Airport Pavement Notes
CEE 4674: Airport Planning/Design

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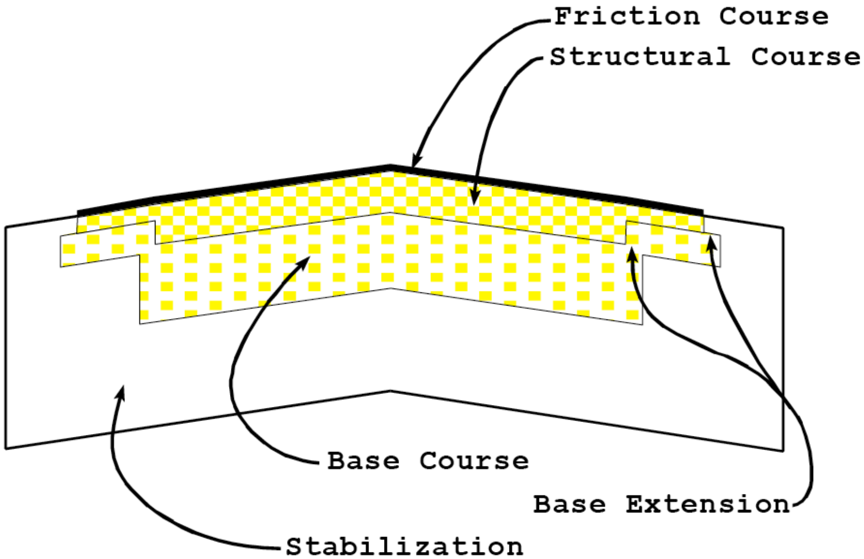
Virginia Tech

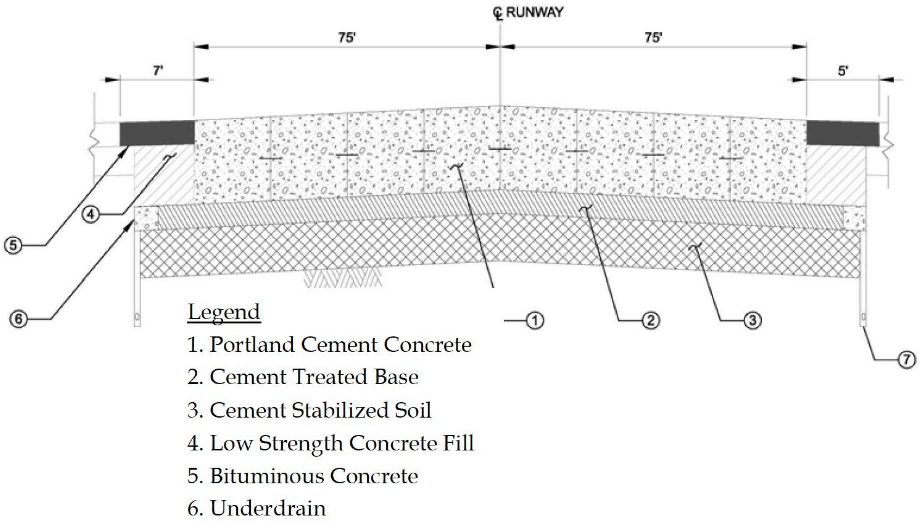
References for Airport Pavement Design

- FAA Advisory Circular 150/5320-6F: Airport Pavement Design and Evaluation
- FAA Advisory Circular 150/5370-10F Standards for Specifying Construction of Airports
- ICAO Aerodrome Design Manual, Part 3 (Montreal)
- Computer Programs:
  - FAARFIELD - Flexible Iterative Elastic Layer Design
  - LEDFAA uses layered elastic theory based design (specifically pavements designed for the Boeing B-777 airplane).

