Airport Pavement Design

Workshop & Lectures on Pavement Engineering, Maintenance and Management

References

- *Principles of Pavement Design*, Yoder and Witczak, 1975
- Advisory Circular – AC 150/5320-6D,

  Airport Pavement Design and Evaluation
- Asphalt Institute, Manual Series No.11, *Thickness Design: Aspahlt Pavements for Air Carrier Airports*

Airport and Highway Pavements

- Load repetitions
- Geometry of pavement
- Distribution of traffic

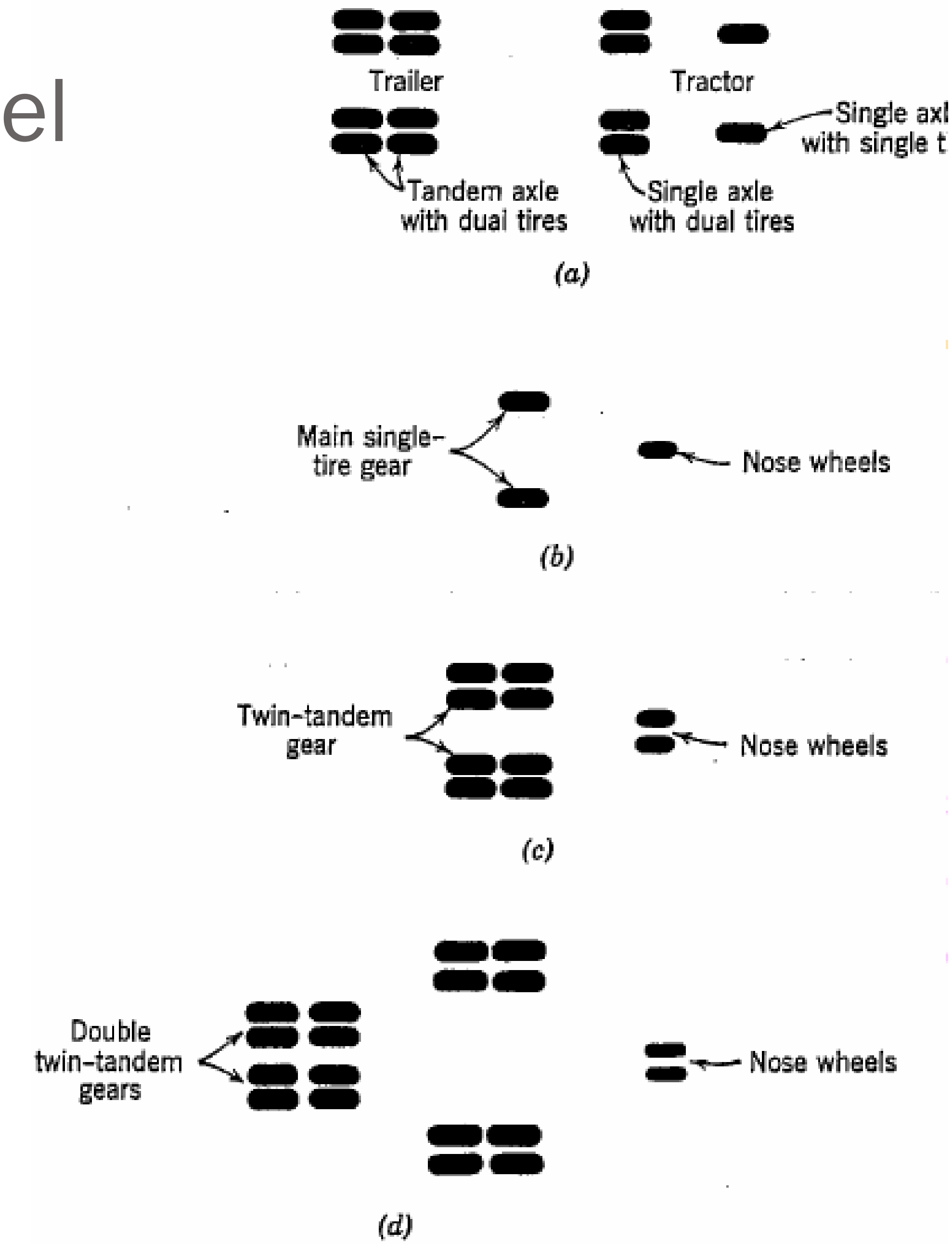
Affected by pavement width and type of aircraft

Airport and Highway Pavements Comparison

Consideration	Highway	Airport
Rigid pavement	Show pumping	Little or no pumping
Flexible pavement	Serious distress at pavement edges	No serious distress at pavement edges
Load magnitude	Lower	Higher
Load repetitions	Higher	Lower
Design load	9,000 lbs on dual tires 1,000-2,000 trucks per day	100,000 lbs wheel load 20,000-40,000 coverages per life time
Tire pressure	60-90 psi	400 psi (jet aircraft)
Traffic distribution	3-4 ft. from edge	center
Geometry	12-24 ft.	Runway 150-500 ft. wide Taxiway 20-100 ft. wide

Basic types of wheel configuration

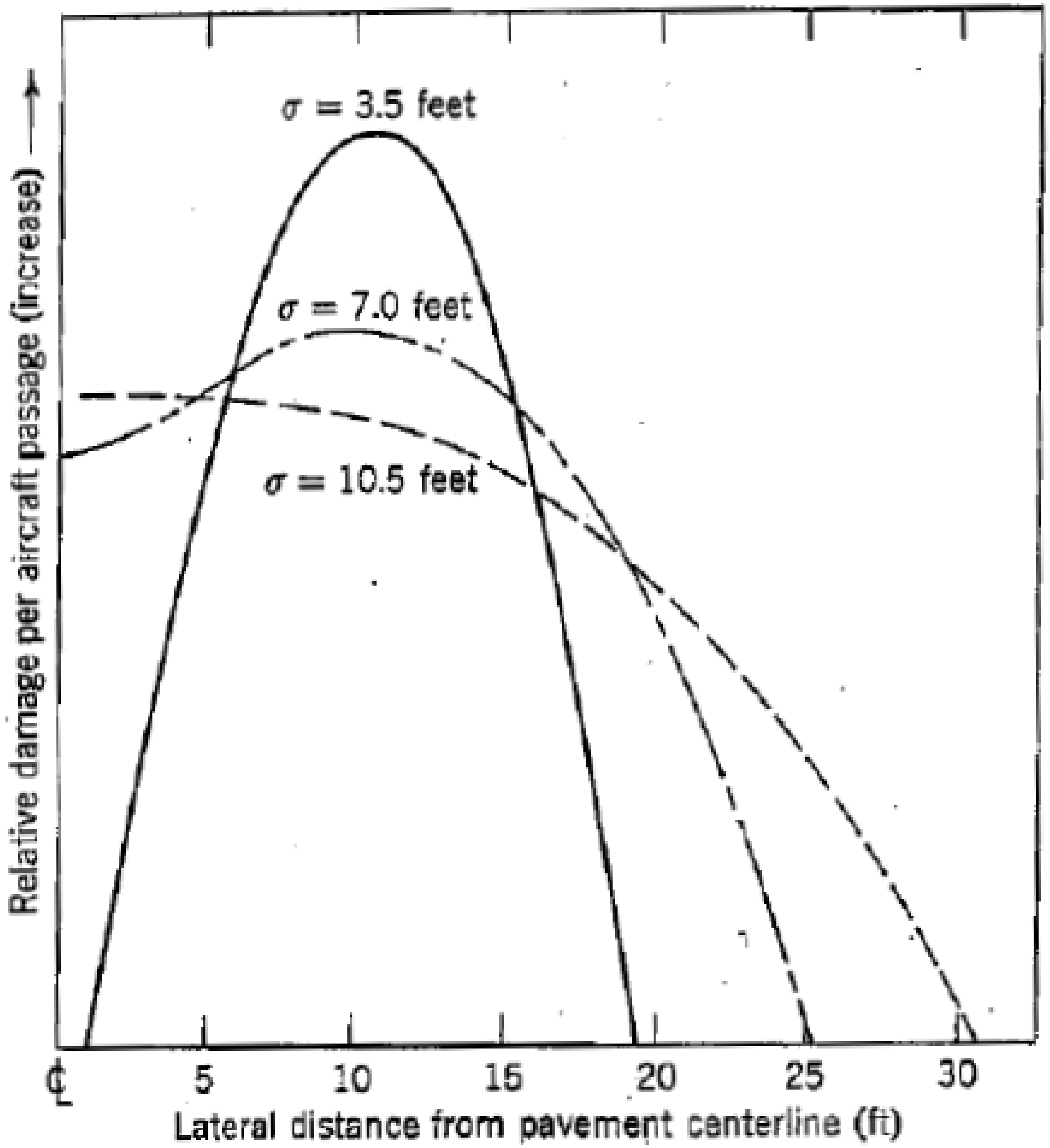
a) Single trailer-truck unit
b) Tricycle landing gear with single tires
c) Twin-tandem landing gear
d) Double twin-tandem gear



Several Typical Aircraft

Type of Plane	Max Gross Weight (lb × 10³)	Type of Gear	Main Gear Dimension (in.)	Max Load Each Main Assembly (lb × 10³)	Tire Pressure (psi)
Boeing 707-320C	336.0	Twin-tandem	56 × 34.5	157.0	180
Boeing 707-120B	258.0	Twin-tandem	56 × 34	120.0	170
Boeing 737	111.0	Twin	30.5	25.8	148
Boeing 727-100	170.0	Twin	34.0	76.9	166
Boeing 747	713.0	Double twin-tandem	58 × 44	166.5	204
Convair Cv 880	185.0	Twin-tandem	45 × 21.5	87.0	150
Lockheed L1011-I	411.0	Twin-tandem	70 × 52	195.0	175
McDonnel–Douglas DC10-10	413.0	Twin-tandem	54 × 64	194.0	175
McDonnel–Douglas DC 8-43	318.0	Twin-tandem	55 × 30	148.0	177
McDonnel–Douglas DC 9-15	91.5	Twin	24	42.4	127
Concorde	388.0	Twin-tandem	66 × 26.4	184.3	184
BAC 1-11-500	100.0	Twin	21	47.5	174

