Transportation Engineering

Course Code –CE-422

Contact Hours -3+3

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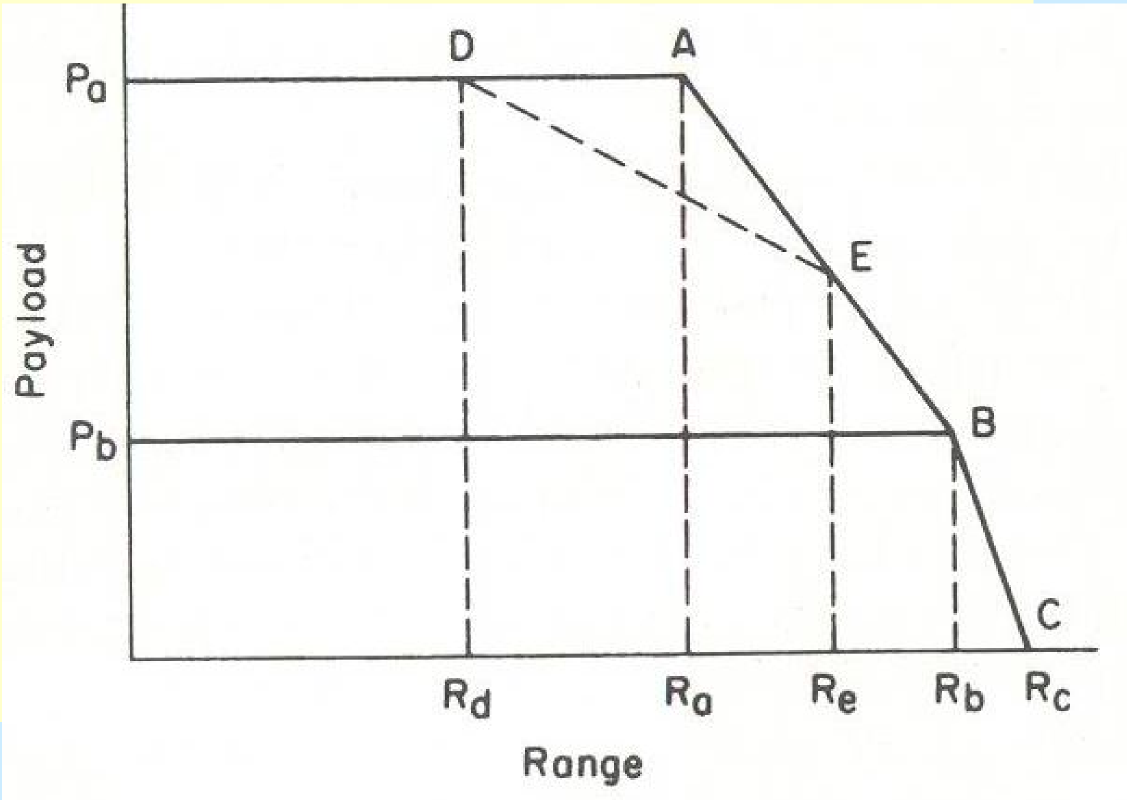
Payload- Range Charts

- Range- distance the aircraft can fly is called range
- Range increases as payload decreases

Point A: range at maximum payload, fuel tank not completely filled.



Payload- Range Charts

- Point B: fuel tank completely filled. Aircraft take off at MTOW
- Point C: maximum distance without payload (ferry range). Take off weight less than maximum.
- For the maximum structural landing weight, path DE is followed. (How long the aircraft can fly with maximum structural payload)

Limitation of Payload

- Can't get lighter than empty operational empty weight (OEW)
- Pavement structure designed on maximum of taxiway weight, take-off and landing weights.
- Need fuel for reserves and trip, limited by tank size
- What is left over is for useful payload

Problem

Aircraft Weight Characteristics		Weight (lbs)
Maximum Structural Take off weight		220000
Maximum Strucutral Landing Weight		198000
Zero fuel weight		182513
Operating empty weight		125513
Maximum structural payload		57000
Fuel capacity		75400
Reserve fuel	**1.25 h**	
Average speed	**540 mile/h**	
Fuel burning	**22.8 lbs/mile**	

Example B777-300

- Assume you need to fly 100,000 lbs payload about 3250 nautical miles at 6000 ft elevation runways

Performance weight manual

CHARACTERISTICS	UNITS	BASELINE AIRPLANE		
MAX DESIGN TAXI WEIGHT	POUNDS	508,000	517,000	537,000
	KILOGRAMS	230,450	234,500	243,500
MAX DESIGN TAKEOFF WEIGHT	POUNDS	506,000	515,000	535,000
	KILOGRAMS	229,500	233,600	242,630
MAX DESIGN LANDING WEIGHT	POUNDS	441,000	445,000	445,000
	KILOGRAMS	200,050	201,800	201,800
MAX DESIGN ZERO FUEL WEIGHT	POUNDS	420,000	420,000	420,000
	KILOGRAMS	190,470	190,470	190,470
SPEC OPERATING EMPTY WEIGHT (1)	POUNDS	298,900	298,900	299,550
	KILOGRAMS	135,550	135,550	135,850
MAX STRUCTURAL PAYLOAD	POUNDS	121,100	121,100	120,450
	KILOGRAMS	54,920	54,920	54,620

Gross Weight

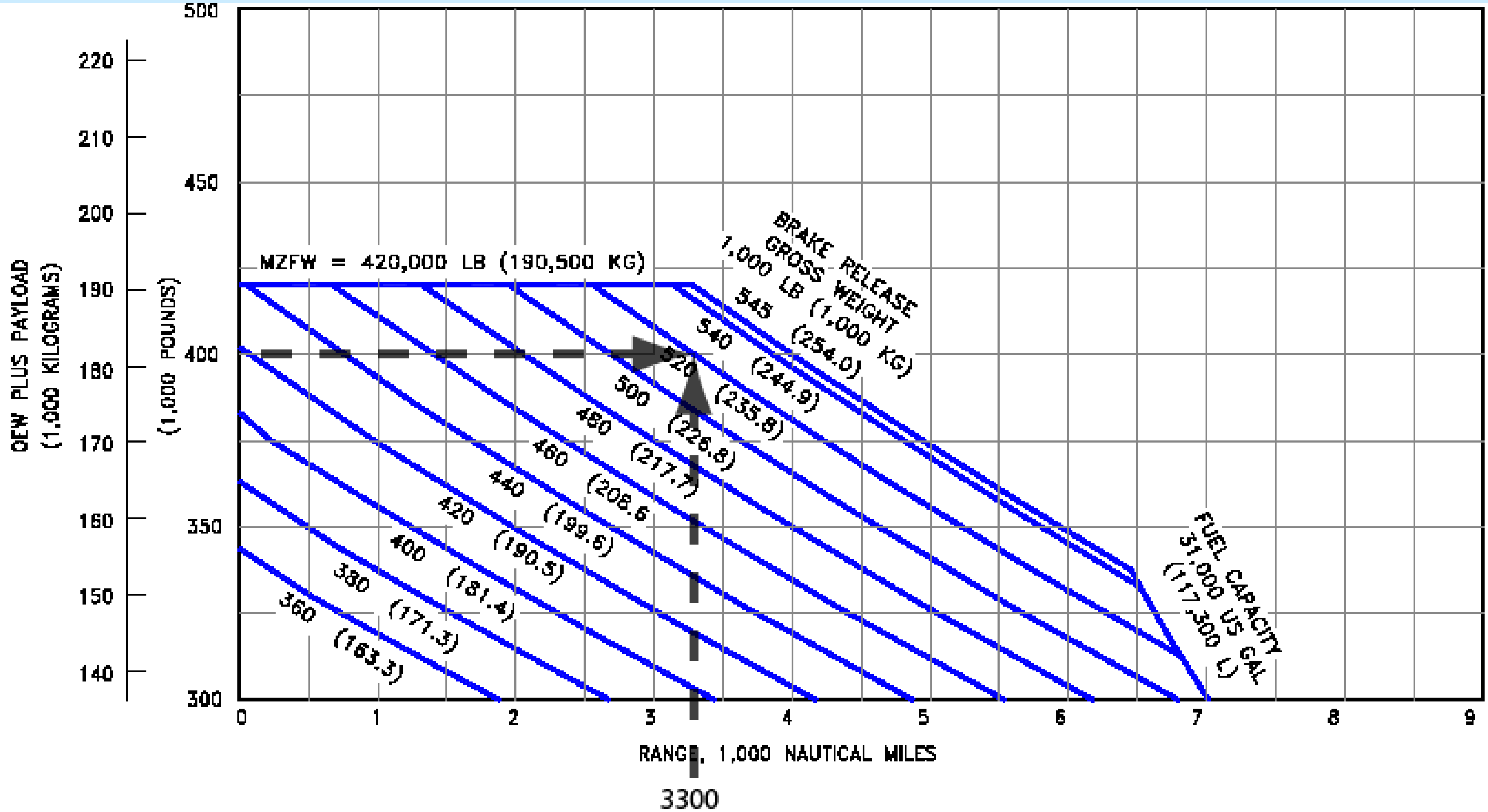
299500

+

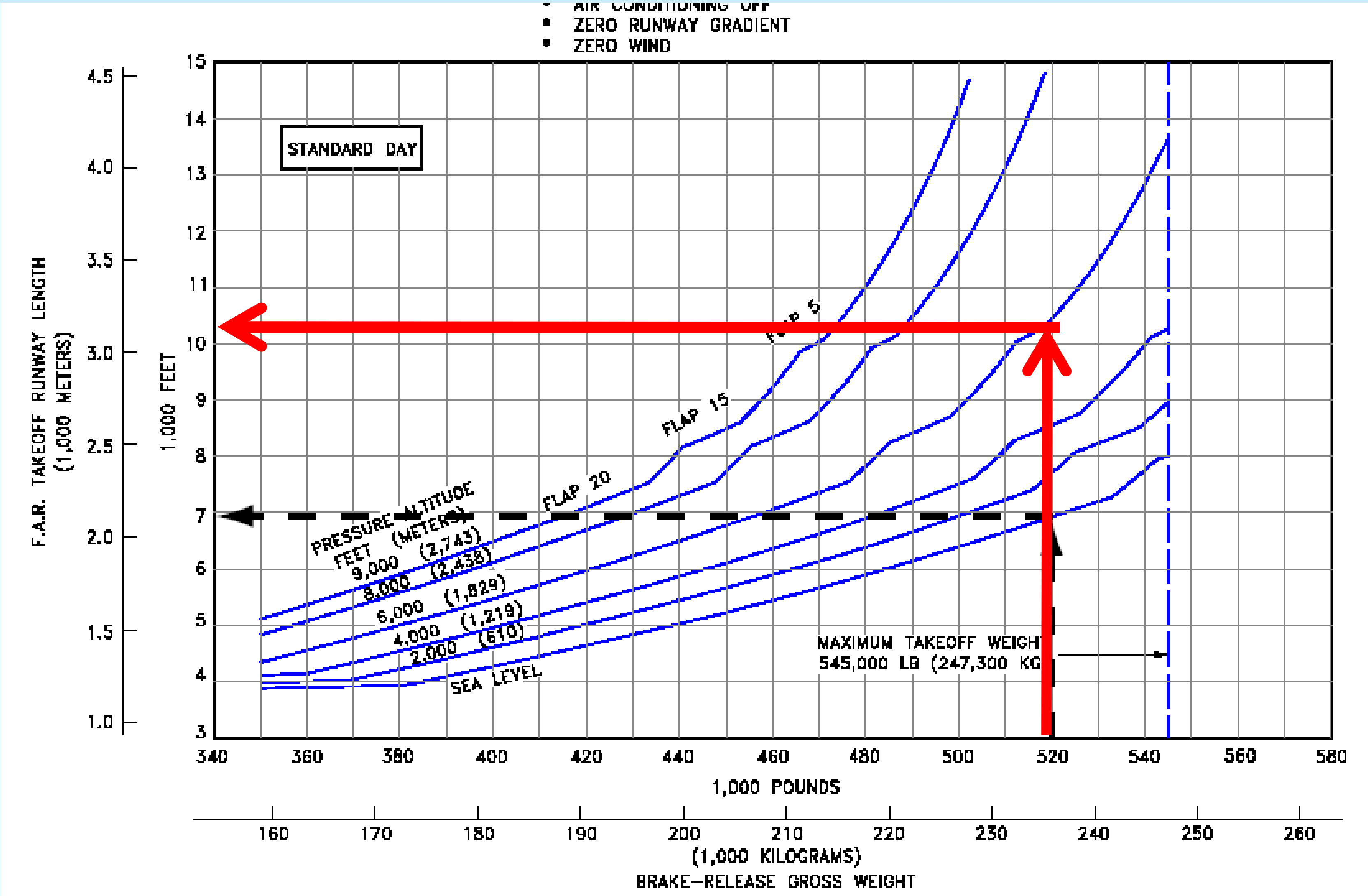
100000

= 400000

Flying 100000 lbs 3250



Runway Length Requirement



Runway Orientation (Usability)

- The percentage of time during which the use of runway is not restricted because of cross wind component.
- Usability of the runway depends upon metrological and topographical factors
- Cross wind component affects function of air plane mass.