Definitions

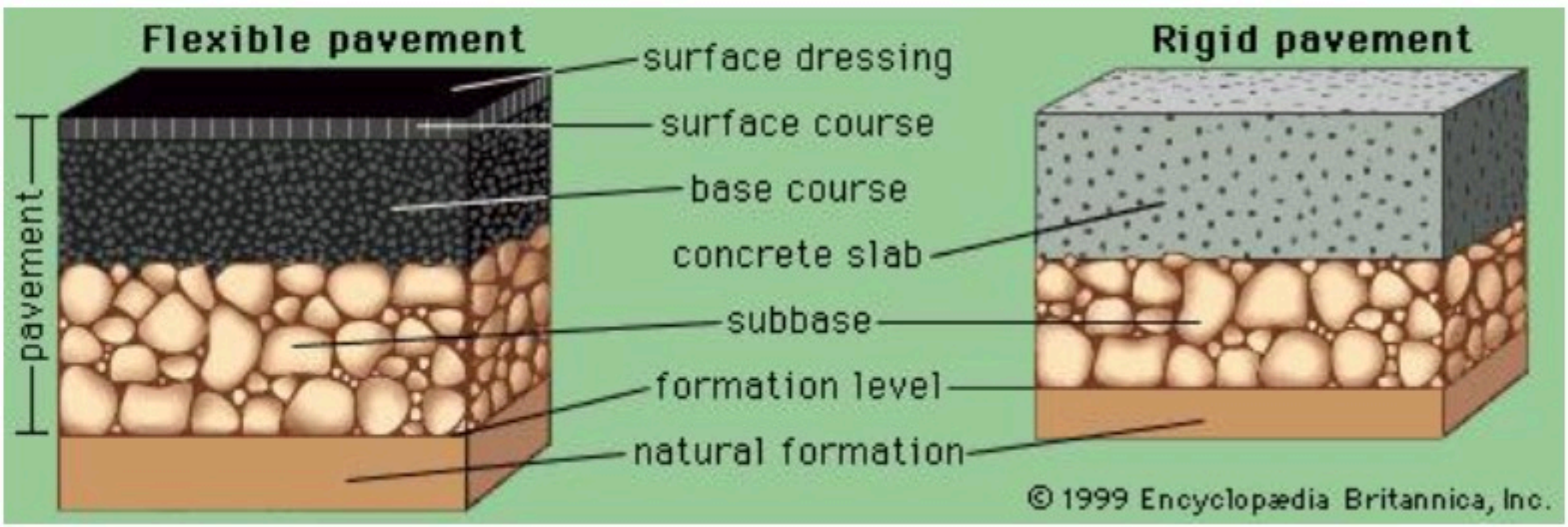
- Friction course
  - Provides a skid-resistance surface
- Structural course
  - Distributes the traffic loads to the base course
- Base course
  - Supports the structural course and distribute loads to the stabilization (subgrade) layer