Aircraft Wander on Pavement Damage

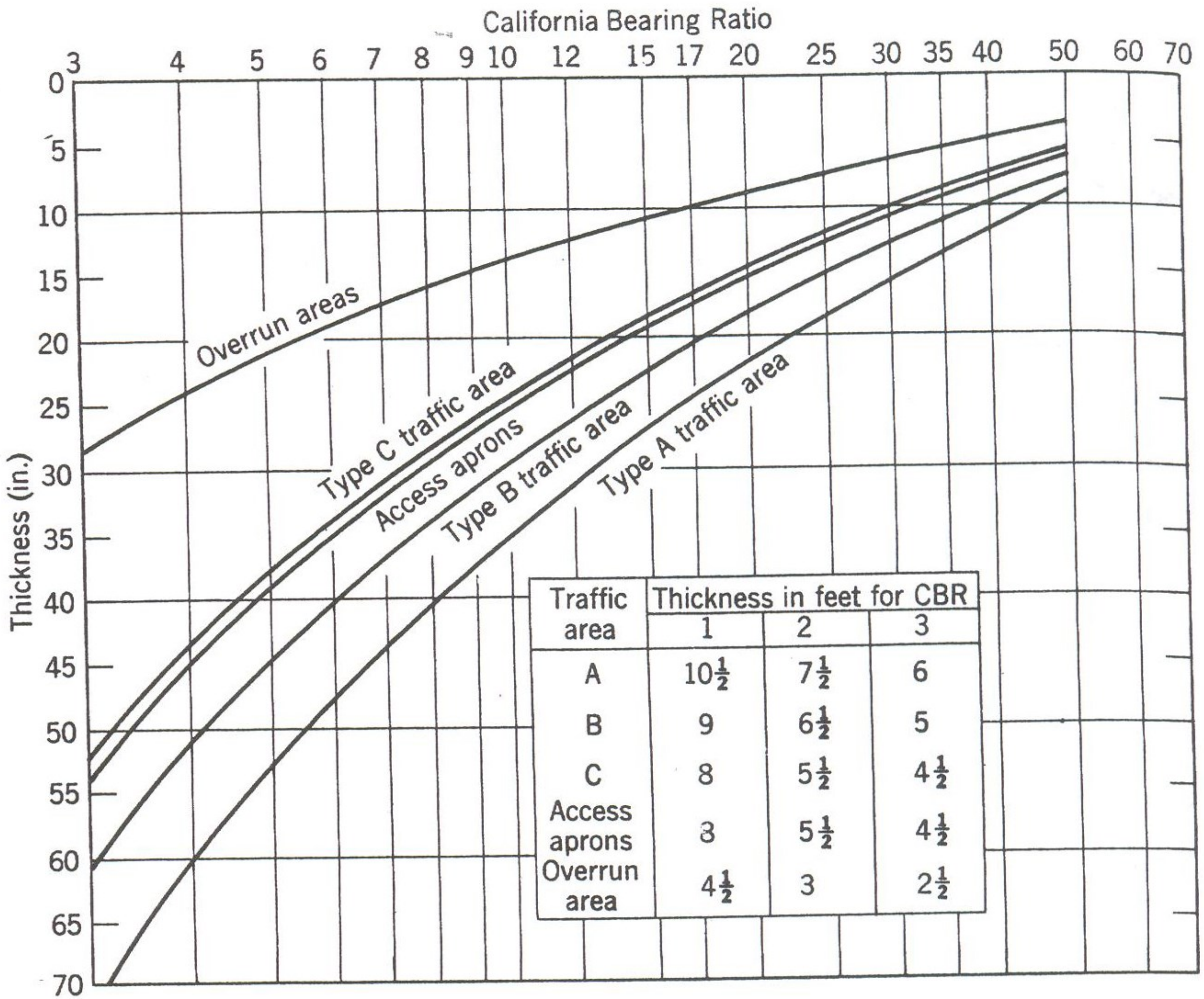


Flexible Pavement Design

Flexible Airport Pavement Design

a) Corps of Engineers-CBR analysis
b) Canadian Department of Transportation (CDOT)
c) Federal Aviation Administration (FAA) method
d) Asphalt Institute method

a) Corps of Engineers (CBR) Method



Traffic area	Thickness in feet for CBR		
	1	2	3
A	10½	7½	6
B	9	6½	5
C	8	5½	4½
Access aprons	8	5½	4½
Overrun area	4½	3	2½

Figure 14.6. Flexible-pavement design curves for medium-load pavement—twin wheels, 37-inch spacing, $A_c = 267$ in.^{2} (From TM 5-824-2/AFM 88-6, Chapter 2.)

b) CDOT Method

- Investigate load-carrying capacity by plate-bearing tests.
- N.McLeod developed emprirical based thickness design equation.
- Effects of frost are accounted.

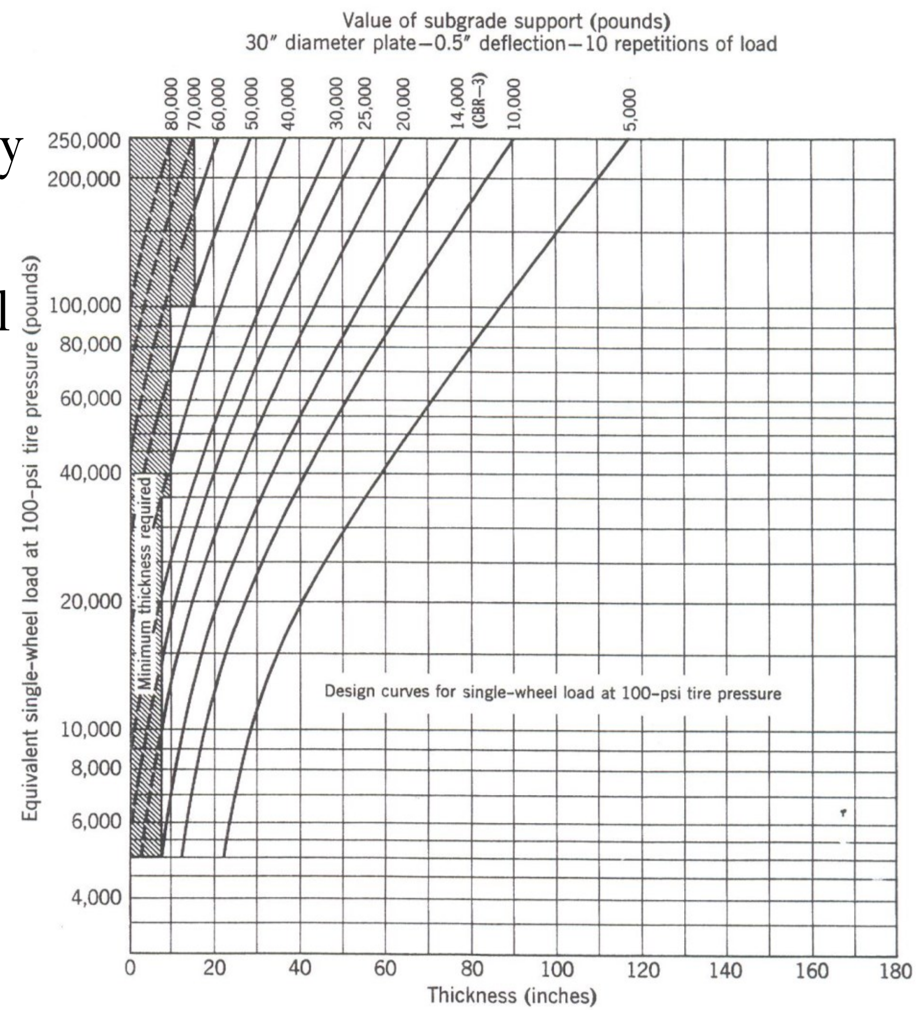


Figure 14.23. Flexible-pavement thickness chart. (From McLeod, *Proceedings*, AAPT, 1956.)

c) FAA Method

- Advisory Circular – AC 150/5320-6D,
  Airport Pavement Design and Evaluation
- Field performance data correlated to soil classification
- Applicable to aircraft with gross weight in excess of 30,000 lbs (13,000 kg).

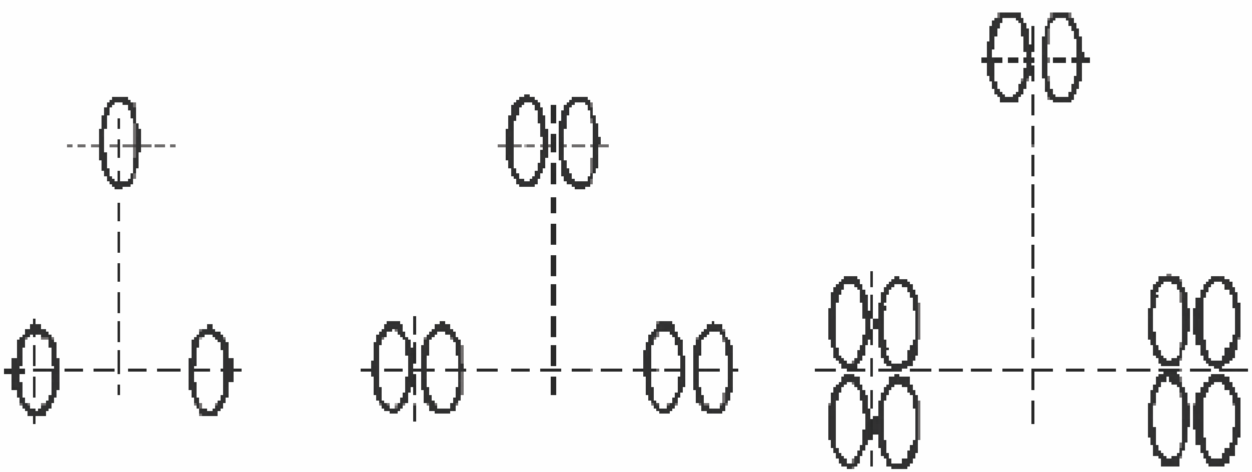
Aircraft Considerations

- Load (95% main landing gear, 5% nose gear)
- Landing gear type and geometry
  - Single gear aircraft
  - Dual gear aircraft
  - Dual tandem gear aircraft
  - Wide body aircraft (B-747, B-767, DC-10, L-1011)
- Tire pressure: 75-200 psi (515-1,380 kPa)
- Traffic Volume