Runway Orientation (Analysis of Wind)

- Provides adequate separation between aircrafts
- Causes least interference and delays in landing, taxing and takeoff operations
- Provide short taxi distance to end of runways
- Provide adequate taxiways so that landing aircrafts can exit runways as quickly as possible

Runway Orientation (Analysis of Wind)

- The principal traffic runway should be oriented as closely as practical so that the cross wind is within maximum permissible limits
- Max allowable cross wind component depends on
  - Size of aircraft
  - Wing configuration
  - Condition of pavement surface
- Guidelines are provided by ICAO for maximum allowable cross wind under different conditions

Permissible Cross Wind Component

- Reference Field Length
  - 1500 m or over
  - 1200 m to 1499 m
  - < 1200 mm
- Maximum cross wind component
  - 20 knots (37 km/hr)
  - 13 knots (24 km/hr)
  - 10 knots (19 km/hr)

Wind Rose Diagram

- Consists of a series of concentric circles cut by radial lines on polar co-ordinate graph paper
- Radial lines are used to scale the wind magnitude
- Each radial line is 22.5 deg increment
- Less than 4mph is referred to as calm
- It requires information regarding the direction and frequency of wind.
- Best orientation is the longest line on wind rose diagram

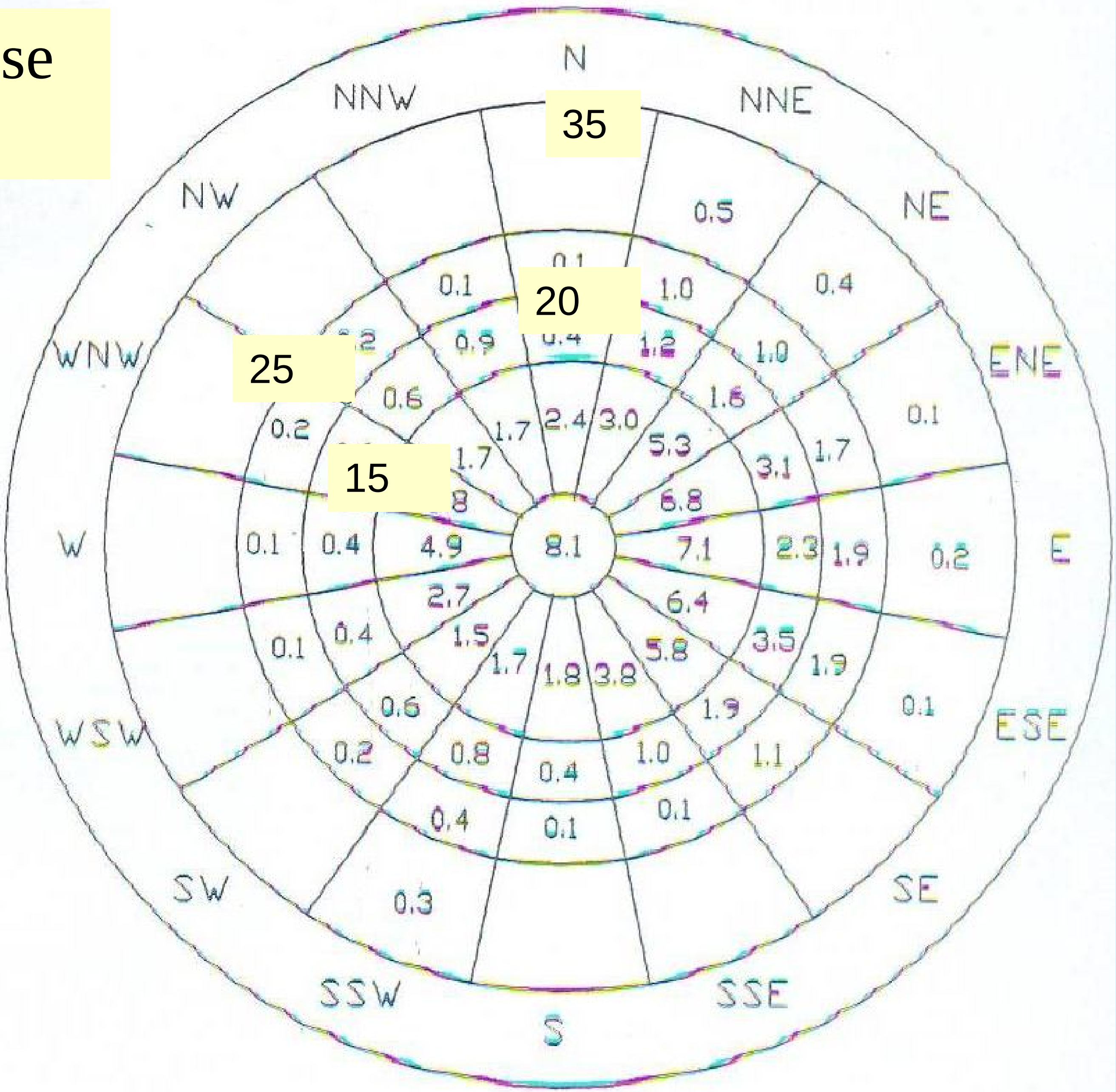
Design Template

- Draw three equidistant parallel lines on transparent template. The middle line is the runway centre line and the distance between outside lines represents the cross wind component
- Template is placed on the wind rose such that the centre line passes through the centre of the wind rose

% Time that wind come from particular directions at various velocities in all weather conditions

Sector	True azimuth	Wind speed range, mi/h 4–15	15–20	20–25	25–35	Total
		Percentage of time				
N	0.0	2.4	0.4	0.1	0.0	2.9
NNE	22.5	3.0	1.2	1.0	0.5	5.7
NE	45.0	5.3	1.6	1.0	0.4	8.3
ENE	67.5	6.8	3.1	1.7	0.1	11.7
E	90.0	7.1	2.3	1.9	0.2	11.5
ESE	112.5	6.4	3.5	1.9	0.1	11.9
SE	135.0	5.8	1.9	1.1	0.0	8.8
SSE	157.5	3.8	1.0	0.1	0.0	4.9
S	180.0	1.8	0.4	0.1	0.0	2.3
SSW	202.5	1.7	0.8	0.4	0.3	3.2
SW	225.0	1.5	0.6	0.2	0.0	2.3
WSW	247.5	2.7	0.4	0.1	0.0	3.2
W	270.0	4.9	0.4	0.1	0.0	5.4
WNW	292.5	3.8	0.6	0.2	0.0	4.6
NW	315.0	1.7	0.6	0.2	0.0	2.5
NNW	337.5	1.7	0.9	0.1	0.0	2.7
Subtotal		60.4	19.7	10.2	1.6	91.9
Calms						8.1
Total						100.0

Wind Rose Diagram



Wind Rose Diagram

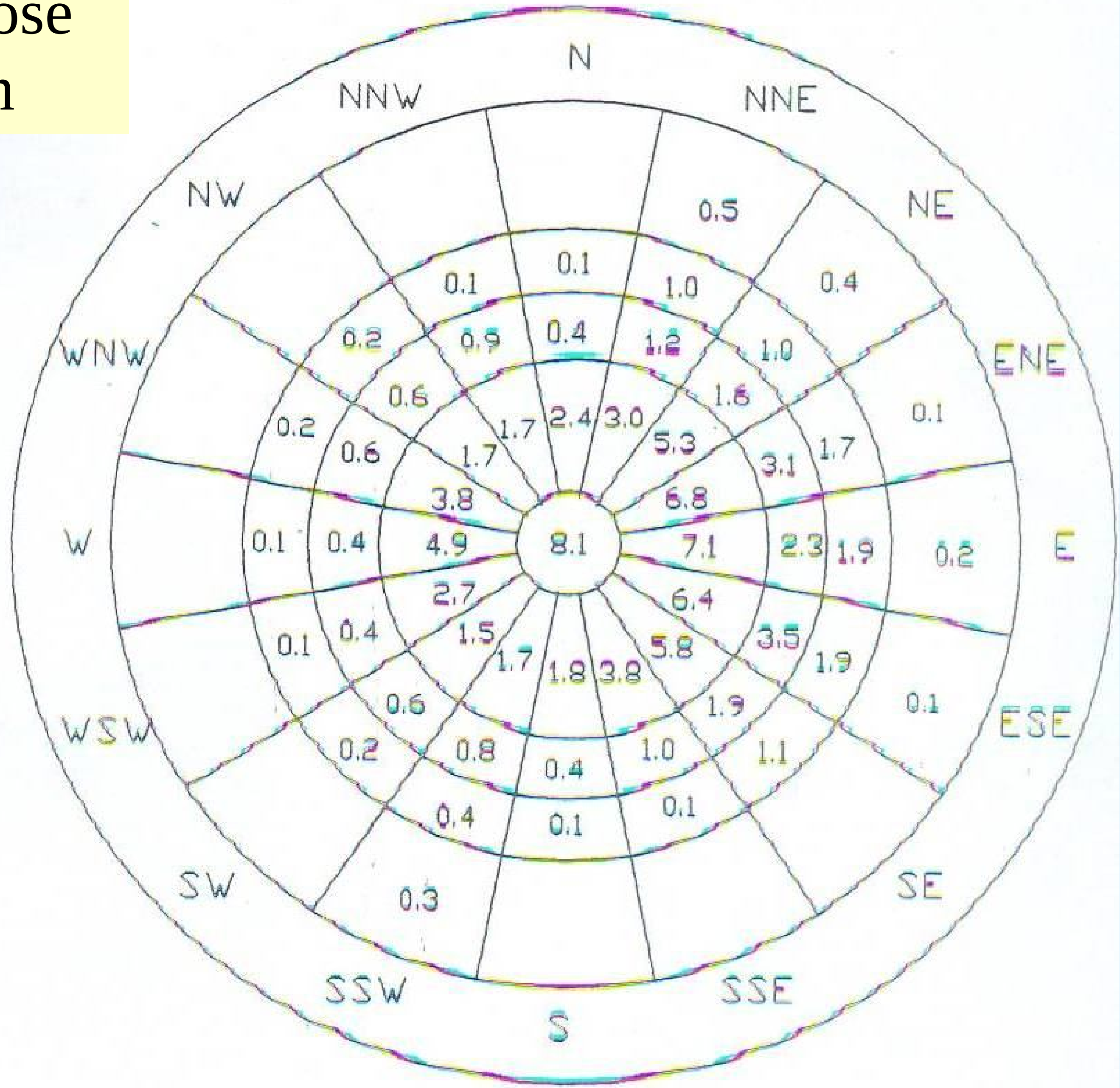


Figure 7-5 Wind data plot for Example Problem 7-1.

Template for cross wind component

Wind Rose Diagram

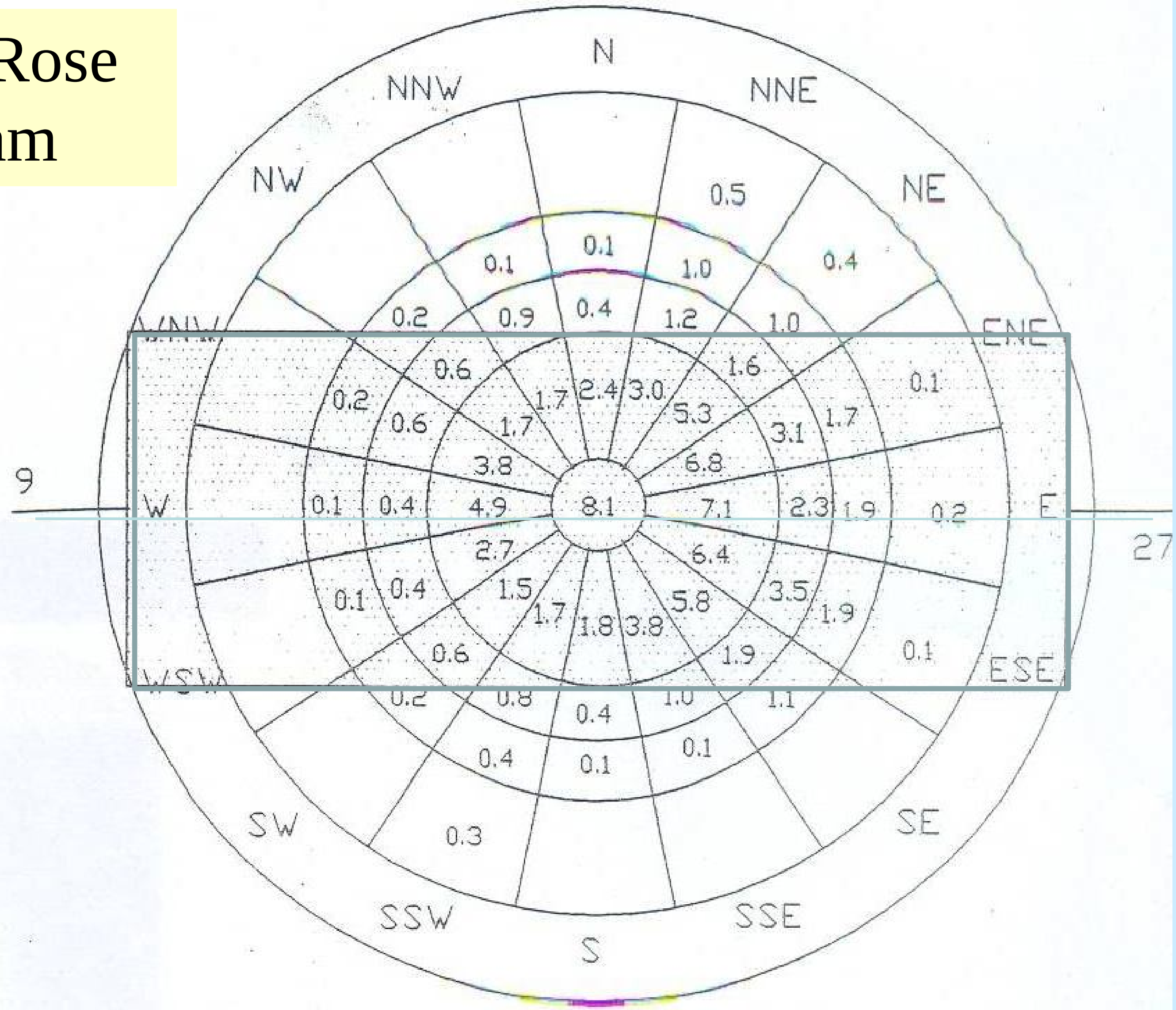


Figure 7-6 Wind coverage for runway 9-27 for Example Problem 7-1.