Types of Pavements

- Flexible pavements
- Rigid pavements



Source: Encyclopedia Britannica

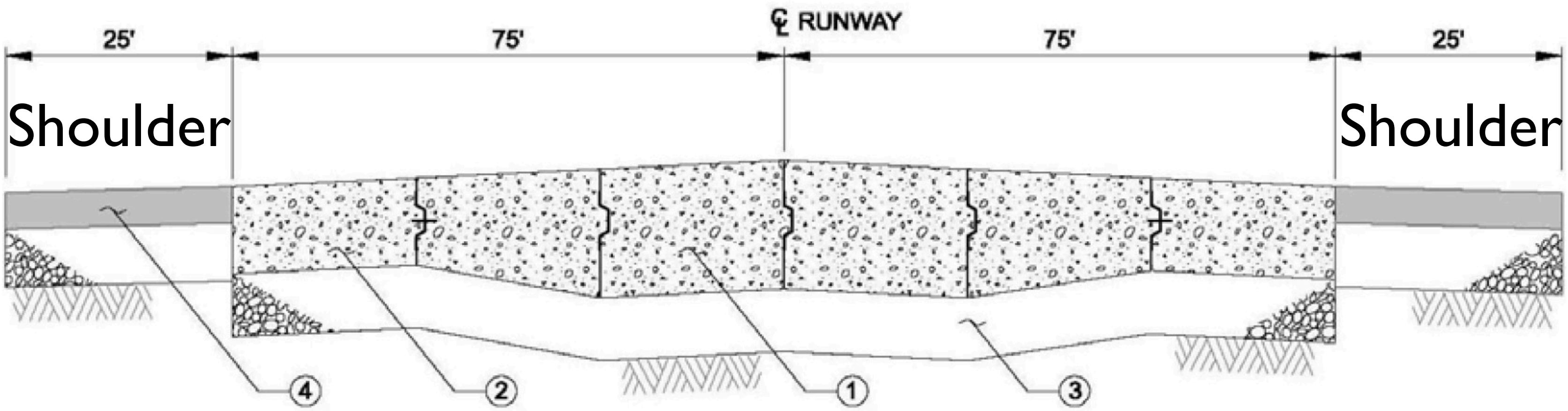
Flexible Pavements

- Multi-Layered system (3-4 layers)
  - Design life is usually 10-20 years
  - Higher maintenance cost
  - Relatively low flexural strength (high deformation of the sub-grade)
  - Better ride quality (no expansion joints)

Rigid Pavements

- Normally 2-3 layers
- Design life 30-40 years
- Lower maintenance cost
- Relatively high flexural strength (less deformation of sub-grade)
- Lower ride quality (due to expansion joints)

Example: Original Airport Pavement for Dulles International Airport (1962)



Legend
1. PCC Pavement, 15 inch depth
2. PCC Pavement, 12 inch depth
3. Aggregate Base, 9 inch depth
4. Bituminous Concrete

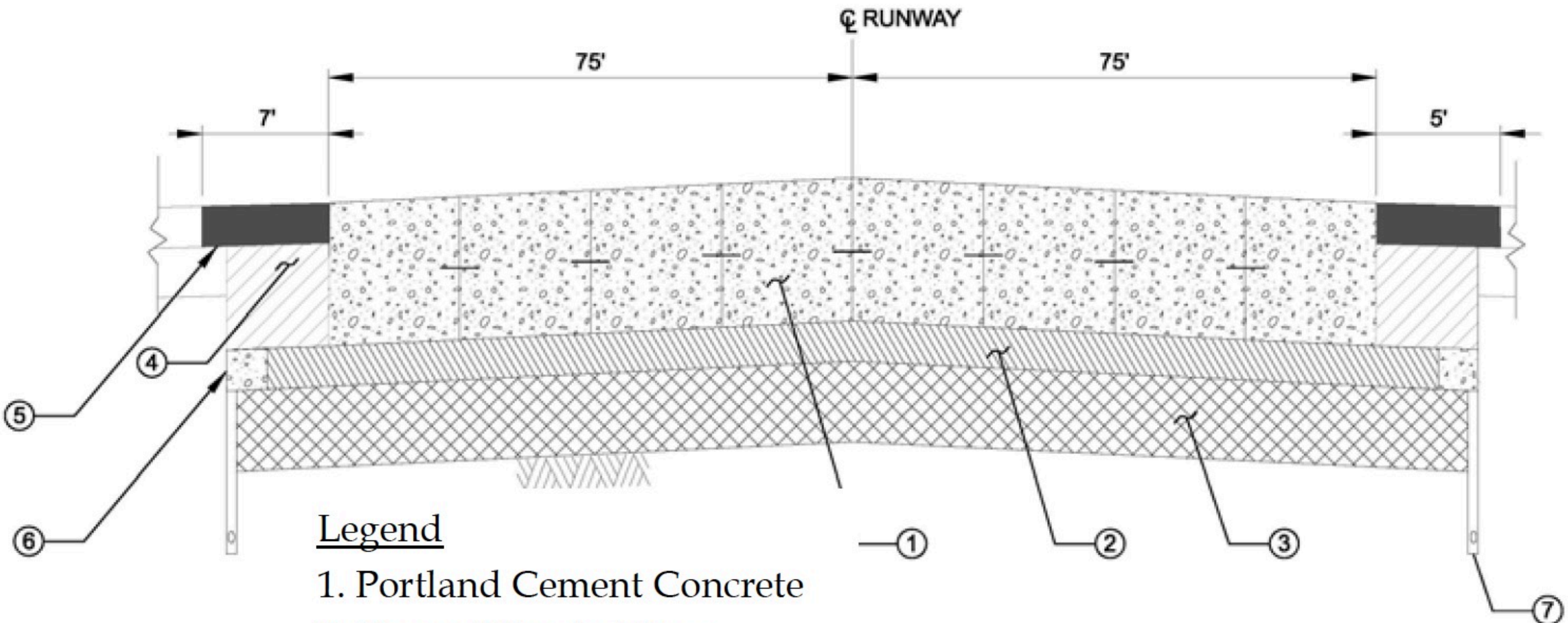
Source: Fuselier, Grubs and McQueen, ASCE 2008