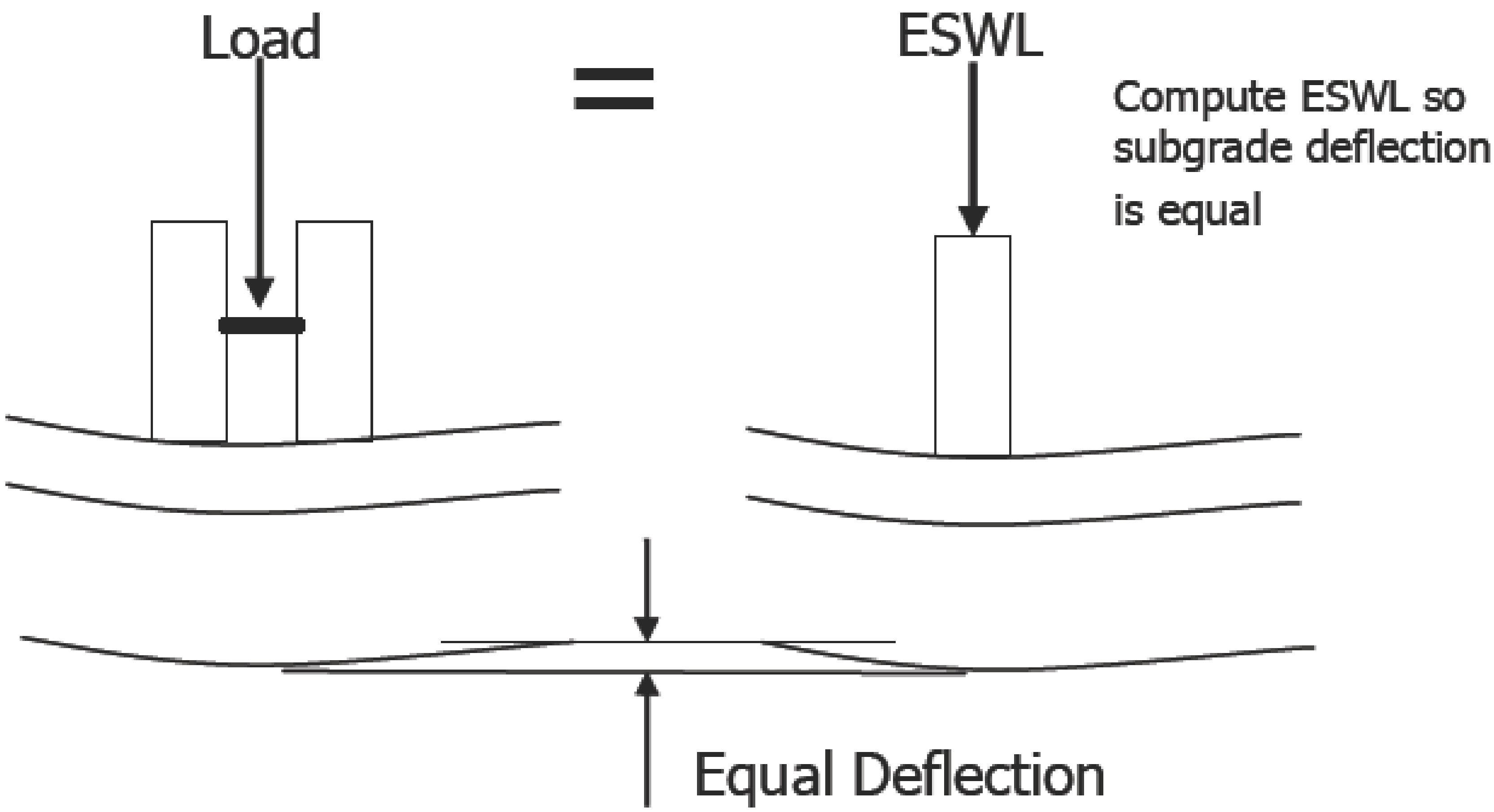
AC 150/5320-6D

The standard CBR procedure was originally developed for a single wheel load and was "expanded" in 1945 to address dual wheel gears and dual tandem gears by the "Equivalent Single Wheel Load" (ESWL)

Basic Gear Configurations



Equivalent Single Wheel Load (ESWL)



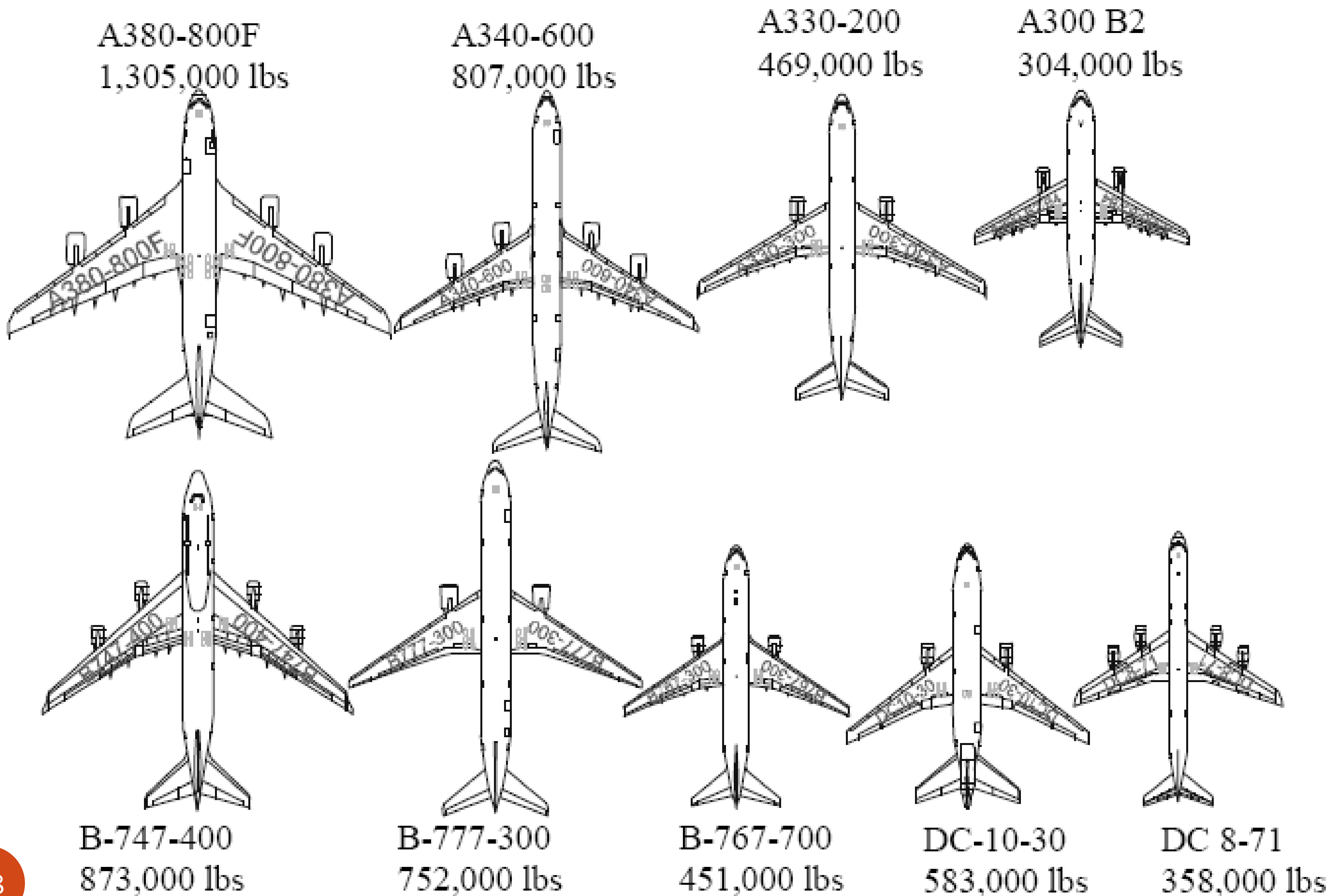
AC 150/5320-6D

The landing gear for the B-777 airplane was a unique configuration which did not appear to be correctly represented by the CBR design procedure

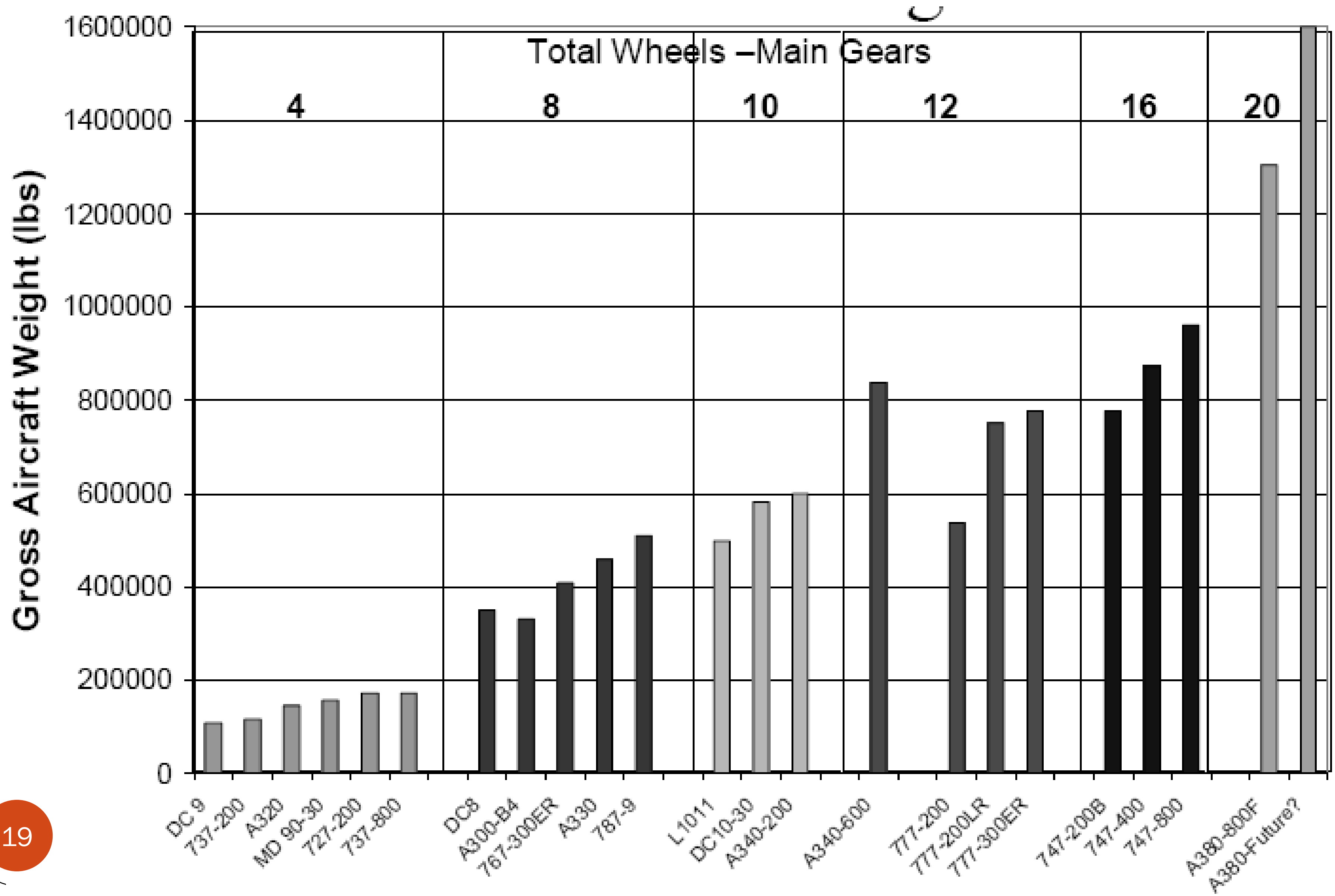
It was felt that the CBR procedure was unduly conservative for this gear configuration