WIND ROSE DIAGRAM

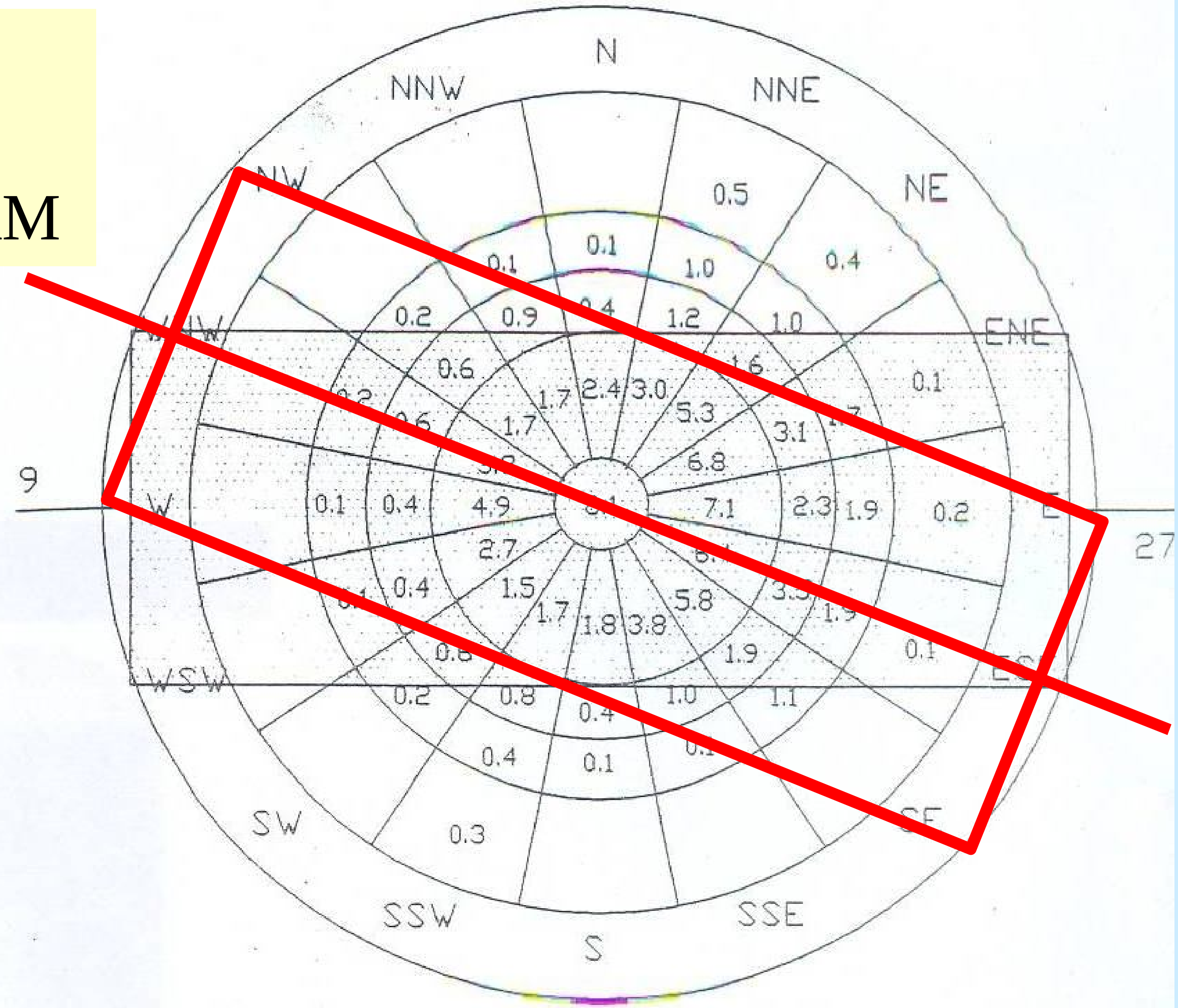


Figure 7-6 Wind coverage for runway 9-27 for Example Problem 7-1.

Runway Length Analysis

The factors influencing runway length are of three categories

- Performance characteristics of a particular type of aircraft
- Trip length (gross weight)
- Safety requirement imposed by ICAO
- Airport Environment

Runway Length Analysis

- Airport Environment
  - Atmospheric
    - Temperature
    - Surface wind
  - Location and condition of runway
    - Altitude
    - Runway gradient
- Most significant factor in terms of size and cost of the airport
- Length is usually designed for critical aircraft (which require maximum runway length)

Performance requirement imposed by Government

- Transport aircraft are licensed and operated under the code of regulations known as Federal Aviation Regulations (FAR)

- The regulations pertaining to turbine aircraft consider three general cases in establishing the runway length
  - Normal Take off
  - Take off Involving Engine Failure/ to brake to stop
  - Landing

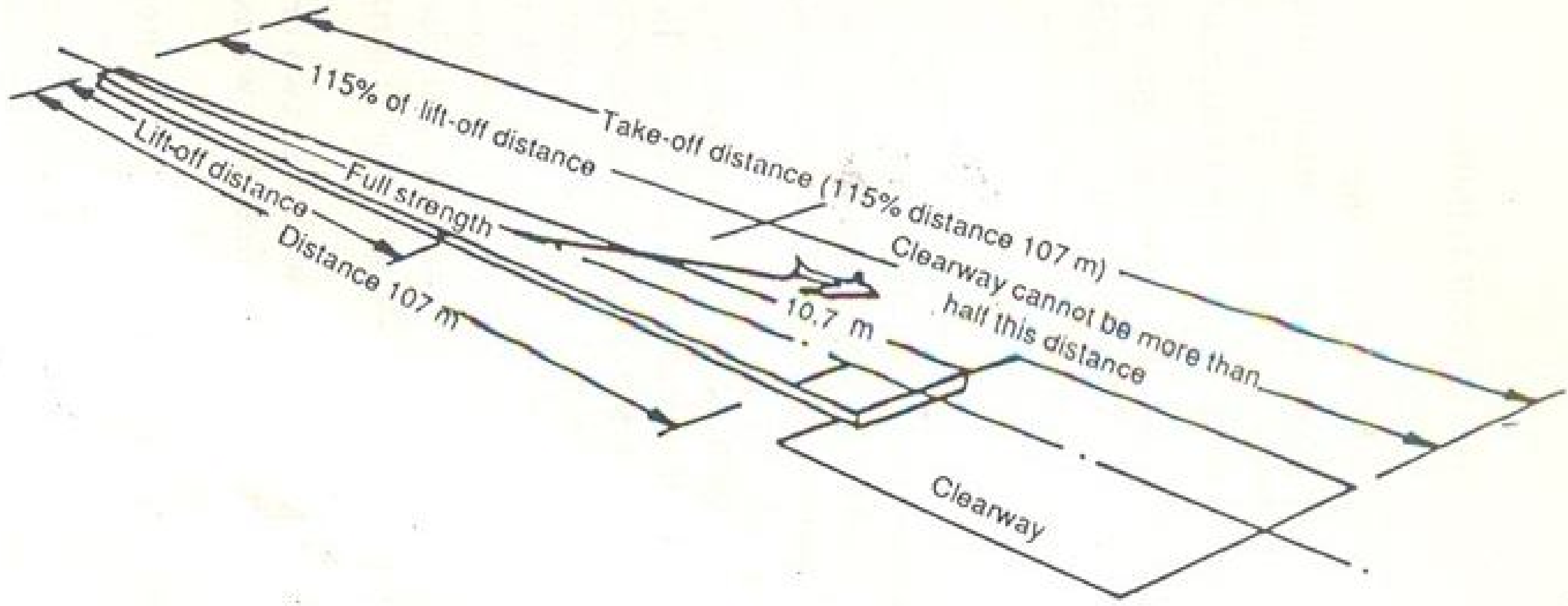
Performance requirement imposed by Government

- The same criteria is applicable to piston engine aircraft.
- The longest length required by any of the three cases is used.
- Design done for controlled conditions of flying speed, aircraft weight and configuration, altitude and temperature.

Performance requirement imposed by Government

- Normal Take
  - A normal take off in which all engines are available and sufficient runway is required to accommodate variation in liftoff techniques.
  - This takeoff distance must be 115% of the distance required by an aircraft to clear an imaginary obstacle of 35 ft (11.7 m). It is designated as D35.
  - Not all of this distance would be a full strength pavement.
  - This distance should be free of obstructions.