Example: Original Airport Pavement for Dulles International Airport (1962) Design Assumptions

- Equivalent Single Wheel Load of 100,000 lbs.
- Using the Portland Cement Association (PCA) methodology
- Airplane whose gross load 500,000 lbs (with DC-8 gear configuration and a tire pressure of 200 psi was assumed equal to the 100,000 lbs equivalent single wheel load)
- The soil was classified as E-8, in accordance with the CA (FAA) soil classification system
- Portland cement concrete - working modulus = 750 @ 28 days and 850 @ 90 days
- Effective Subgrade Modulus at top of aggregate subbase, k = 200 psi
- Factor of Safety - 1.7 for Critical Areas and 1.25 for Non-critical Areas

Source: Fuselier, Grubs and McQueen, ASCE 2008

Reconstructed Airport Pavement for Dulles International Airport (2005)



Legend

1. Portland Cement Concrete
2. Cement Treated Base
3. Cement Stabilized Soil
4. Low Strength Concrete Fill
5. Bituminous Concrete
6. Underdrain

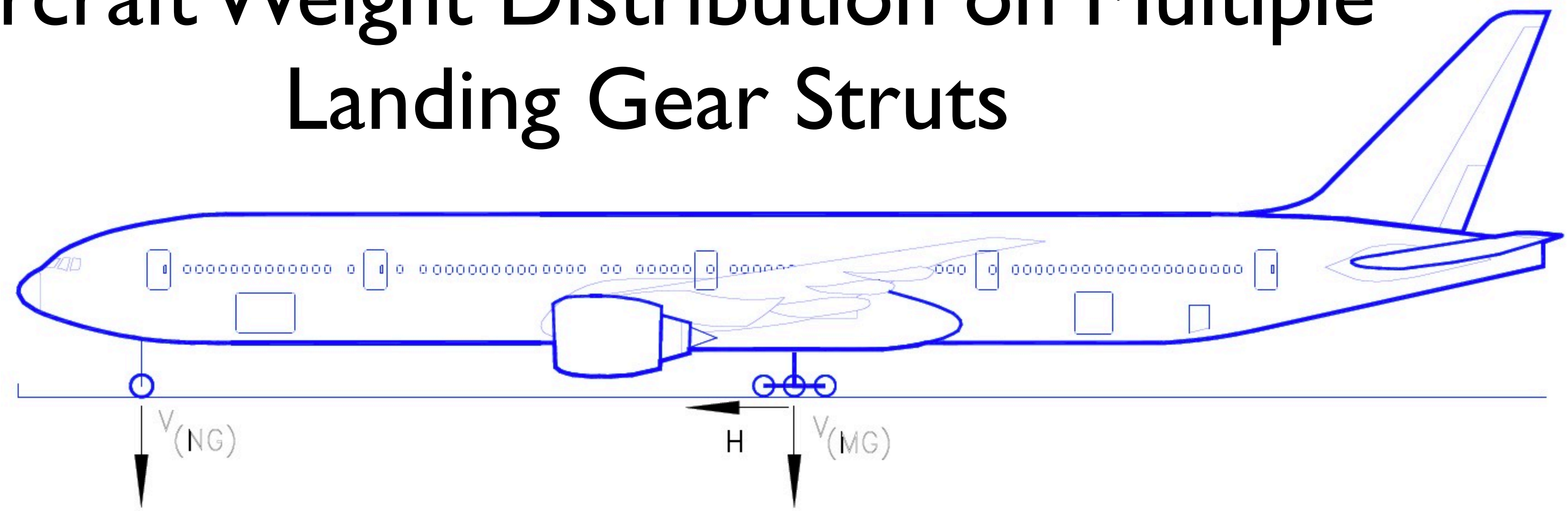
18 inches of PCC
6 inch Cement Treated Base layer
12 inch subgrade Soil Cement Stabilized