Increased Loading Gear Complexity

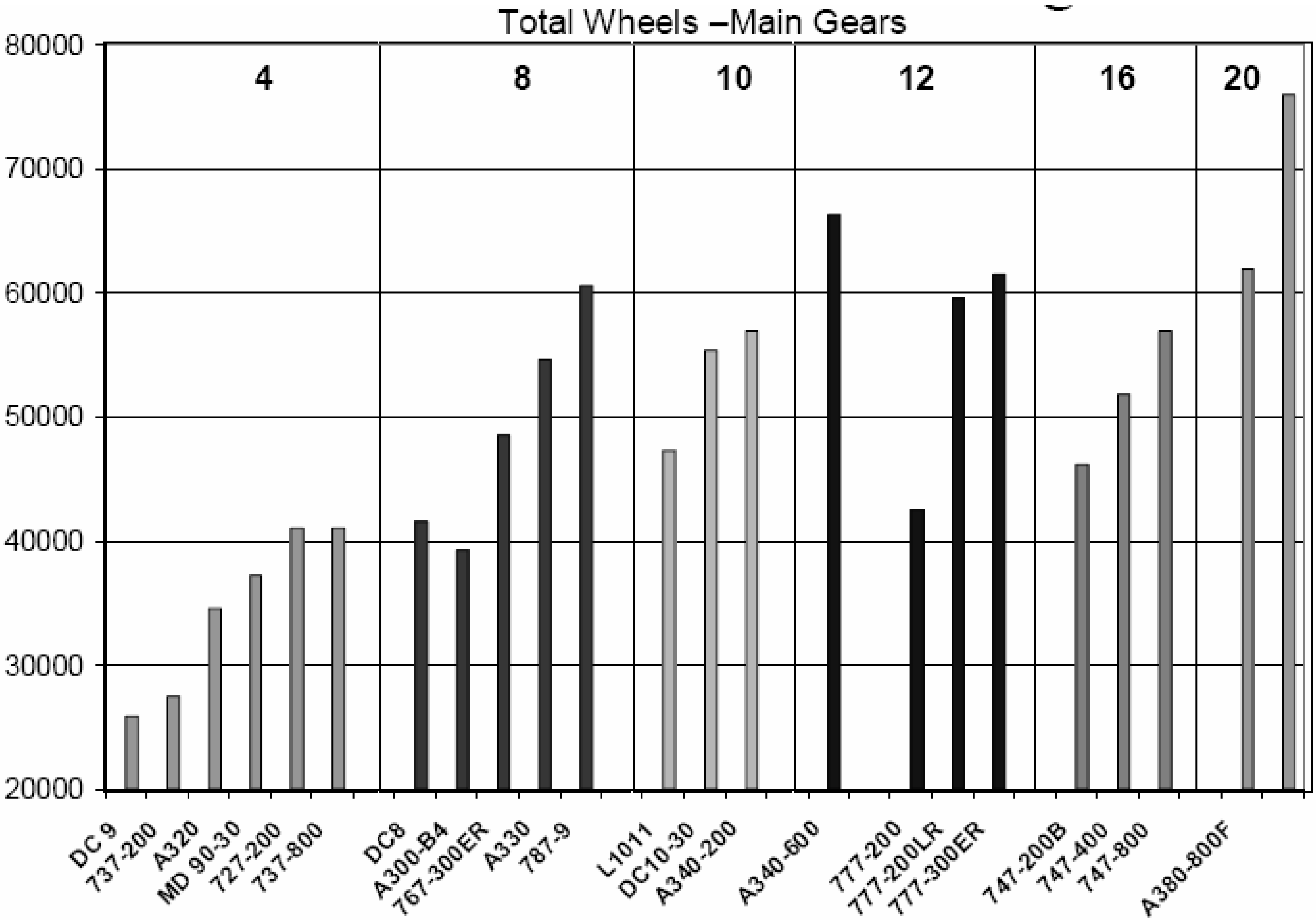
Aircraft Size



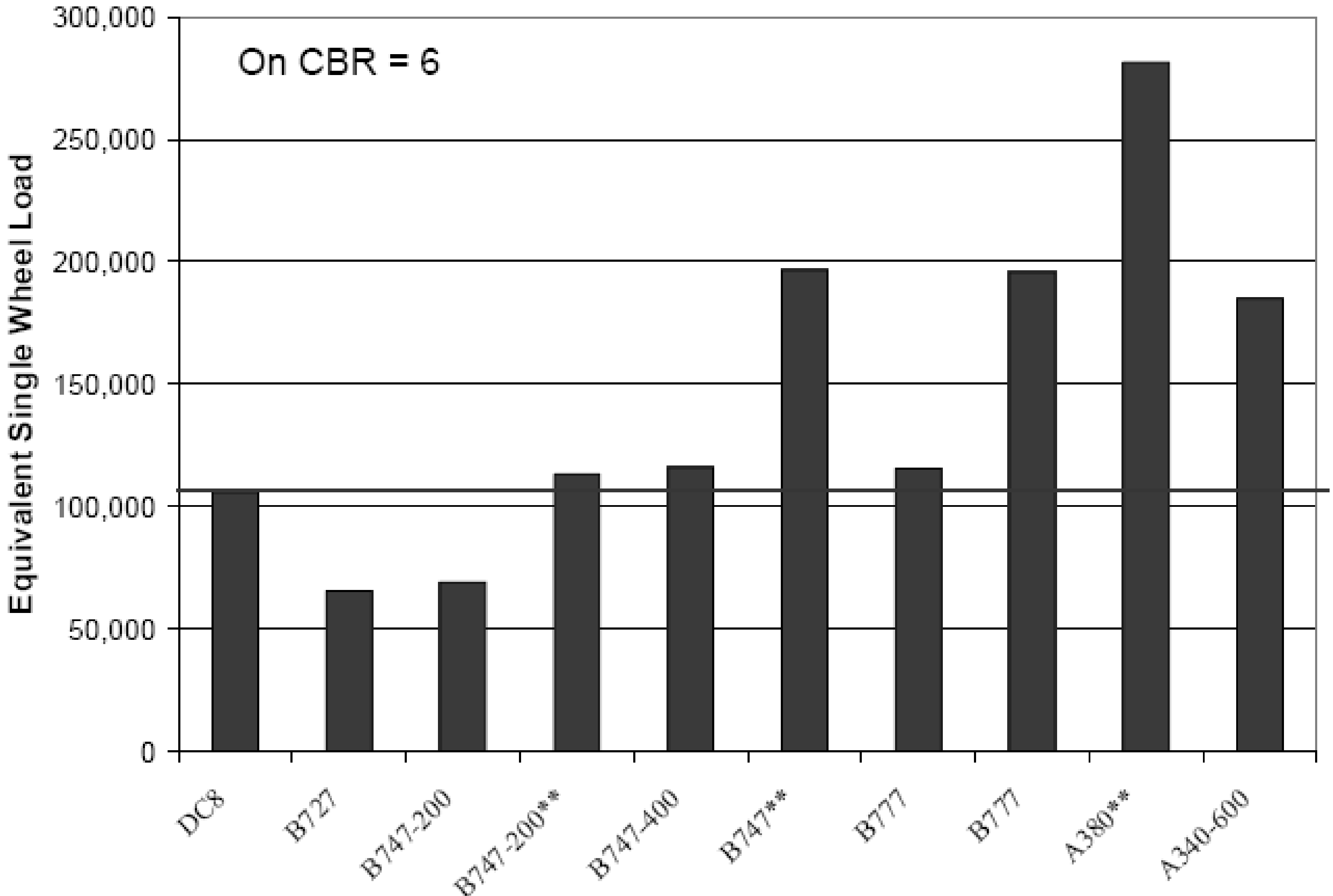
Gross Aircraft Weight



Gross Aircraft Weight



Equivalent Single Wheel Load



** analysis assuming interaction between all wheels

New Procedure Needed

For unique pavement loading characteristics of new aircraft
→ Boeing B-777 or Airbus A380

New Design Procedures

- In the early 1990's, FAA pursues new pavement design procedures to address complex gear configurations and increases in aircraft weight
- In October 1995, FAA published AC 150/5320-16, Airport Pavement Design for the Boeing 777 Airplane.

FAA Design Procedure

- Select design aircraft which procuces the greatest pavement thickness
- Forecast number of annual departures for that aircraft
- Convert other aircrafts to the same landing gear type as the design aircraft

Find Equivalent Annual Departures by Design Aircraft

Conversion factors to convert from one landing gear type to another

To Convert From	To	Multiply Departures by
single wheel	dual wheel	0.8
single wheel	dual tandem	0.5
dual wheel	dual tandem	0.6
double dual tandem	dual tandem	1.0
dual tandem	single wheel	2.0
dual tandem	dual wheel	1.7
dual wheel	single wheel	1.3
double dual tandem	dual wheel	1.7

Conversion to Equivalent Annual Departure of Design Aircraft

$$\log R_1 = \log R_2 \times \left(\frac{W_2}{W_1}\right)^{\frac{1}{2}}$$

R_1= equivalent annual departures by the design aircraft
R_2= annual departures expressed in design aircraft landing gear
W_1= wheel load of the design aircraft
W_2= wheel load of the aircraft in question

Treated each wide body aircraft as 300,000 lbs dual tandem aircraft

Example

727-200 requires the greatest pavement thickness and thus is the design aircraft

Aircraft	Gear type	Avg. ann depart.	Max. takeoff Weight (lbs)	Equiv. dual gear depart	Wheel load (lbs)	Wheel load Design aircraft (lbs)	Equiv. ann. depart. design aircraft
727-100	Dual	3760	160,000	3760	38,000	45,240	1,891
727-200	Dual	9080	190,500	9080	45,240	45,240	9,080
707-320B	Dual tandem	3050	327,000	5185	38,830	45,240	2,764
DC-9-30	Dual	5800	108,000	5800	25,650	45,240	682
CV-880	Dual tandem	400	184,500	680	21,910	45,240	94
737-200	dual	2650	115,500	2650	27,430	45,240	463
L-1011-100	Dual tandem	1710	450,000	2907	35,625	45,240	1,184
747-100	Double dual tandem	85	700,000	145	35,625	45,240	83