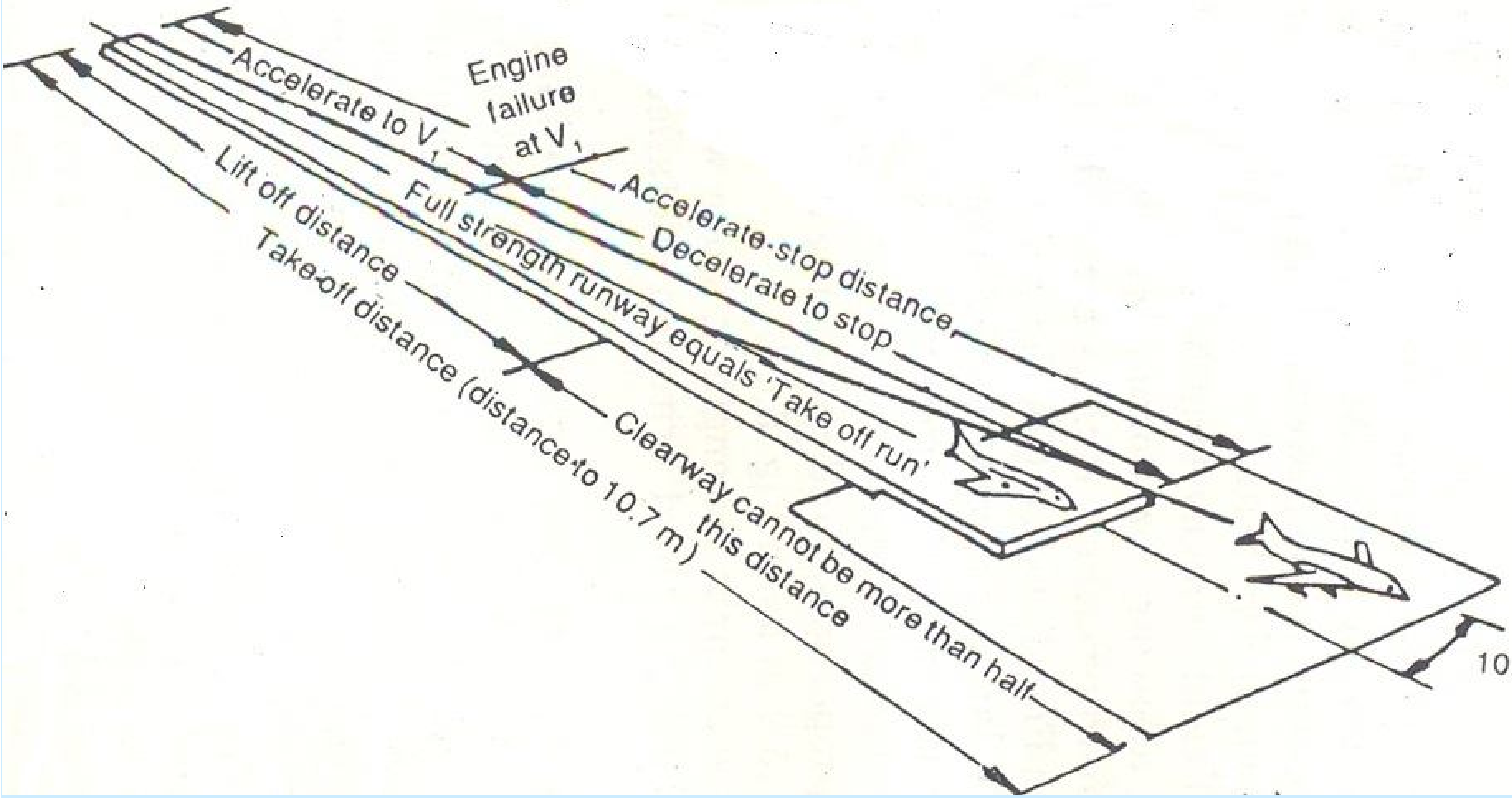
Normal Take Off Case



Engine Failure Case

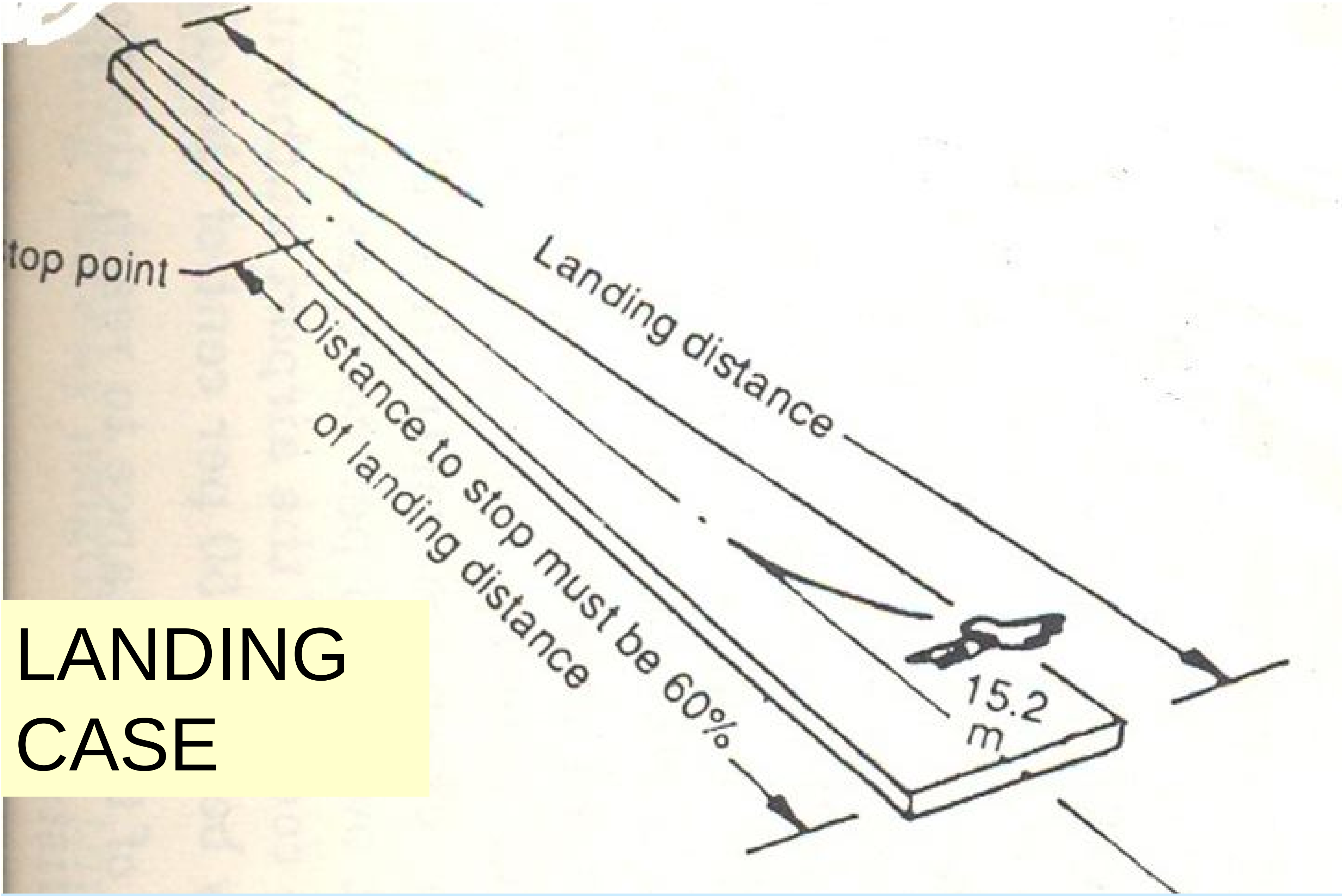
- Take off distance required is the actual distance to reach a height of 35 ft (D35) with no %age applied.
- However, engine failure is very rare.
- Also, engine failure case requires the sufficient distance be available to stop the plane rather than takeoff.
- This is referred to as accelerate stop distance (DAS or ASD).

Engine Failure Case



Landing Distance Case

- Sufficient runway length is to provided to enable safe landing for normal variation in the landing techniques, poor approaches etc.
- The landing distance needed for each aircraft should be long enough to permit the aircraft to a full stop within 60% of this distance.
- Pilot approaches at proper speed and crosses the threshold of the runway at a height of 15.0 m



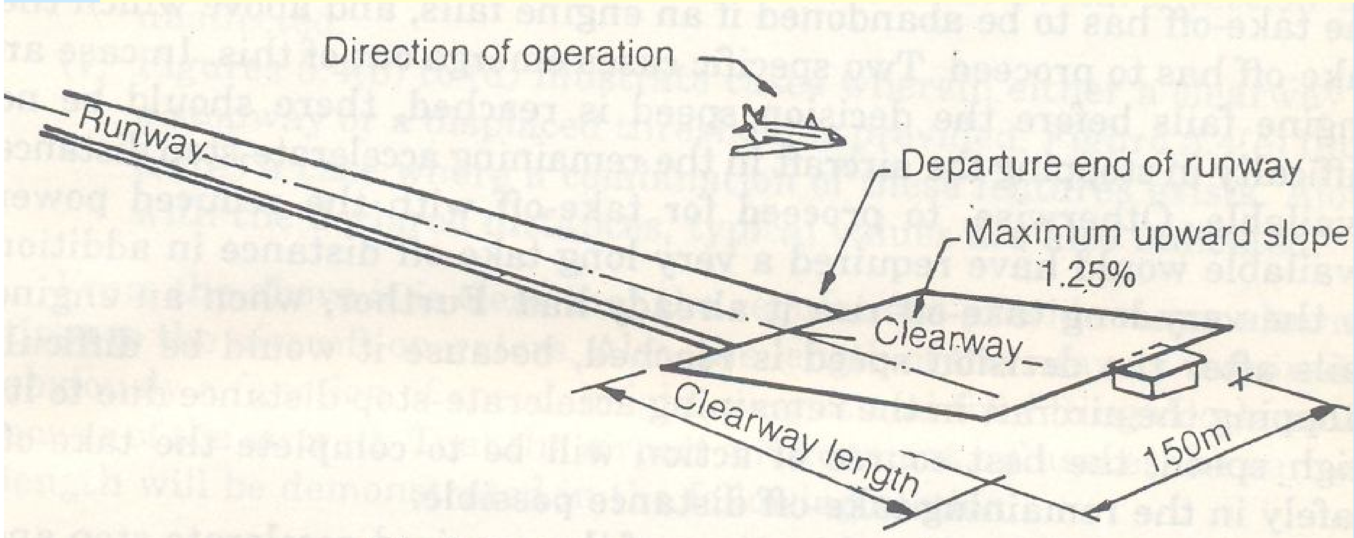
LANDING CASE

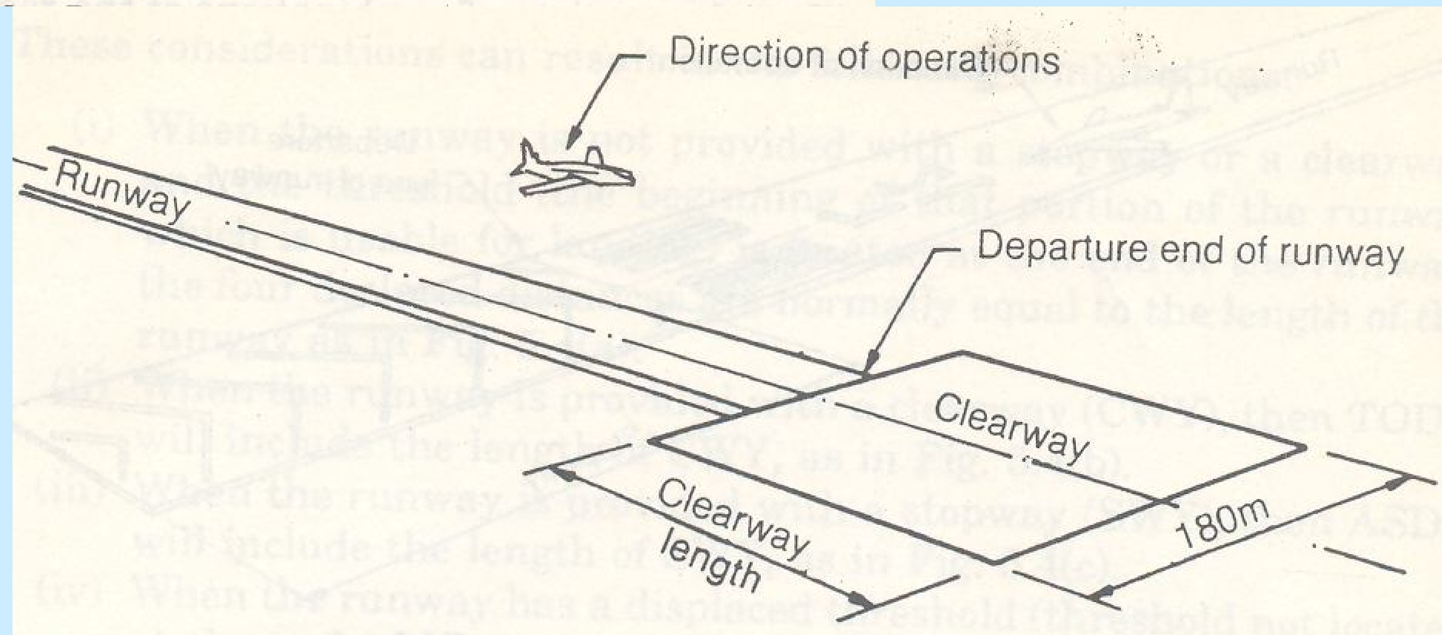
Typical Runway Length		
Aircraft Type	**Takeoff (ft)**	**Landing (ft)**
B747-200 B	10500	6150
DC-10-30	10490	5960
Concorde	10280	8000
B727-200	10080	4800
A300 B4	8740	5590
B737-200	6550	4290
DC-9-50	7880	4680
F28-2000	5490	3540
F27-500	5470	3290
SD3-30	3900	3400

Components of Runway

- Clear Way (CL)
  - Rectangular area beyond the runway not less than 500 ft wide and not longer than 1000 ft.
  - Extend from the end of runway with a slope not exceeding 1.25% above which no object protrude except for threshold lights on two sides of the runway (not higher than 26 in)
  - Allows aircraft to climb to a height of 11 m.

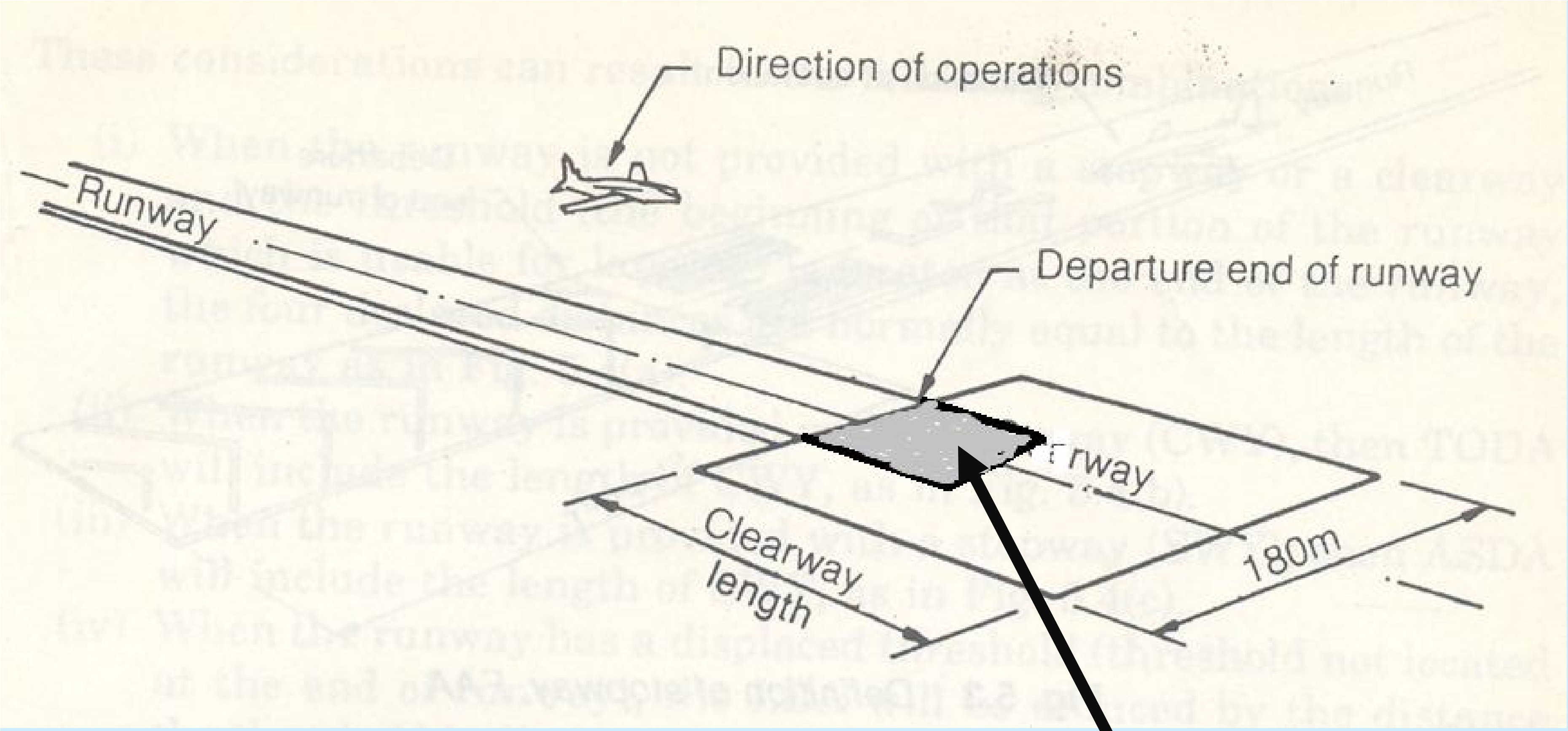
Definition of Clearway by FAR





STOPWAY (SW)

