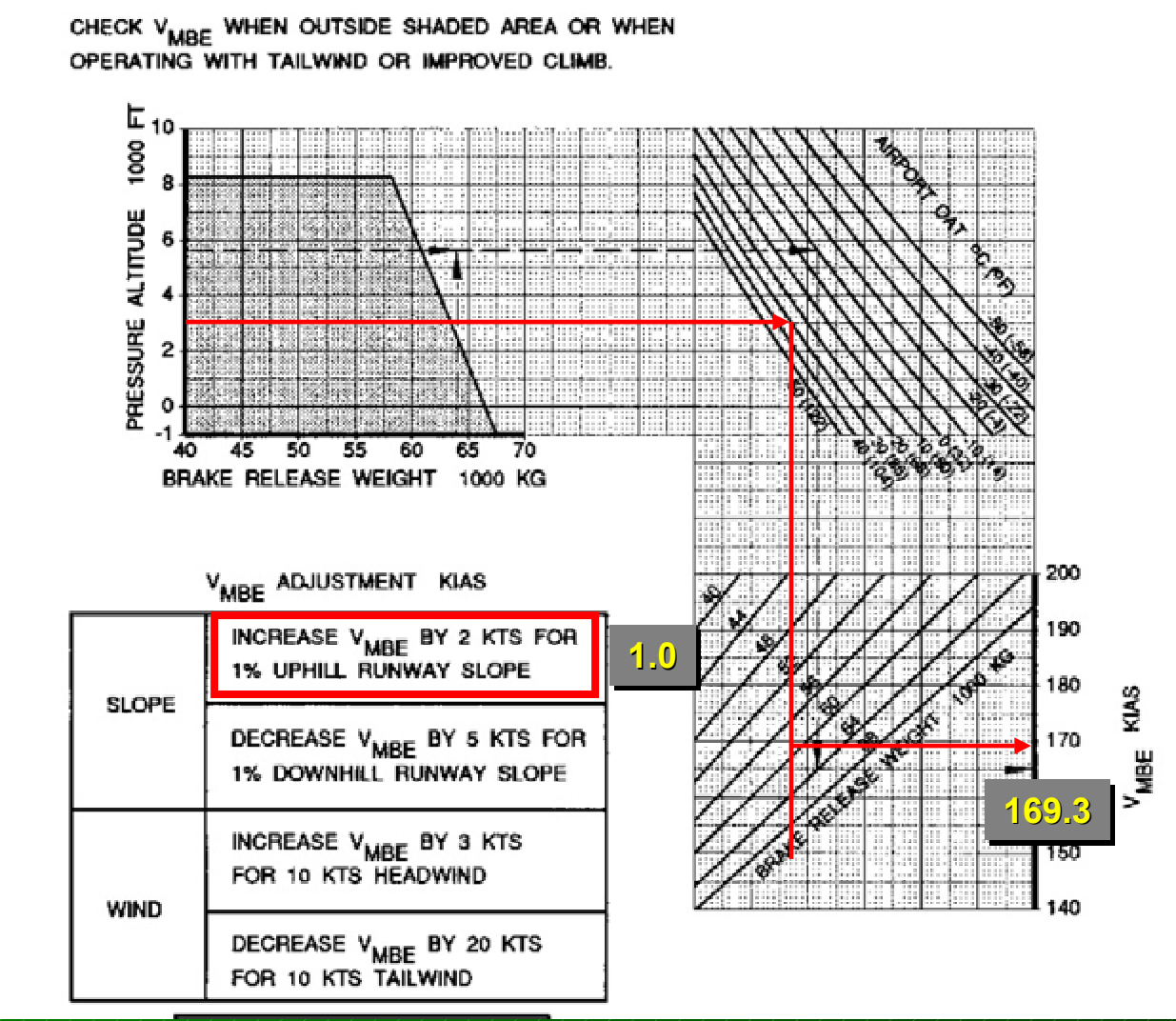
PMC OFF CORRECTION IS -1 KT

ADJUST V_{MBE} FOR SLOPE AND WIND.

NORMAL TAKEOFF: DECREASE BRAKE RELEASE WEIGHT BY 300 KG FOR EACH KNOT V_1 EXCEEDS V_{MBE}. DETERMINE NORMAL V_1, V_R, V_2 SPEEDS FOR LOWER BRAKE RELEASE WEIGHT.

IMPROVED CLIMB TAKEOFF: DECREASE CLIMB WEIGHT IMPROVEMENT BY 160 KG FOR EACH KNOT V_1 EXCEEDS V_{MBE}. DETERMINE V_1, V_R, V_2 SPEED INCREMENTS FOR THE LOWER CLIMB WEIGHT IMPROVEMENT.

Example Problem (FPPM Format)



Example Problem (FPPM Format)

Calculation of Improved Climb Takeoff Weight

Climb Limit Weight	57,000 kg
Climb Weight Improvement	2,075 kg
Improved Climb Takeoff Weight	59,075 kg

Calculation of Improved Climb Takeoff Speeds

	V_1	V_R	V_2
Base Speeds	145	148	154
Slope Correction	0.5		
Improved Climb Correction	5.9	7.1	7.1
Improved Climb Takeoff Speeds (knots)	151.4	155.1	161.1

Example Problem (FPPM Format)

Airplane = 737-400
Engines = CFM56-3-B2
Flaps = 5
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Airconditioning = Auto
Anti-Skid = ON
OAT = 30 Deg C
Wind = 0 Kts
Altitude = 3000 ft
Obstacles = None
V1/Vr Ratio
Climb Limit Weight = 57,000 kg
Field Limit Weight = 62,000 kg
Tire Speed Limit Weight = 69,000 kg

Improved Climb Weight	59,075 kg
Improved Climb V_1	151.5 Kt
Improved Climb V_R	155 Kt
Improved Climb V_2	161 Kt

Improved Climb

Performance Engineer Operations

Flight Operations Engineering

Tom Ruckman

November 2001