Total = 16,241

300,000x0.95/8

Wide body

1.7 x 85

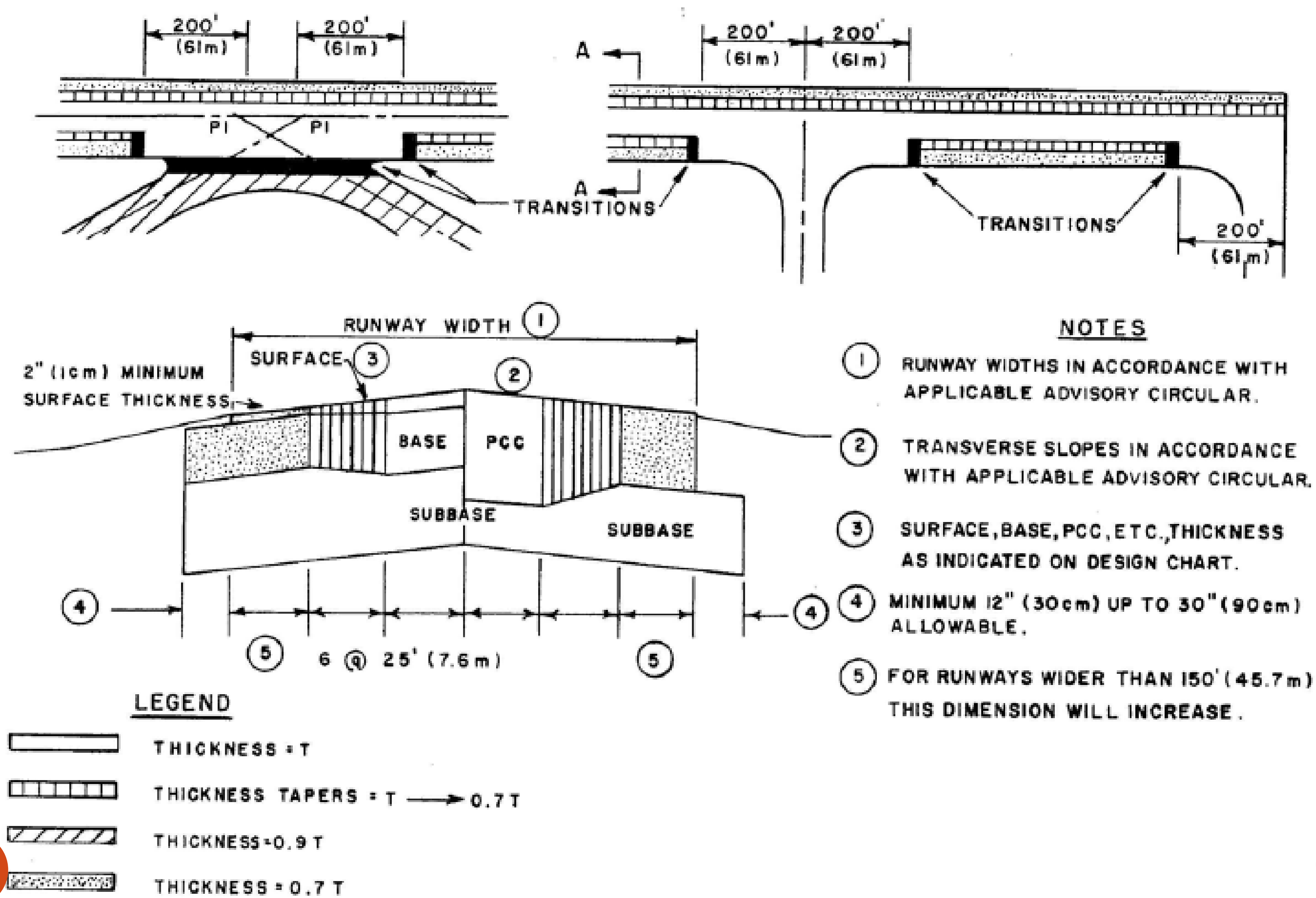
Conversion factor

190,500x0.95/4

$$\log R_1 = \log(145) \cdot \sqrt{\frac{35625}{45240}}$$

nal design: 16,241 annual departures of a dual wheel aircraft weighing 190,500lbs

Typical Design Section



FAA: Flexible Pavement Design

- HMA Surfacing: Item P-401
- Base Course:
  - Minimum CBR value of 80
  - Item P-208 – Aggregate Base Course
  - Item P-209 – Crushed Aggregate Base Course
  - Item P-211 – Lime Rock Base Course
  - Item P-304 – Cement Treated Base Course
  - Item P-306 – Econocrete Subbase Course
  - Item P-401 – Plant Mix Bituminous Pavements

FAA: Flexible Pavement Design

- Subbase:
  - Minimum CBR value of 20
  - Item P-154 – Subbase Course
  - Item P-210 – Caliche Base Course
  - Item P-212 – Shell Base Course
  - Item P-213 – Sand Clay Base Course
  - Item P-301 – Soil Cement Base Course

Items P-213 and P-301 are not recommended where frost penetration into the subbaseis anticipated

Subgrade Compaction Requirement

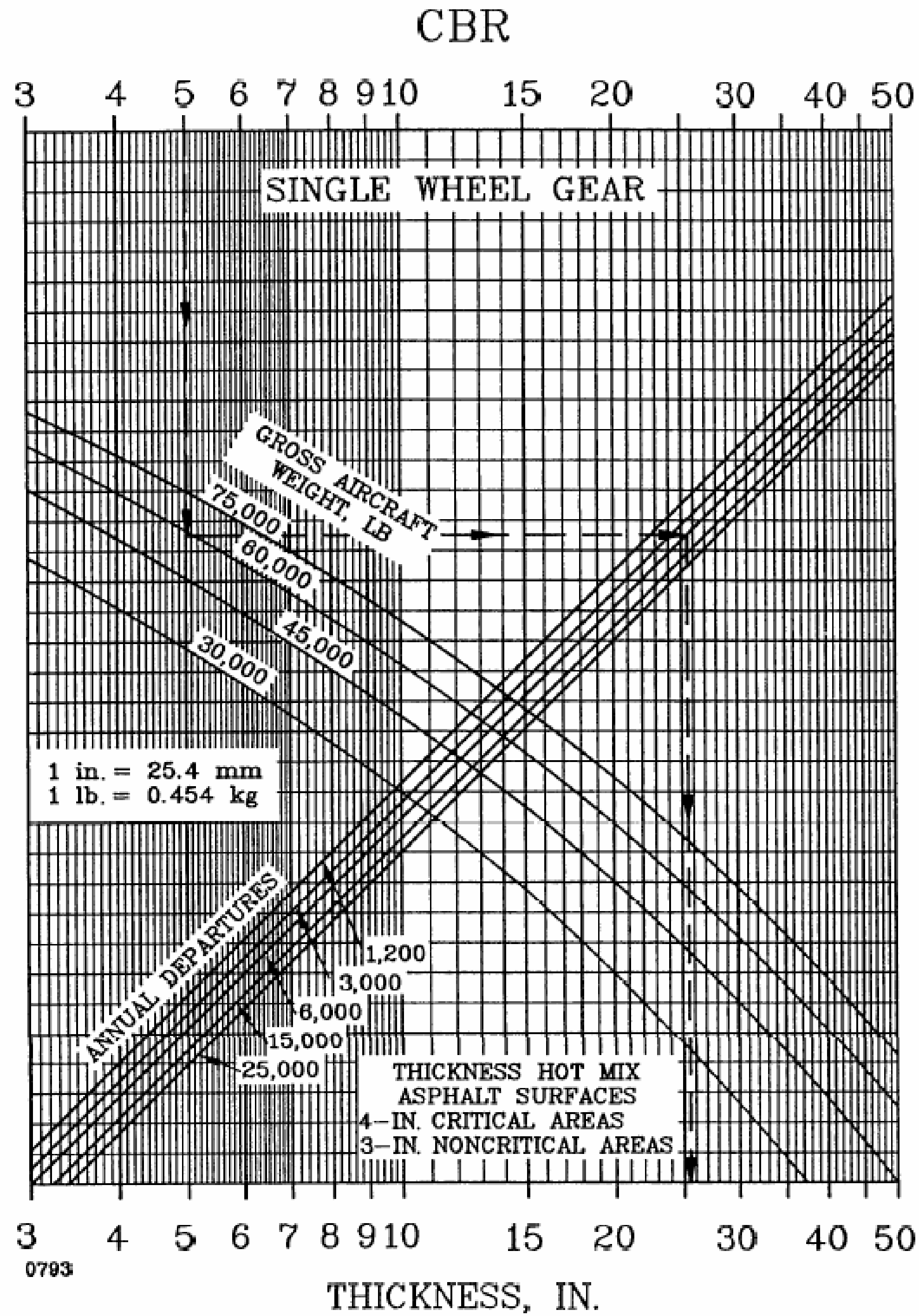
DESIGN AIRCRAFT	Gross Weight lbs.	NON-COHESIVE SOILS Depth of Compaction In.				COHESIVE SOILS Depth of Compaction In.			
		100%	95%	90%	85%	95%	90%	85%	80%
Single Wheel	30,000	8	8-18	18-32	32-44	6	6-9	9-12	12-17
	50,000	10	10-24	24-36	36-48	6	6-9	9-16	16-20
	75,000	12	12-30	30-40	40-52	6	6-12	12-19	19-25
Dual Wheel (incls. C-130)	50,000	12	12-28	28-38	38-50	6	6-10	10-17	17-22
	100,000	17	17-30	30-42	42-55	6	6-12	12-19	19-25
	150,000	19	19-32	32-46	46-60	7	7-14	14-21	21-28
	200,000	21	21-37	37-53	53-69	9	8-16	16-24	24-32
Dual Tand. (incls. 757, 767, A-300)	100,000	14	14-26	26-38	38-49	6	6-10	10-17	17-22
	200,000	17	17-30	30-43	43-56	6	6-12	12-18	18-26
	300,000	20	20-34	34-48	48-63	7	7-14	14-22	22-29
	400,000	23	23-41	41-59	59-76	9	9-18	18-27	27-36
DC-10	400,000	21	21-36	36-55	55-70	8	8-15	15-20	20-28
L1011	600,000	23	23-41	41-59	59-76	9	9-18	18-27	27-36
747	800,000	23	23-41	41-59	59-76	9	9-18	18-27	27-36

Selection of Design CBR Value

- Rule of thumb: design CBR value should be equal to or less than 85% of all subgrade CBR values
- Corresponds to a design value of one standard deviation below mean value