- Area beyond the runway width not less than runway.
- Paved surface that allows aircraft to stop in situation of abandoned takeoff (engine failure in turbine aircraft is not very common)
- Permit use of lesser strength pavement for turbine powered, while for piston aircraft require FS for entire SW


Direction of operations
Runway
Departure end of runway
rway
Clearway
length
180m

STOPWAY

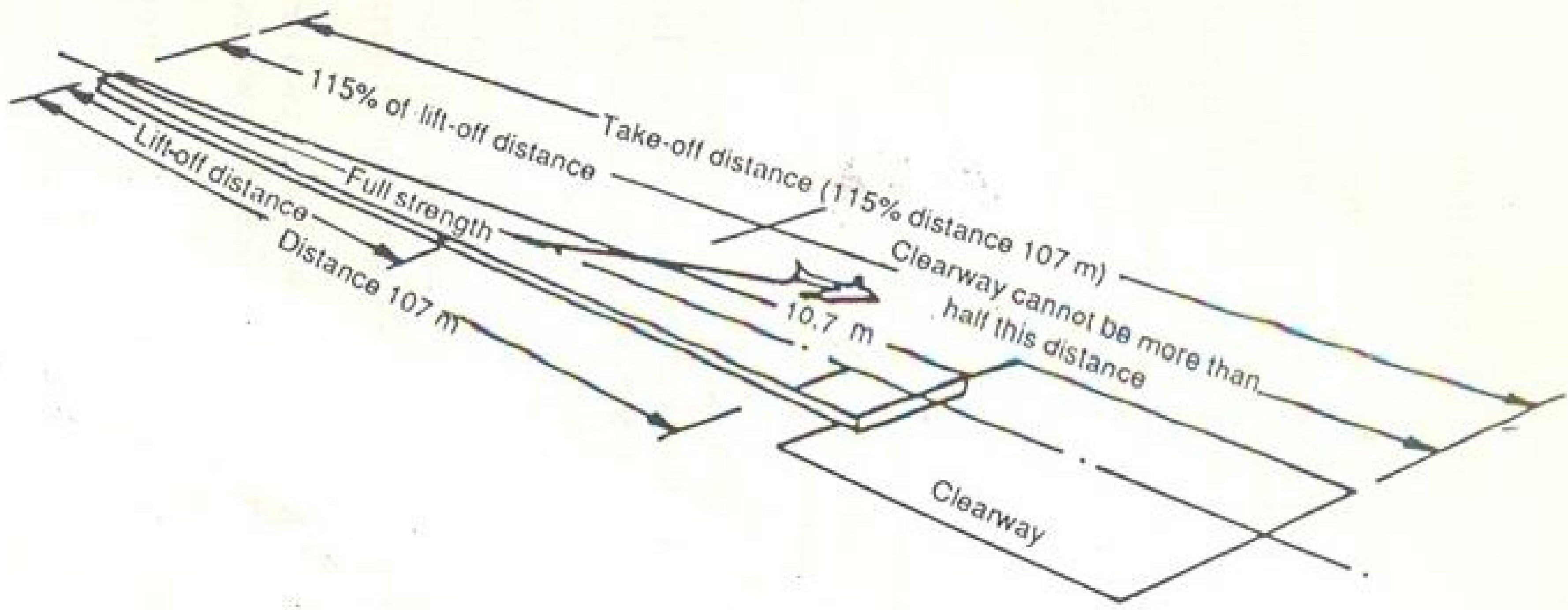
Nomenclature used for Runway Length

- FS- full strength pavement distance
- CL- clearway distance
- SW- stopway distance
- FL- field length (FS+SW+CL)
- LOD- liftoff distance
- TOR- takeoff run
- TOD- takeoff distance
- LD- landing distance
- SD- stopping distance
- D35- distance to clear 35 ft obstacle
- DAS- distance to accelerate and stop (ASD)

Runway Design Concept

- Runway refers to full strength pavement (FS)- Supports the full weight of the aircraft.
- For turbine aircraft the regulations do not requires FS for entire takeoff distance (TOD) while for piston aircraft requires FS for entire TOD.
- Runway field length has three basic components
  - Full strength pavement also referred to as runway
  - Clearway (CL)
  - Stopway (SW)

Normal Take Off Case

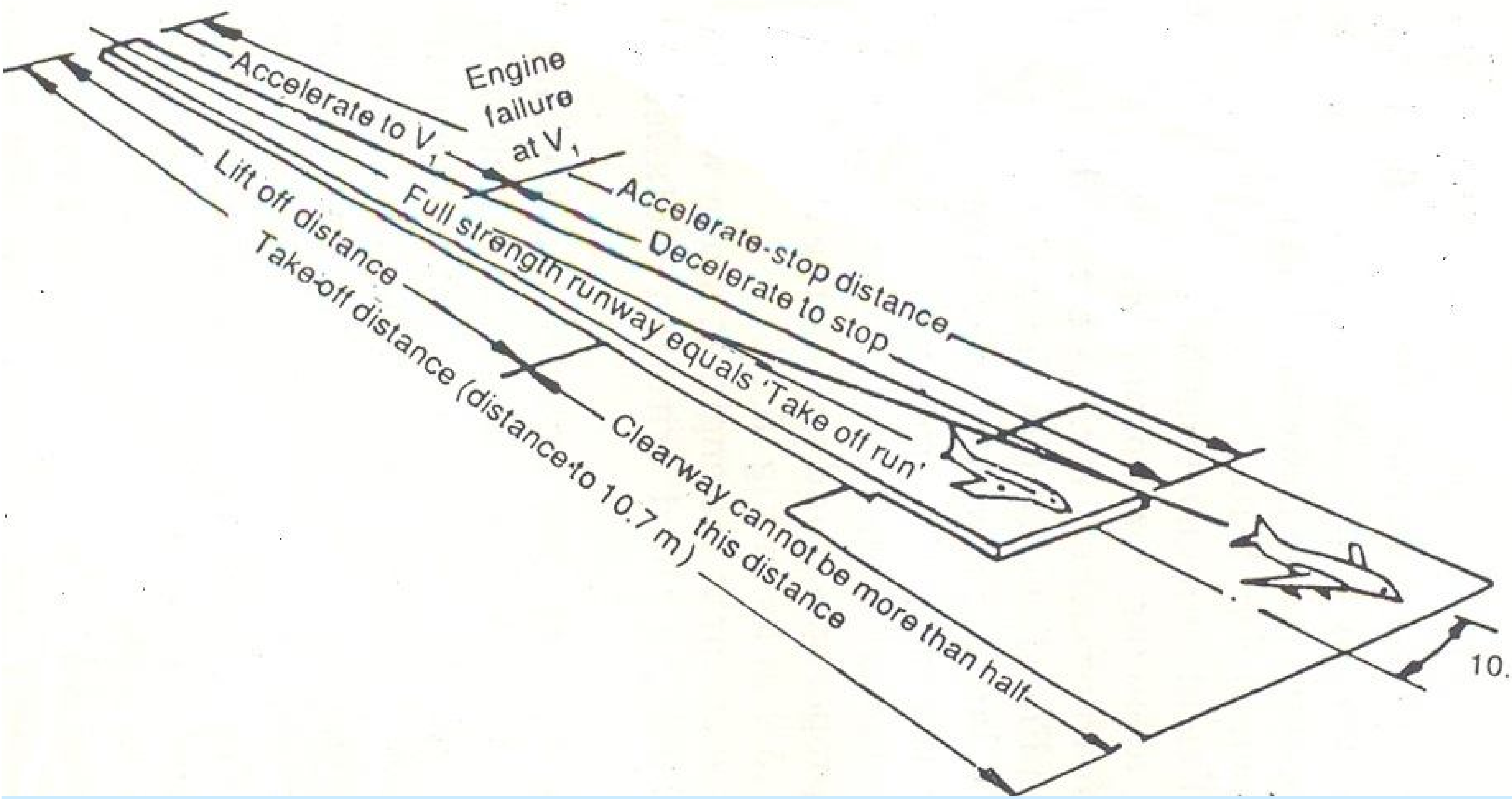


Runway length- Normal Takeoff: Case –I

- $FL_1 = FS_1 + CL_{1\ max}$

Where

- $TOD_1 = 1.15\ (D_{35})$
- $CL_{1\ max} = 0.5\ [TOD_1 - 1.15(LOD_1)]$
- $TOR_1 = TOD_1 - CL_{1\ max}$
- $FS_1 = TOR_1$



Engine Failure Case

Engine Failure takeoff: Case-II

- $FL_2 = FS_2 + CL_{2\ max}$
- Where
- $TOD_2 = (D_{35})_2$
- $CL_{2\ max} = 0.5\ [TOD_2 - (LOD_2)]$
- $TOR_2 = TOD_2 - CL_{2\ max}$
- $FS_2 = TOR_2$

Engine Failure aborted takeoff: Case-III

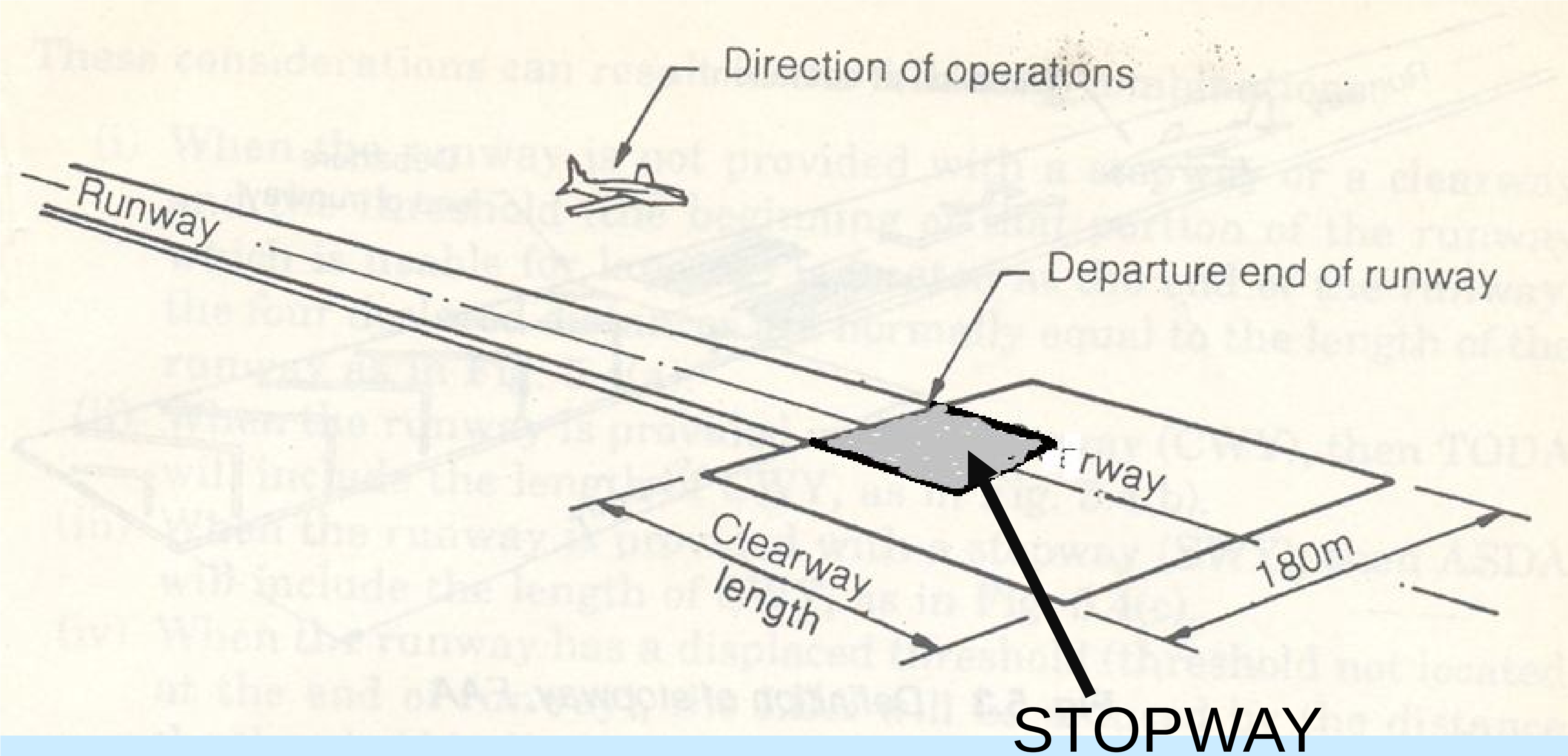
- FL_3= FS+SW
- FL_3=DAS

Landing Case-IV

- The landing distance should be 66.7% longer than the demonstrated distance to stop (SD) an aircraft.
- Crosses the threshold at 15 m in height.
- FL_4= LD_4 where LD =SD /0.6
- FS_4= LD_4

Field Length

- The result of the final analysis
- $FL = \max(TOD_1, TOD_2, DAS, LD)$
- $FS = \max(TOR_1, TOR_2, LD)$
- $SW = DAS - \max(TOR_1, TOR_2, LD)$
  $SW_{min} = 0$
- $CL = \min(FL - DAS, CL_{1\,max}, CL_{2\,max})$
- $CL_{min} = 0$, $CL_{max} = 1000$ ft



Note:

If both ends of runway are to be used by aircraft, the field length component (FS, SW and CL) must exist in each direction

Balanced Runway or Balanced Field

- The take off distance and accelerate stop distance depends upon the speed that the aircraft achieved when an engine fails.
- The speed at which engine failure is assumed to occur is selected by aircraft manufacturer and is referred to as critical engine failure speed V1.
- If an engine actually fails prior to this speed than the pilot brakes to stop.
- If the engine fails at a greater speed than this critical speed the pilot has no choice but to continue take off.