Source: Fuselier, Grubs and McQueen, ASCE 2008

Pavement Thickness Increased Substantially from the Original Design

- Airbus A380-800 has a maximum takeoff weight of 570 metric tons (1.254 million pounds)
- The original design weight was 500,000 lb

Aircraft Weight Distribution on Multiple Landing Gear Struts



AIRPLANE MODEL	UNITS	MAX DESIGN TAXI WEIGHT	V_{NG}		V_{MG} PER STRUT AT MAX LOAD AT STATIC AFT C.G.	H PER STRUT (4)	
			STATIC AT MOST FWD C.G.	STATIC + BRAKING 10 FT/SEC^2 DECEL		STEADY BRAKING 10 FT/SEC^2 DECEL	AT INSTANTANEOUS BRAKING (μ = 0.8)
777-200LR	LB	768,000	68,269	115,317	352,435	119,270	281,924
	KG	348,358	30,966	52,307	159,862	54,100	127,879
777-300ER	LB	777,000	59,019	98,480	359,207	120,668	287,333
	KG	352,441	26,771	44,670	162,934	54,734	130,332
777F	LB	768,800	81,367	128,464	352,495	119,395	281,949
	KG	348,722	36,907	58,270	159,889	54,157	127,890

Note: At rest, ~91-95% of the aircraft weight is supported main landing gear

Landing Gear Arrangements (Tricycle)

Boeing 747-400

Beechcraft BE400

Landing Gear Arrangements (Single Wheel)

Beechcraft King Air C-90

Cessna 182

Cessna Excel XLS

Landing Gear Arrangements (Dual Tire Main Gear)

Embraer 190

Boeing 737-800

Airbus A319

Landing Gear Arrangements (Dual In-Tandem)

Boeing MD-10

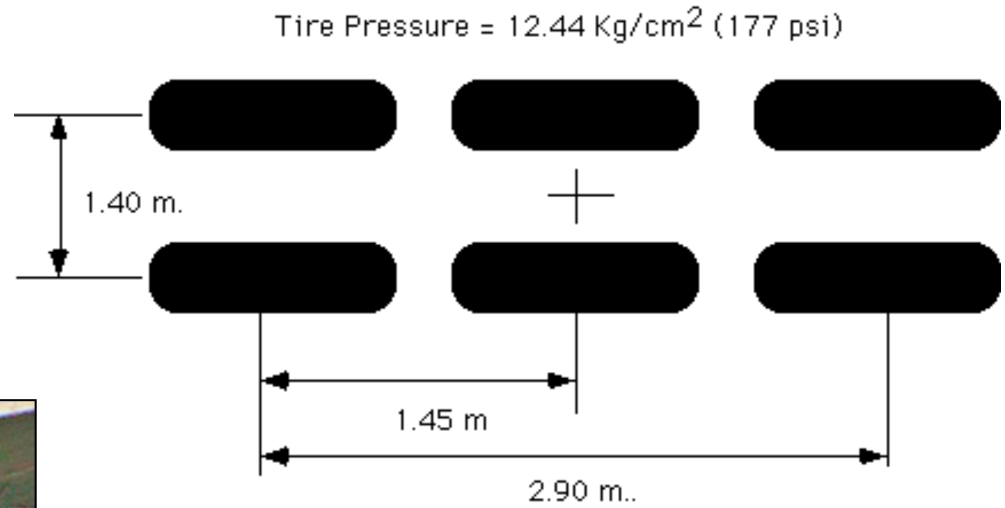
Airbus A330-300

Boeing 757-200

Boeing 787-8

Landing Gear Arrangements (Triple In-Tandem)