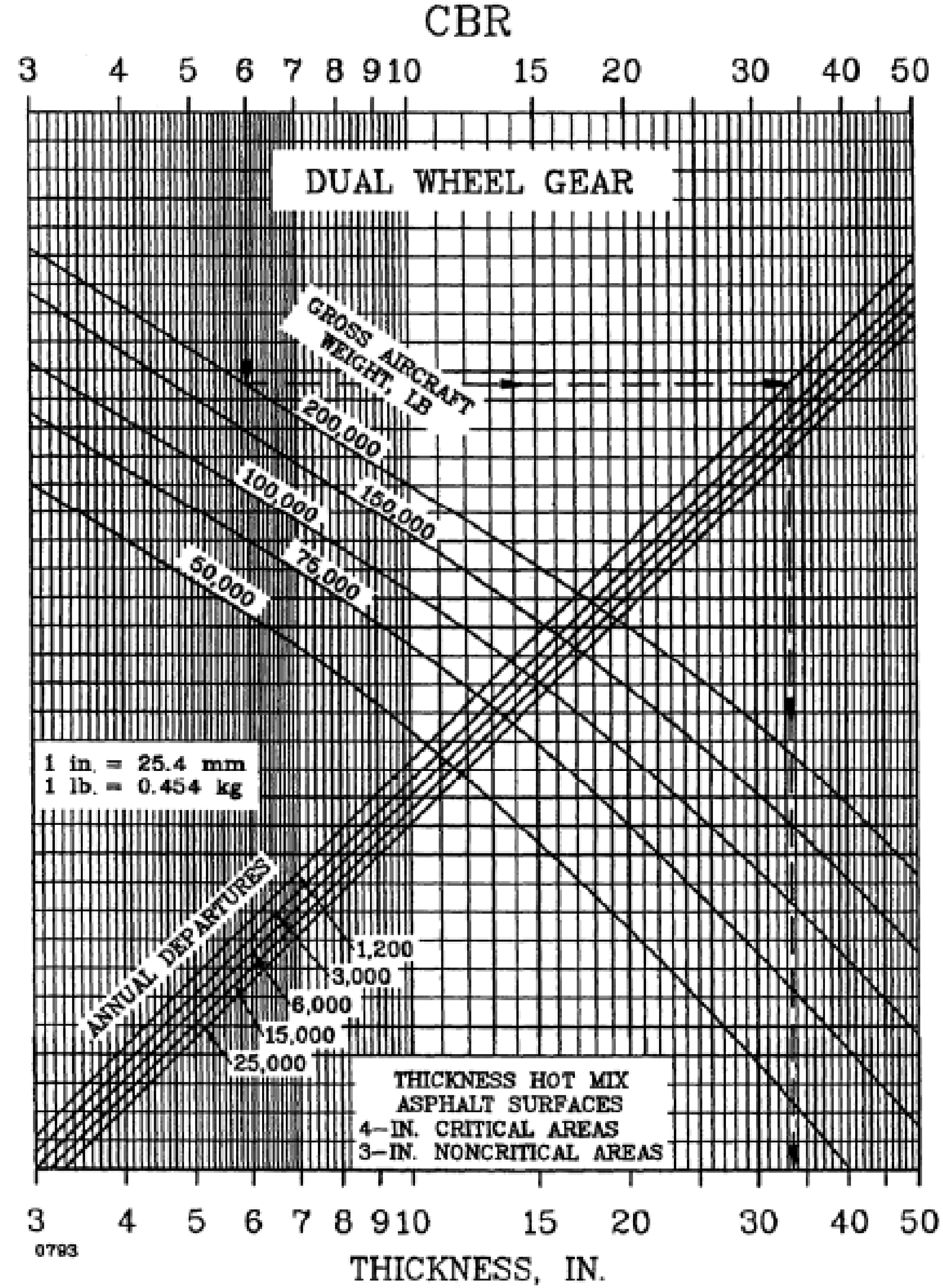
Design Curves

Single Wheel Gear



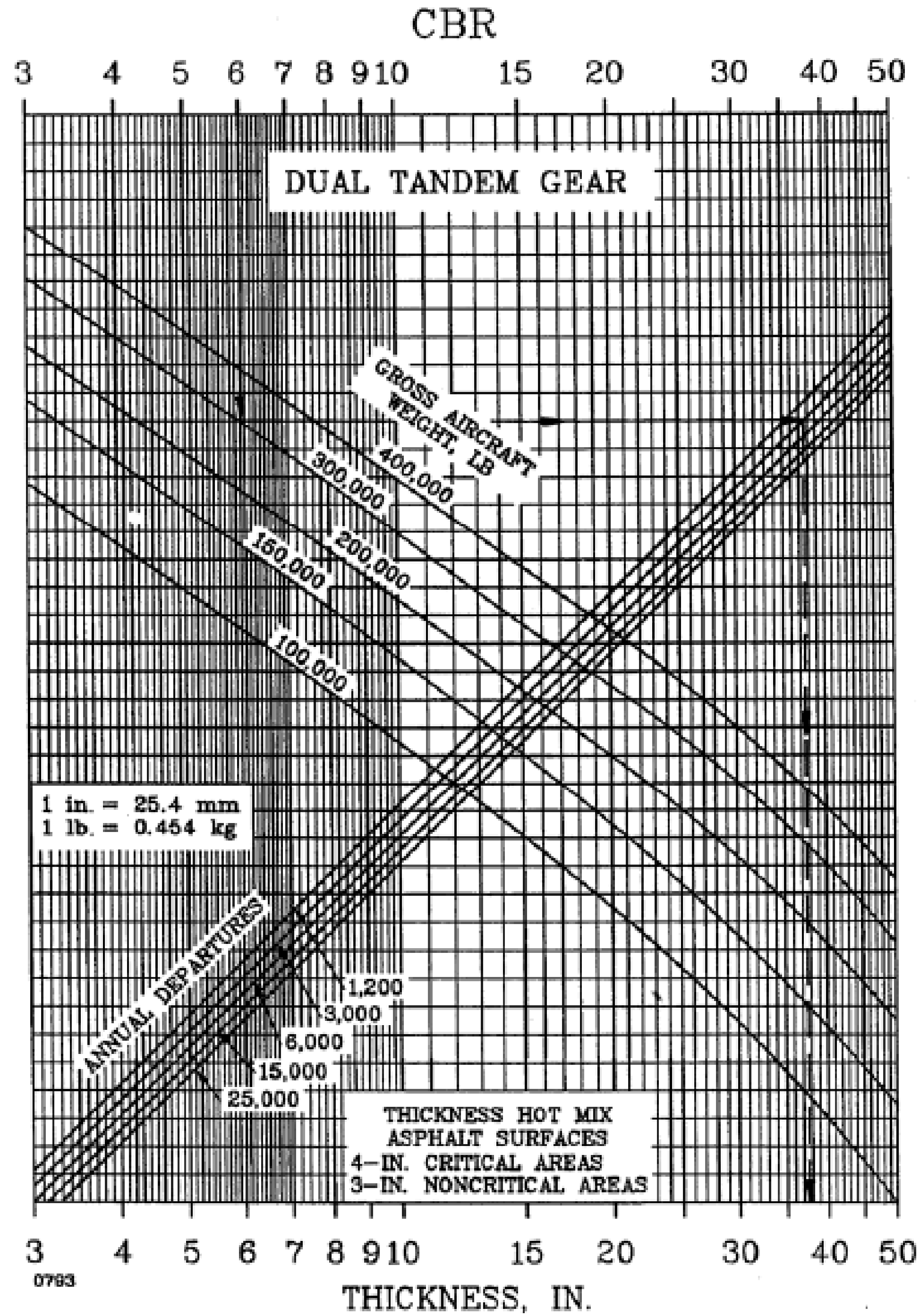
Design Curves

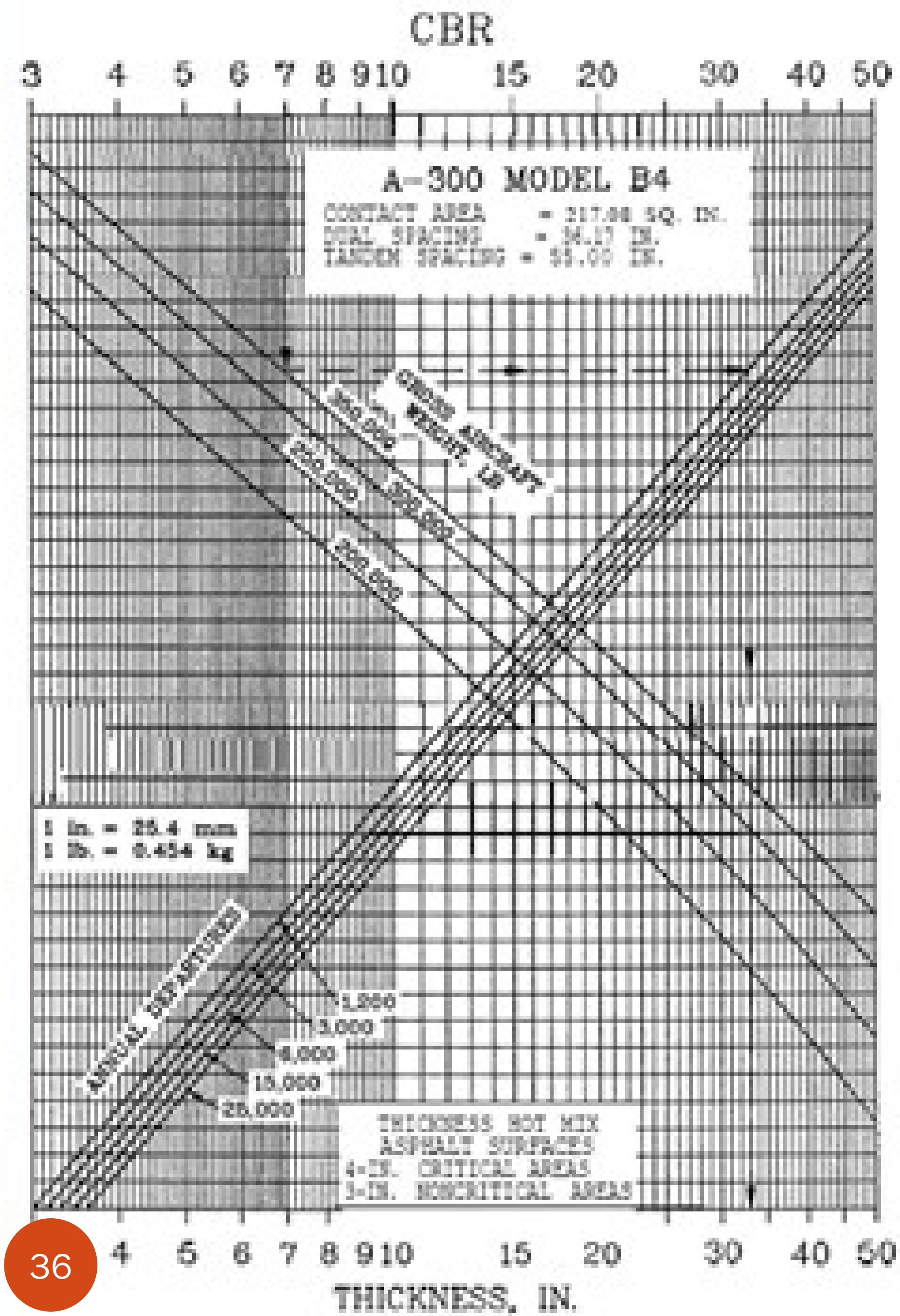
Dual Wheel Gear

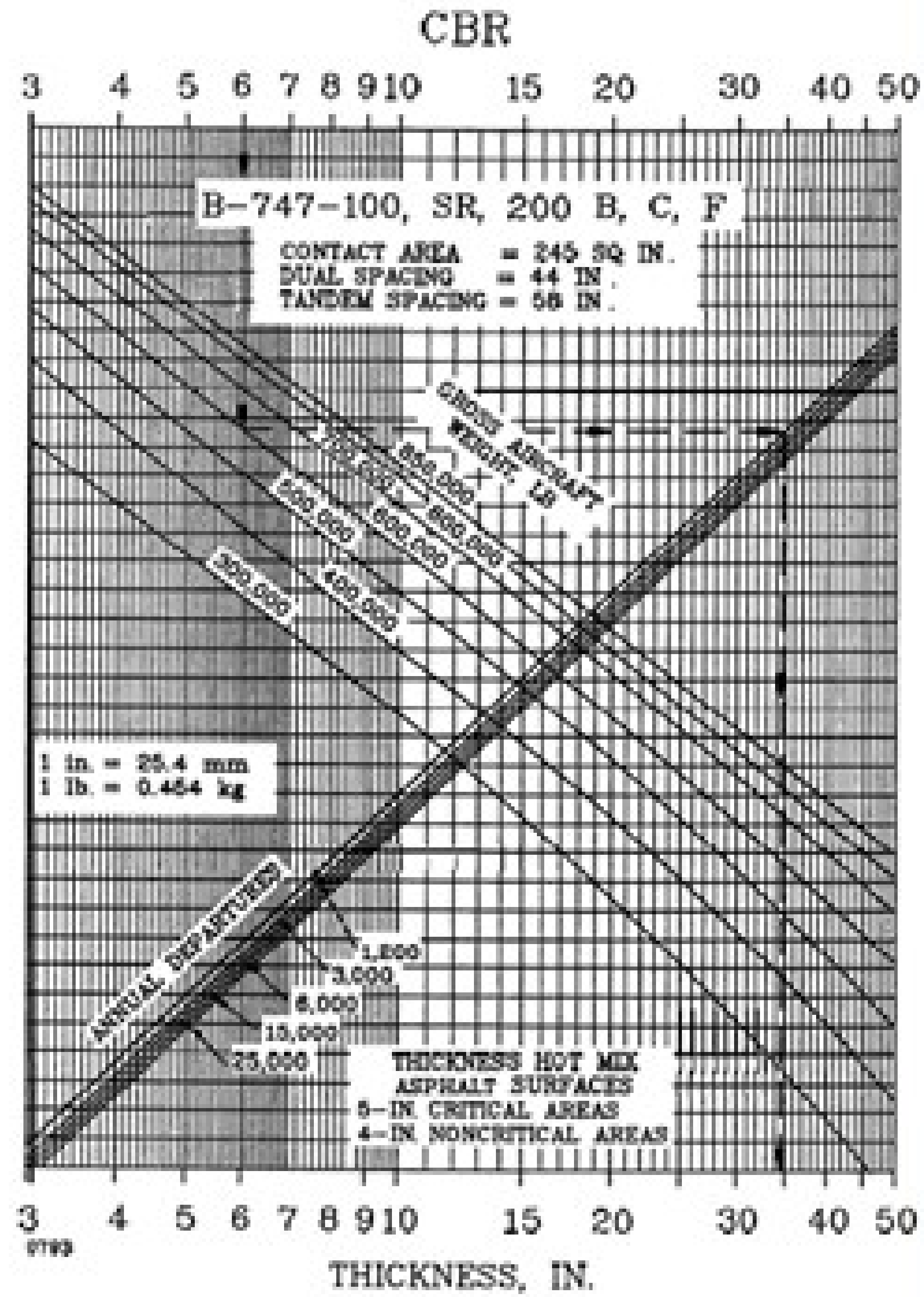


Design Curves

Dual Tandem Gear




CBR
3 4 5 6 7 8 9 10 15 20 30 40 50
A-300 MODEL B4
CONTACT AREA
DUAL SPACING
TANDEM SPACING
GROSS AIRCRAFT WEIGHT, LB
1 in. = 25.4 mm
1 lb. = 0.454 kg
ANNUAL DEPARTURES
1,200
3,000
6,000
15,000
25,000
THICKNESS HOT MIX
ASPHALT SURFACES
4-IN. CRITICAL AREAS
3-IN. NONCRITICAL AREAS
4 5 6 7 8 9 10 15 20 30 40 50
THICKNESS, IN.


CBR
3 4 5 6 7 8 9 10 15 20 30 40 50
B-747-100, SR, 200 B, C, F
CONTACT AREA = 245 SQ IN.
DUAL SPACING = 44 IN.
TANDEM SPACING = 58 IN.
GROSS AIRCRAFT WEIGHT, LB
1 in. = 25.4 mm
1 lb. = 0.454 kg
ANNUAL DEPARTURES
1,200
3,000
6,000
15,000
25,000
300,000
400,000
THICKNESS HOT MIX
ASPHALT SURFACES
5-IN. CRITICAL AREAS
4-IN. NONCRITICAL AREAS
3 4 5 6 7 8 9 10 15 20 30 40 50
THICKNESS, IN.

Minimum Thicknesses of Base Course

Design Aircraft	Design Load Range				Minimum Base Course Thickness	
	lbs.		(kg)		in.	(mm)
Single Wheel	30,000 -	50,000	(13 600 -	22 700)	4	(100)
	50,000 -	75,000	(22 700 -	34 000)	6	(150)
Dual Wheel	50,000 -	100,000	(22 700 -	45 000)	6	(150)
	100,000 -	200,000	(45 000 -	90 700)	8	(200)