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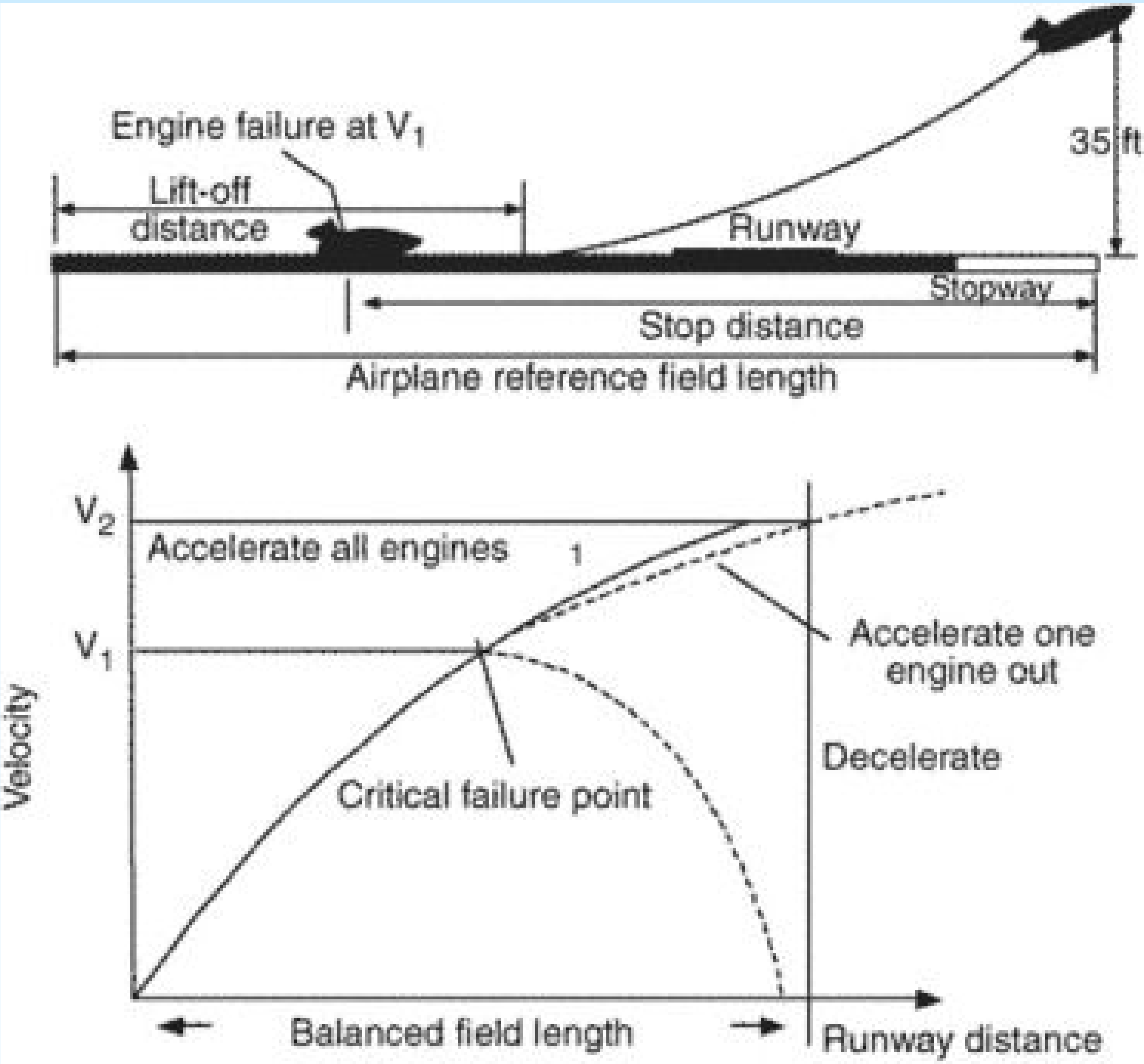


Engine failure at V_1
Lift-off distance
Runway
35 ft
Stopway
Stop distance
Airplane reference field length
V_2
Accelerate all engines
1
V_1
Velocity
Accelerate one engine out
Decelerate
Critical failure point
Balanced field length
Runway distance

Problem

- Normal Take off Case
  - Lift off distance = 7000 ft
  - Distance to clear 35 ft height = 8000 ft
- Engine Failure
  - Lift off distance = 8200 ft
  - Distance to clear 35 ft height = 9100 ft
- Engine failure aborted take off
  - Accelerate stop distance = 9500 ft
- Normal Landing
  - Stop distance = 5000 ft
- Determine the length of the runway

Problem

- Normal Take off Case
  - Lift off distance = 2100 m
  - Distance to clear 35 ft height = 2400 m
- Engine Failure
  - Lift off distance = 2460 m
  - Distance to clear 35 ft height = 2730 m
- Engine failure aborted take off
  - Accelerate stop distance = 2850 m
- Normal Landing
  - Stop distance = 1500 m
- Determine the length of the runway

Correction for Runway Length

Runway Length- Standard Factor

- Performance characteristics of the aircraft using the airport
- Landing and gross takeoff weight of the aircrafts
- Elevation of the airport site: standard provide location of airport at mean sea level

Correction for Runway Length

- Average maximum airport temperature: the standard temperature at mean sea level is at 15ºC
- Runway gradient: standard provides for level or zero gradient of runway

Correction Factors

- Temperature
- Surface wind
- Runway gradient
- Altitude at the airport
- Runway surface conditions

Temperature

- Higher temperature requires longer runways
- Higher temperature results in lower air density resulting in lower output of thrust
- Increase is not linear with temperature, rate of increase higher at higher temperature
- Standard temperature is 59ºF or 15ºC at mean sea level (MSL)
- Increase in length is 0.42% to 0.65% per degree Fahrenheit

Surface Wind

- Greater the head wind shorter is the runway
- The direction of the wind also effect the allowable takeoff weight for the airplane
- A 5-knot head wind approximately reduces the takeoff length by 3%
- A 5-knot tail wind approximately increases the takeoff length by 7%
- For planning no wind is considered if light wind occurs at the airport sight.

Runway Gradient

- Uphill gradient requires more length of the runway than the downward gradient.
- Increase and decrease in runway length is linear with change in gradient.
- Length increase by 7-10% for each 1% increase in gradient (max gradient is 1.5%)
- Average Uniform gradient: straight line joining the ends of the runway (no point 5 ft above the average)
- Effective gradient: difference between highest and lowest points divided by length of the runway

Altitude (Elevation)

- Higher altitude require longer runway length
- Increase not linear but varies with temperature
- Rate of increase higher at higher altitudes and vice versa
- Increase of 7-10% per 1000 ft of altitude for most airports.

Condition of Runway Surface

- Presence of water or slush (reduce braking resistance)
- Jet operations are limited to 0.5 inch of slush or water
- From 0.25 to 0.5 in of slush, take off weight must be substantially reduced to over come the retarding force of water and slush.
- Velocity at which hydroplaning develops:
  - For tire pressure range 120-200 psi, Vp range from 110 to 140 mph (usual landing and take off speed)

$$Vp = 10^* \text{ (tire pressure)}^{0.5}$$

Condition of Runway Surface

- Hydroplaning
  - No resistance between tyre and runway surface
  - Aquaplaning or hydroplaning by the tires of a road vehicle, aircraft or other wheeled vehicle occurs when a layer of water builds between the wheels of the vehicle and the road surface, leading to a loss of traction that prevents the vehicle from responding to control inputs.

Summary of Correction Factors

- Increase the required runway length at the rate of 7% for each 300 m (1000 ft) airport elevation above mean sea level

  – Elevation factor, Fe = 0.07*E+1

Where E is airport elevation above MSL in units of 300 m (1000 ft)

Summary of Correction Factors

- The length corrected for elevation is to be further increased at a rate of 1% for each degree centigrade by which the airport Reference temperature exceeds the Standard temperature at the elevation of the airport side.
- Reference temperature (T) is defined as

$$T = T_1 + (T_2 - T_1)/3$$

Summary of Correction Factors

- T_1- mean of mean daily temperature for the hottest month of the year (hottest month has highest mean daily temperature)
- T_2- Mean maximum daily temperature for the same month
- Standard temperature at the airport site can be determined by reducing the standard temperature at MSL (15ºC) at the rate of 6.5ºC per 1000 m or 1.981ºC per 1000 ft rise in the airport elevation

Summary of Correction Factors

- Temperature correction Ft is computed through the following equation
  - Ft = 0.01[T-(15-6.5*E)] + 1 (in meters)
  - Ft = 0.01[T-(15-1.981*E)] + 1 (in feet)
- Where E is airport elevation

Correction for Gradient

- The runway length having been corrected for elevation and temperature be further increased at a rate of 10% for each 1% of the runway Effective Gradient (G)

$$G = (RL_{max} - RL_{min})/L$$

$$F_g = 0.1*G+1$$

- Where RL_{max} and RL_{min} are the reduced levels of the highest and lowest points along the runway centre line

Problem

- Find out the length of runway having field length of 1800 m. The airport is located 450 m above mean sea level. The runway effective gradient is 0.5%. The monthly mean maximum and mean daily temperature of hottest month of the year are 27 and 18 degree respectively.

Problem

- Determine the length of the runway The airport is located 1000 m above mean sea level. The runway effective gradient is 0.5%. The monthly mean maximum and mean daily temperature of hottest month of the year are 26 and 18 degree respectively.

Runway Configuration

- Runway configuration is the number and orientation of the runways and location of the terminal area relative to the runway.
- The number of runways provided at the airport depends upon the volume of traffic.
- Orientation of runways depends upon the following factors
  - Direction of prevailing wind pattern in the area
  - Size and shape of area available for air port development
  - Land use or air space restriction in the vicinity of the air port

Runway Configuration

- Runways and taxiways should be so arranged
  - Provide adequate separation between aircraft in the air traffic pattern
  - Cause least interference and delay in landing, taxing and take off operations
  - Provide shortest taxi distance from terminal areas to the ends of the runways
  - Provide adequate taxiways so that the landing aircraft can exit the runway as quickly as possible and follows the shortest possible route to the terminal area.