Dual Tandem	100,000 -	250,000	(45 000 -	113 400)	6	(150)
	250,000 -	400,000	(113 400 -	181 000)	8	(200)
757 767	200,000 -	400,000	(90 700 -	181 000)	6	(150)
DC-10 L1011	400,000 -	600,000	(181 000 -	272 000)	8	(200)
B-747	400,000 -	600,000	(181 000 -	272 000)	6	(150)
	600,000 -	850,000	(272 000 -	385 700)	8	(200)
C-130	75,000 -	125,000	(34 000 -	56 700)	4	(100)
	125,000 -	175,000	(56 700 -	79 400)	6	(150)

Pavement Thickness for High Departure Levels

Annual Departure Level	Percent of 25,000 Departure Thickness
50,000	104
100,000	108
150,000	110
200,000	112

1-inch of thickness increase should be HMA surfacing

The remaining thickness increases should be proportioned between base and subbase

Critical and Noncritical Areas

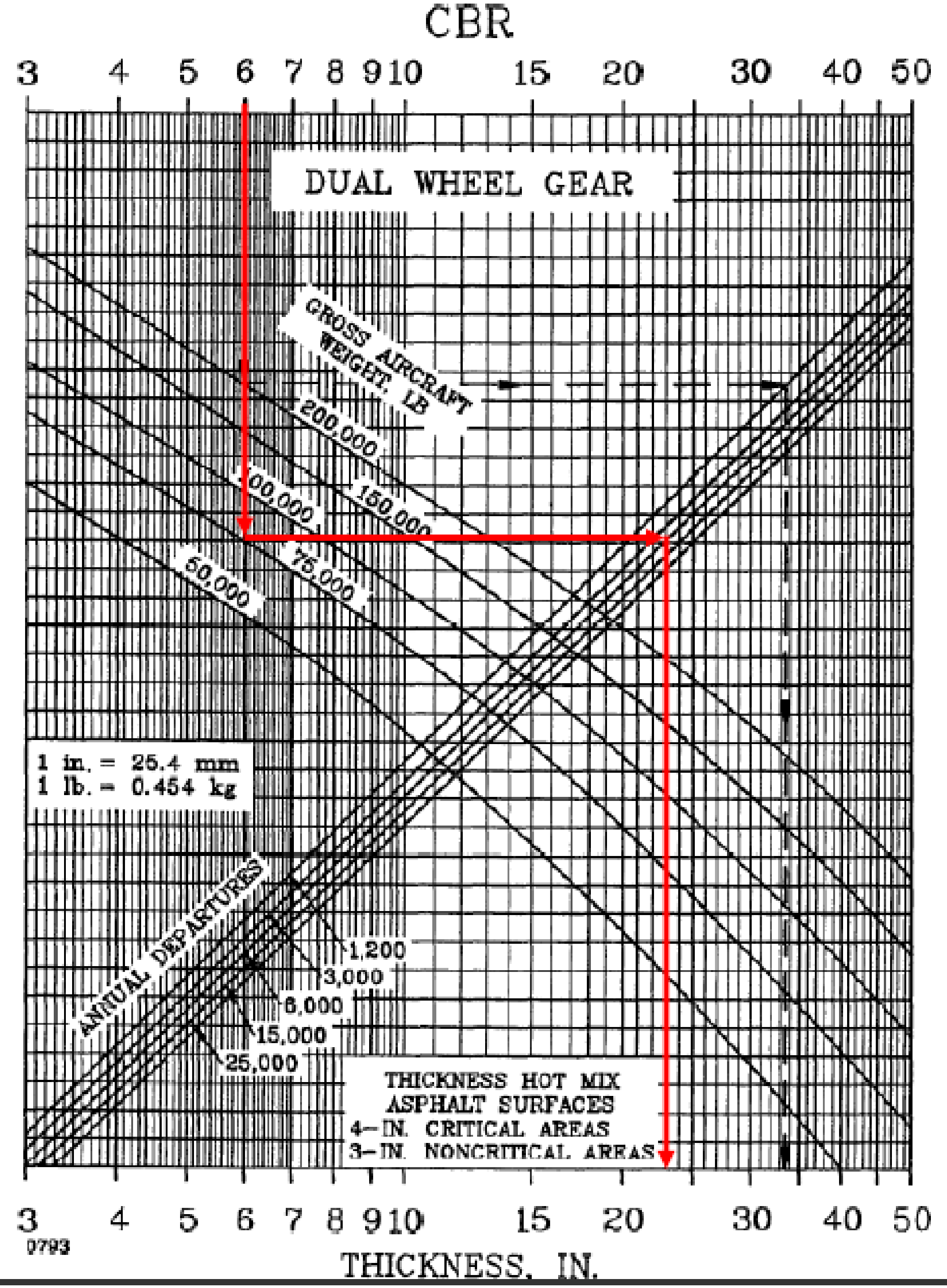
- Total critical pavement thickness = T
- Noncritical pavement thickness (for base and subbase only) = 0.9T
- For variable section of the transition section and thinned edge, the reduction applies only to the base course
- The 0.7T thickness for base shall be the minimum permitted

Design Example

- Flexible airport pavement is to be designed for a dual gear aircraft
- Gross weight = 75,000 lbs (34,000 kg)
- Annual equivalent departures of design aircraft = 6,000
- CBR for subbase = 20
- CBR for subgrade = 6