Types of Runway Configurations

- Single runway
- Parallel runway
- Open V runways
- Intersecting runways
- Combination of runway configurations

Types of Runway Configurations

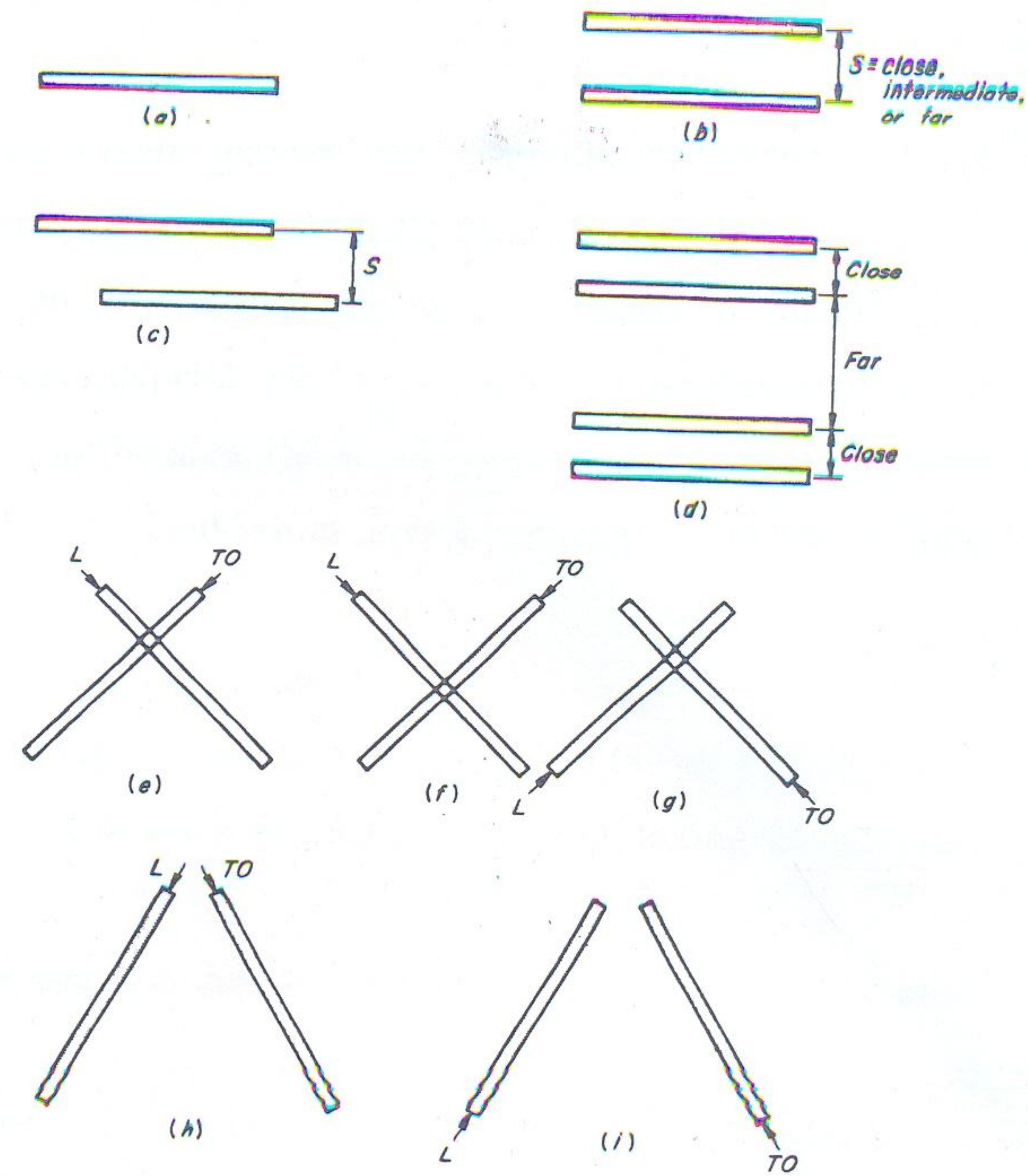
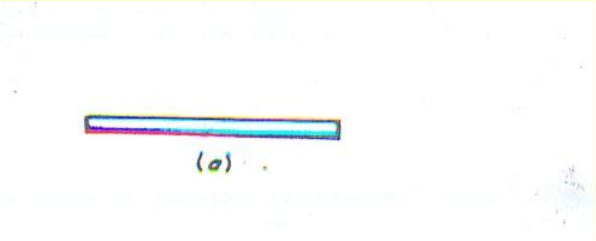


Figure 7-1 Typical runway configurations: (a) Single runway; (b) two parallel runways—even threshold; (c) two parallel runways—staggered threshold; (d) four parallel runways; (e) intersecting runways; (f) intersecting runways; (g) intersecting runways; (h) open-V runways; (i) open-V runways.

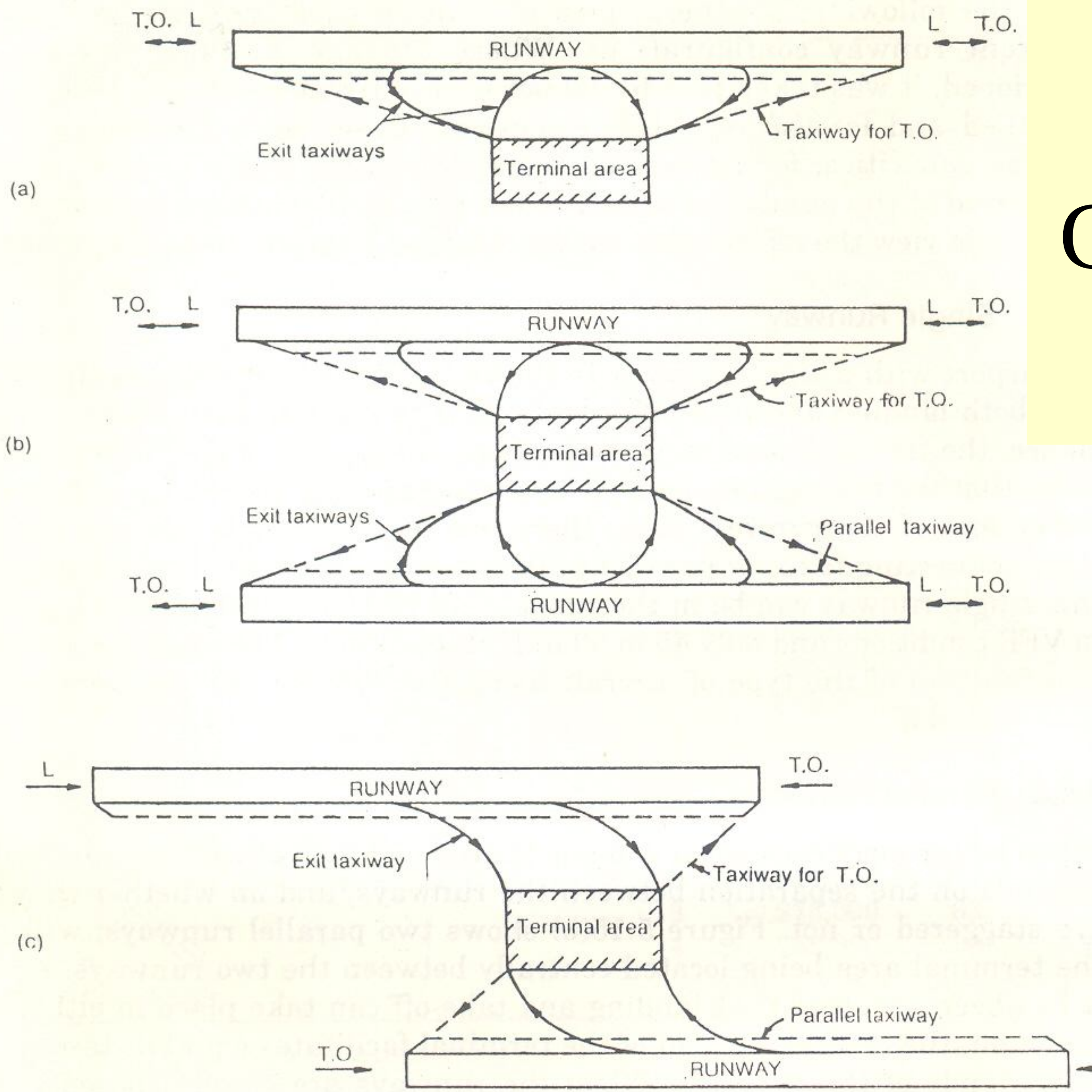
Single Runway

- One runway positioned optimally for prevailing wind direction and other determining factors



Single Runway

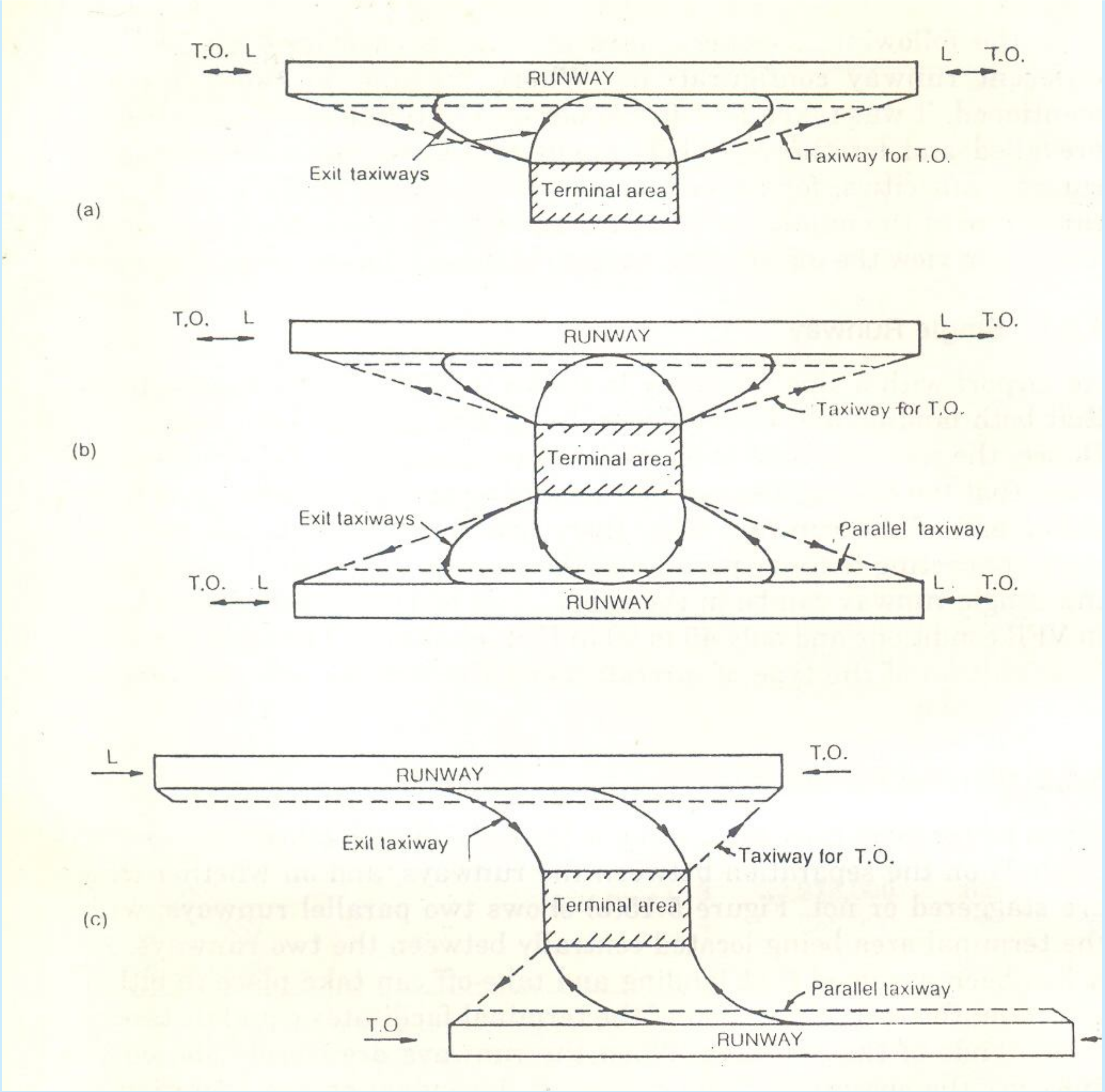
- One runway positioned optimally for prevailing wind direction and other determining factors
- During VFR (visual flight rules) conditions, single runway should accommodate upto 99 light aircraft operations per hour.
- While under IFR (instrumental flight rules) it should accommodate 50 to 70 operations per hour depending upon traffic mix and navigational aids.