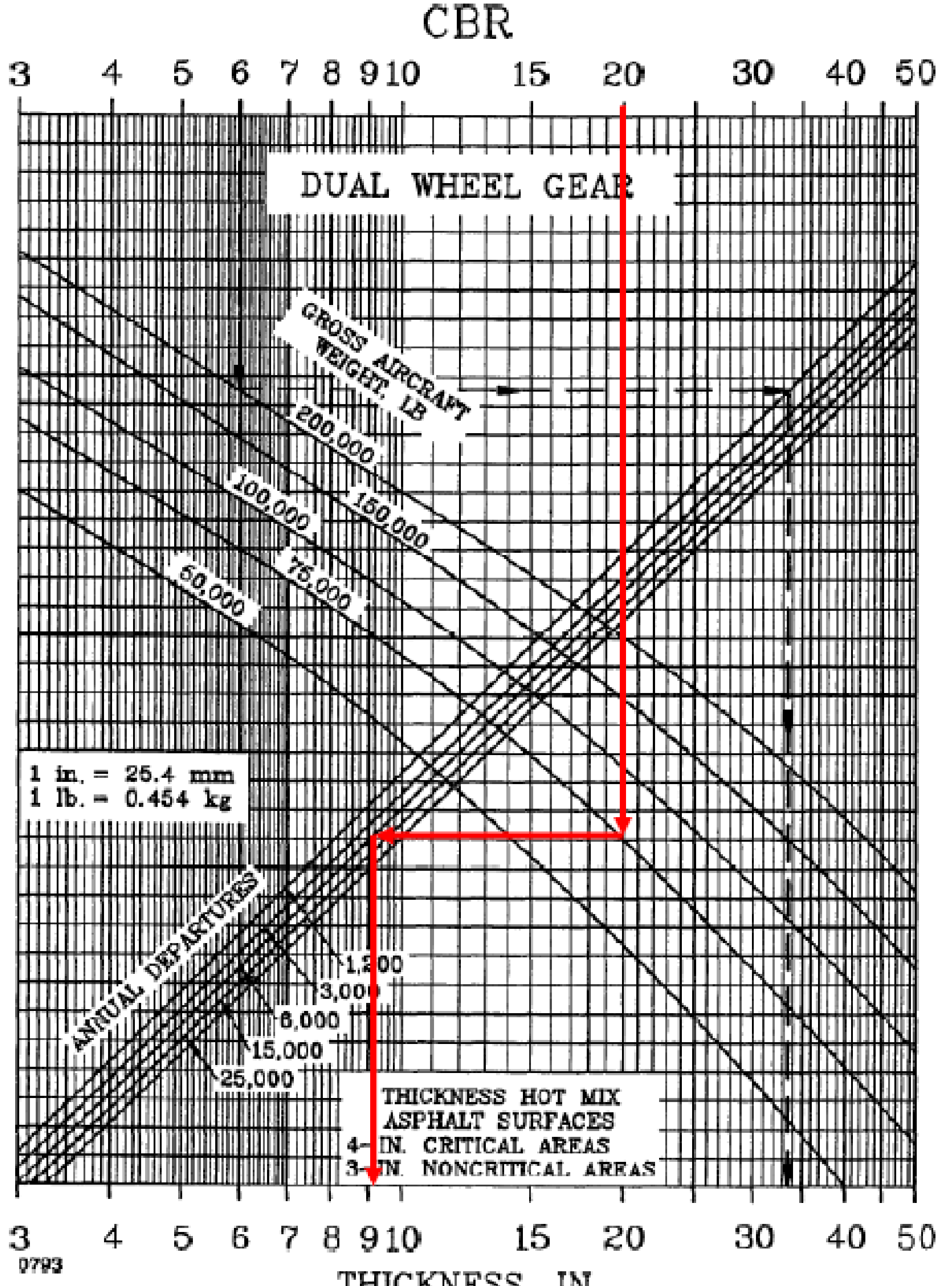
Find total pavement thickness

- Use subgrade CBR to find total pavement thickness
- **23 in.**



Find subbase thickness

- Use subbase CBR to find combined thickness of HMA and base course needed over a 20 CBR subbase is 9.2 in.
- **Subbase = 23-9.2 = 13.8 in. (14 in.)**



Design Pavement Thicknesses

- HMA Surface (critical area) = 4 in.
- Base course = 9.2-4 = 5.2 in. (6 in.)
- Subbase course = 14 in.

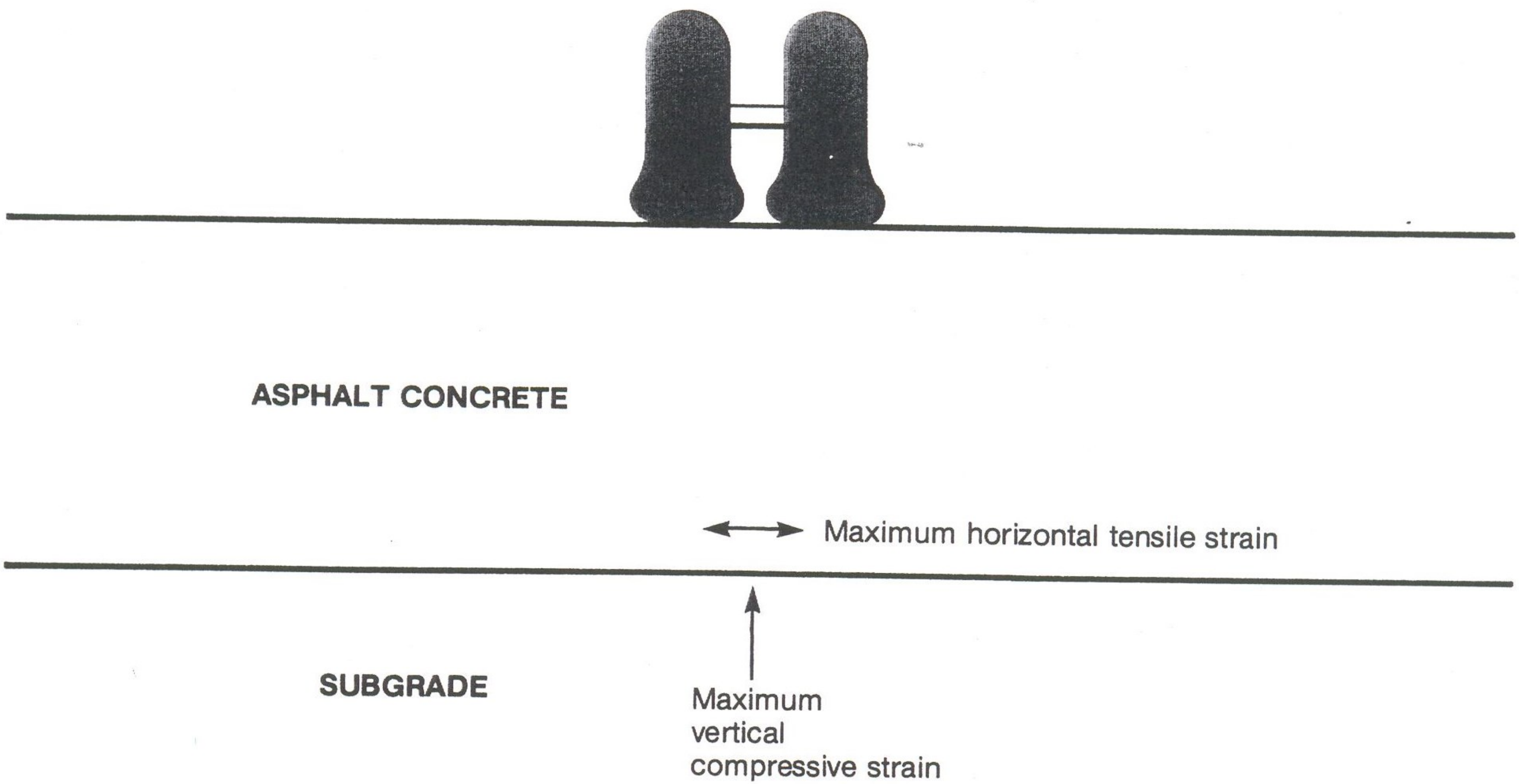
d) AI Method

- Asphalt Institute, Manual Series No.11, *Thickness Design: Aspahlt Pavements for Air Carrier Airports*
- Full-depth asphalt pavement
- For aircraft > 270 kN (60,000 lbs) gross weight

AI Method: Design Principles

- Multi-layered elastic system analysis
- Two critical elastic strains
  - Horizontal tensile strain (ε_t)at bottom of asphalt concrete
  - Verticle compressive strain (ε_c) at top of subgrade
- The greater of thicknesses is selected as final design thickness.
- E* of asphalt concrete depends on type of mix, temperature, and rate of loading
  - Design frequency of 2 Hz. For dual tandem aircraft gear at taxiing speed of 16-32 km/hr (10-20 mph)

Location and direction of tensile and compressive strains in Full-Depth asphalt pavement



AI Method: Design Principles

- Design location – taxiway
  - More aircraft movements
  - Greater aircraft weights at departure
  - Slower aircraft speeds
  - Greater degree of traffic channelization
- Lateral effect
  - Taxiway/runway receive greater number of stress repetitions nearer central portion of pavement than at edges
- Cumulative strain repetitions
  - Function of aircraft type, gear load, number of aircraft passes, lateral&transverse wander characteristics

AI Method: Design Subgrade

- Resilient modulus (M_r)
  - Direct measurement by M_r test
  - From CBR test

    M_r (Mpa) = 10.3 CBR or

    M_r (psi) = 1,500 CBR
  - From Resistance Value (R) test

    M_r (Mpa) = 8.0+3.8 (R-value) or

    M_r (psi) = 1155+555 (R-value)
  - From plate bearing test

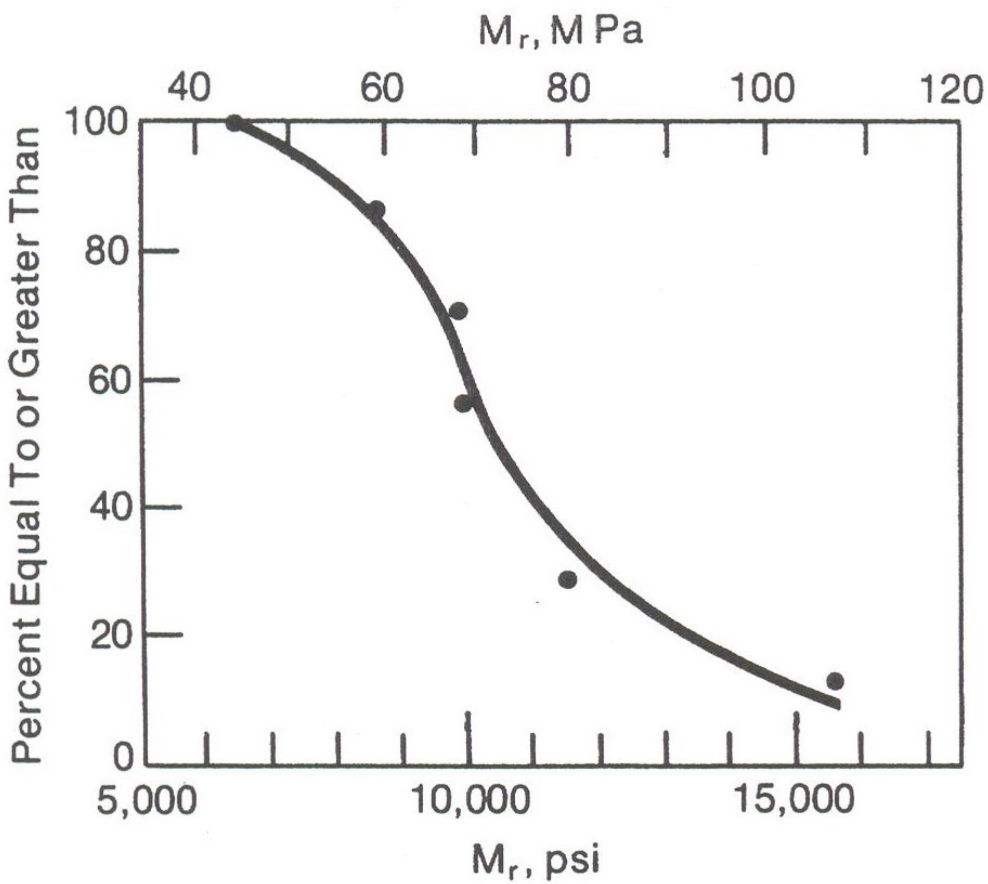
AI Method: Design Subgrade M_r

- Design subgrade resilient modulus equal to or greater than 85% of all M_r values
- <u>Example:</u> Find design subgrade resilient modulus from the results of 7 tests from runway section site

Test Values		Number equal to or greater than	Percent equal to or greater than
MPa	Psi		
106.9	15,500	1	(1/7)100=14
80.0	11,600	2	(2/7)100=29
68.3	9,900		
68.3	9,900	4	(4/7)100=57
67.6	9,800	5	(5/7)100=71
58.6	8,500	6	(6/7)100=86
44.8	6,500	7	(7/7)100=100

AI Method: Design Subgrade M_r

- Design subgrade value at 85 percent = 58.6 Mpa (8,500 psi)



AI Method: Environmental Effects

- Moisture
- Volume change
- Frost