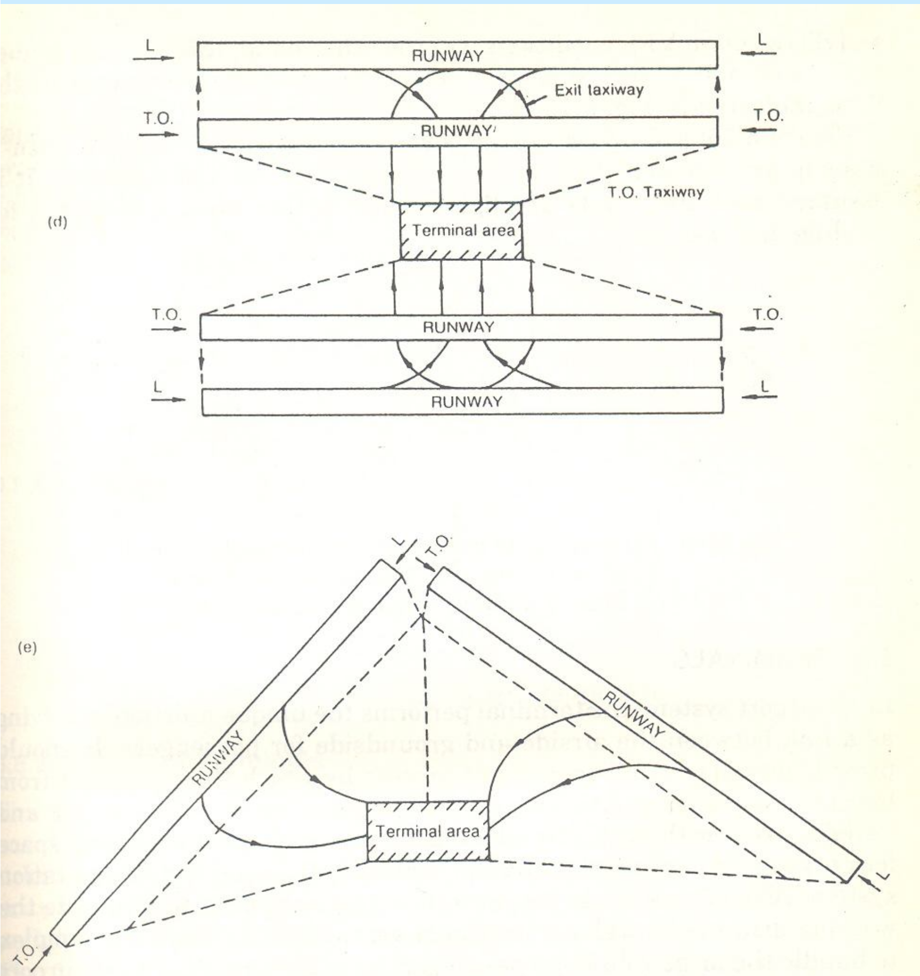
Runway Configuration

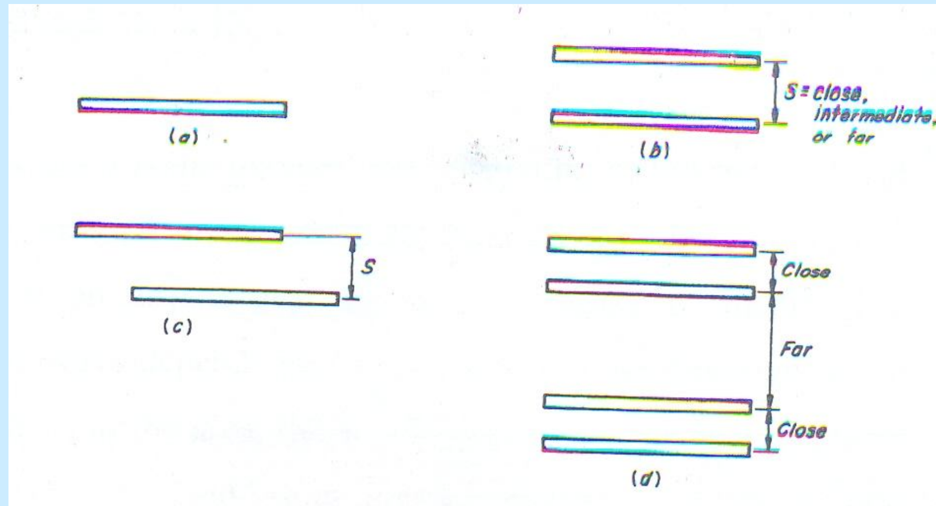
Parallel Runways

- Four types of parallel runways
  - Close Parallel- less than 2500 ft between runways
  - Intermediate runways- 2500 to 4300 ft
  - Far parallel- 4300 ft or greater in between runways
  - Dual line runway – 4300 ft or more between each pair
- Named accordingly how closely they are placed next to each other.
- Operations per hour will vary depending on total number of runways and the type of aircraft.
- In IFR condition for predominantly light aircraft, the number of operations would range between 64 to 128 per hour.


T.O. L
L T.O.
RUNWAY
Exit taxiways
Taxiway for T.O.
Terminal area
(a)
T.O. L
L T.O.
RUNWAY
Taxiway for T.O.
(b)
Terminal area
Exit taxiways
Parallel taxiway
T.O. L
L T.O.
RUNWAY
L
T.O.
RUNWAY
Exit taxiway
Taxiway for T.O.
Terminal area
(c)
Parallel taxiway
T.O
RUNWAY

Parallel Runways and Intersecting Runway





Parallel Runways

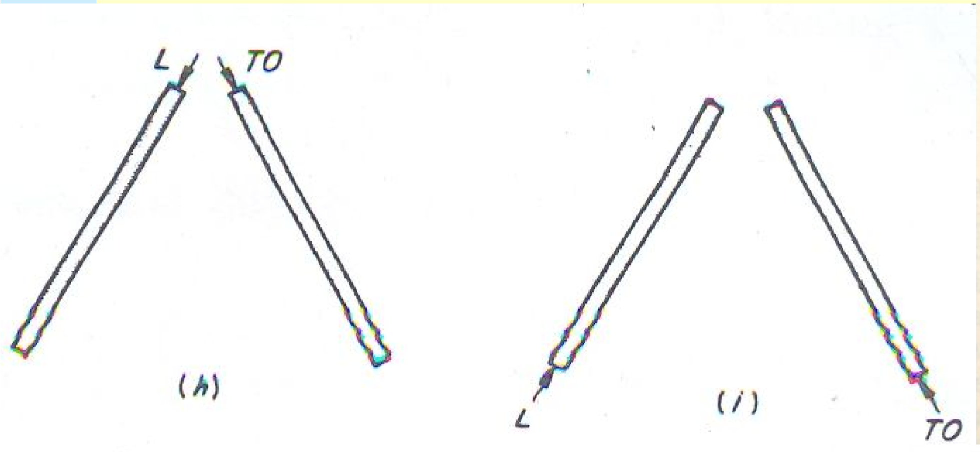
- Safety and the effect on the runway capacity depends upon the separation of parallel runways.
- Spacing of the runways depends upon
  - Whether operations are VFR or IFR
  - Simultaneous or staggered use of runways

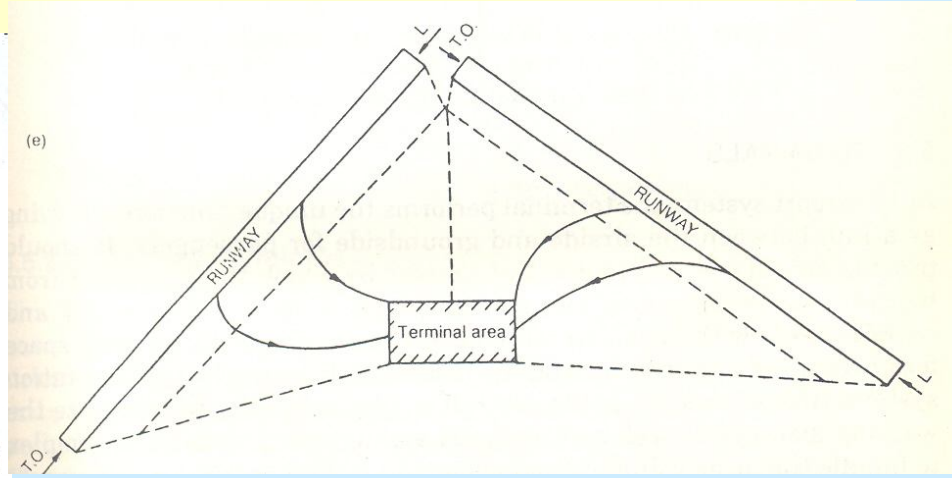
Open V Runways

- Two runways that diverge from different directions but do-not intersect form a shape that look like an open-V
- This configuration is useful when there is no wind as it allows for both runways to be used at the same time.
- When wind becomes strong in one direction only one runway is used at a time

Open V Runways

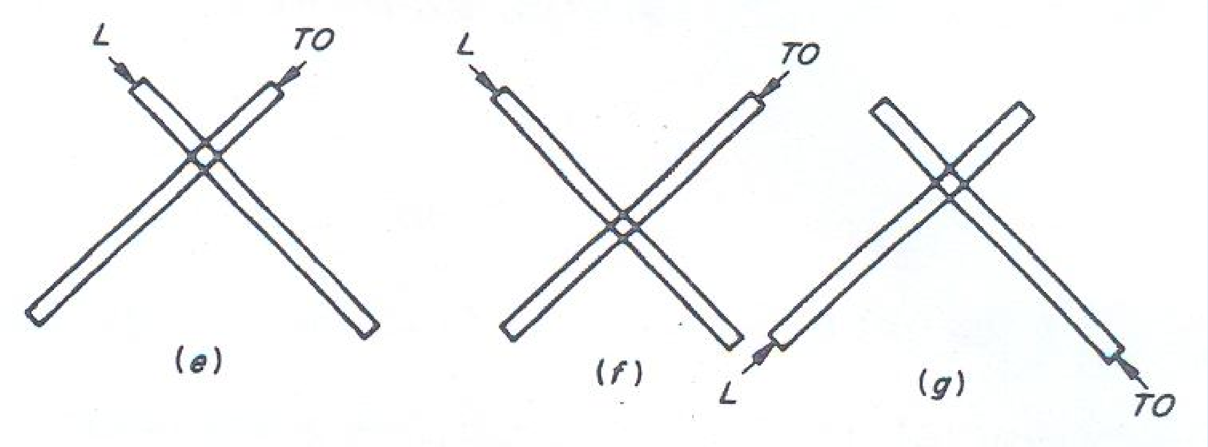
- When landing and take off are made away from two closer ends, the number of operation per hour significantly increases.
- When take and landing are made towards the two closer ends the number of operations per hour can be reduced by 50%.





Intersecting Runways

- This type of configuration is used when there are relatively strong prevailing wind in more than one direction during the year.
- When the winds are strong in one direction, operation will be limited only to one runway
- Capacity depend upon the location of intersection and the manner in which runways are operated (IFR, VFR, aircraft mix).
- This also use a great amount of land area than parallel runway configuration.



Combinations of runway configurations

- Single direction is most desirable in terms of capacity and traffic control
- Routing of aircraft in one direction is less complex than in multiple directions
- Open V runways is more desirable than intersecting runways
- For intersecting runway place the point of intersection close to the threshold (landing & take off)

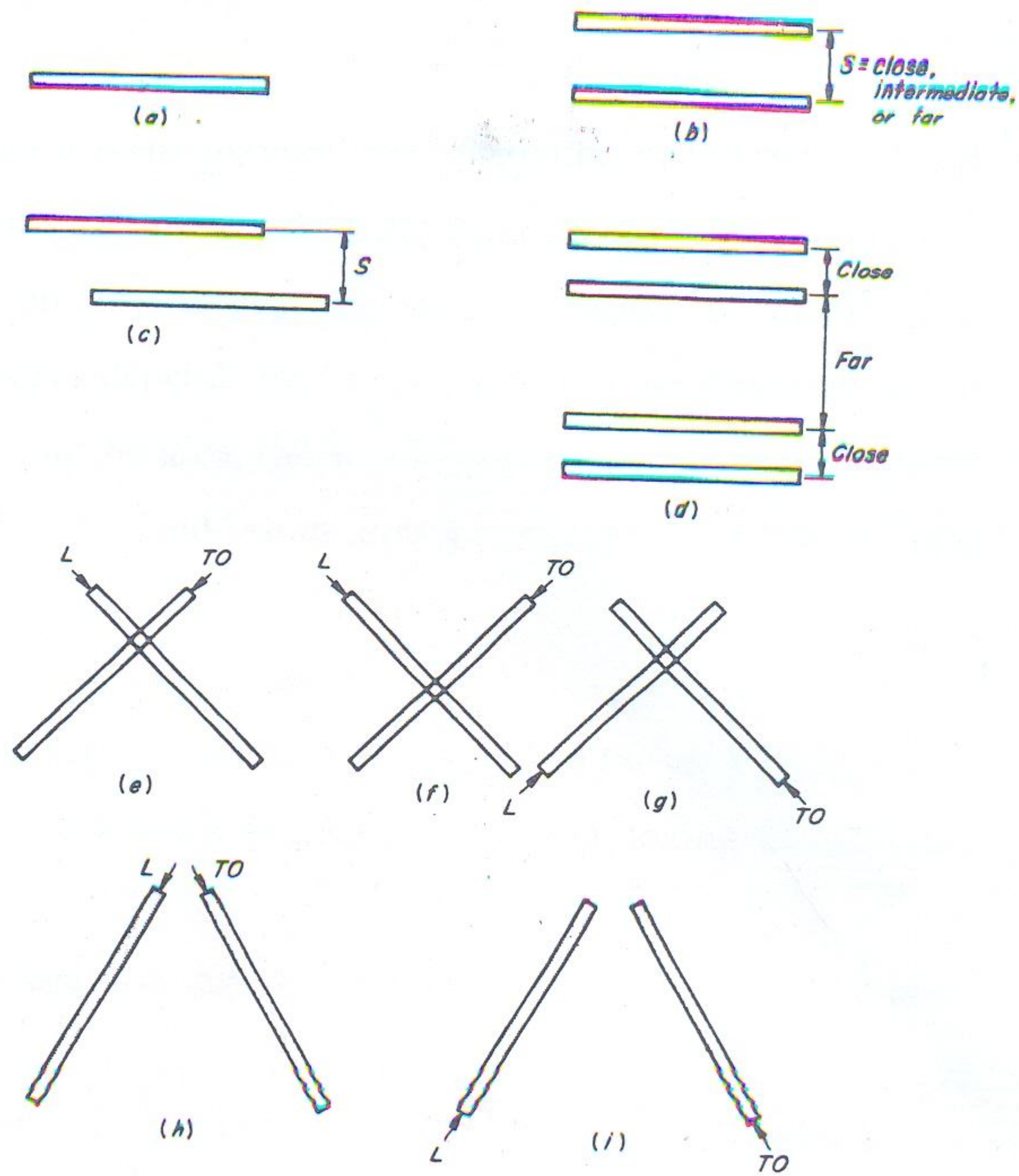


Figure 7-1 Typical runway configurations: (*a*) Single runway; (*b*) two parallel runways—even threshold; (*c*) two parallel runways—staggered threshold; (*d*) four parallel runways; (*e*) intersecting runways; (*f*) intersecting runways; (*g*) intersecting runways; (*h*) open-V runways; (*i*) open-V runways.