Boeing 777-200



Source: The Boeing Airplane Company

Boeing 777-300ER

Landing Gear Arrangements (Multiple Gears)

Boeing747-400 (2 x dual in-tandem)

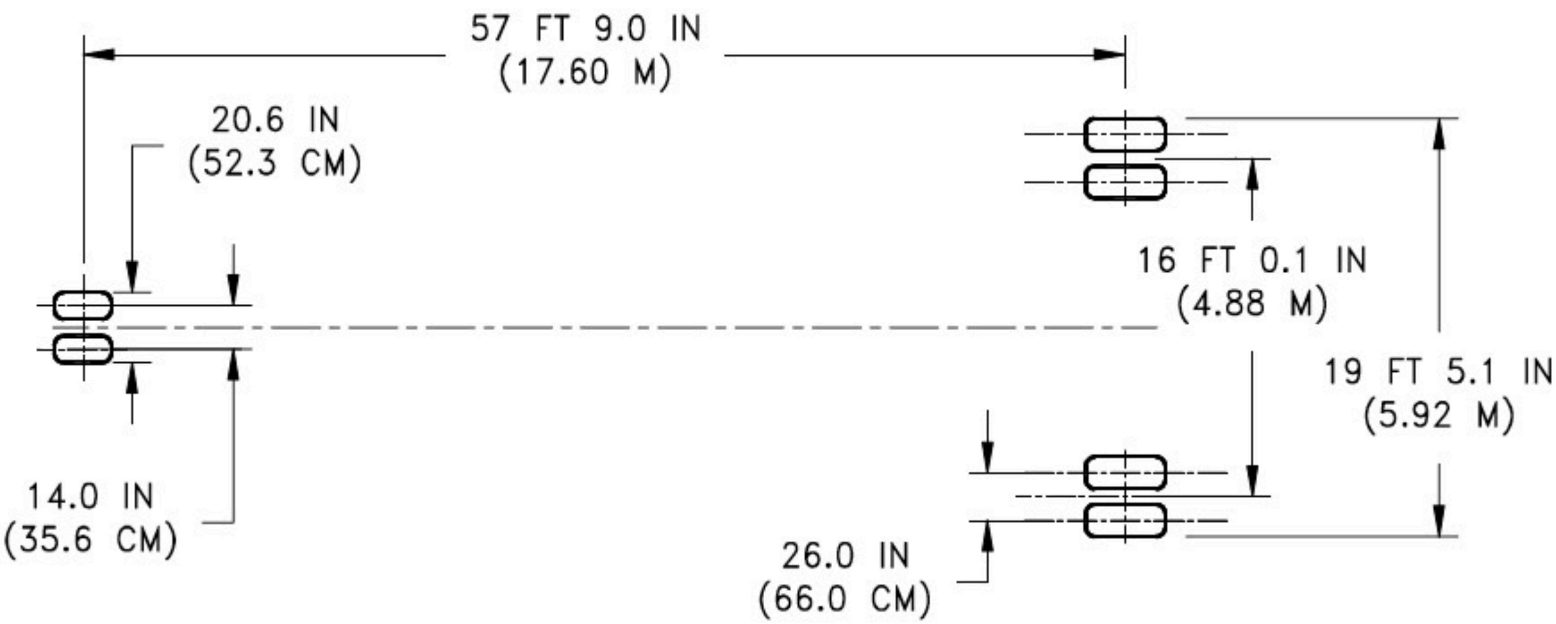
Boeing 747-8 (2 x dual in-tandem per side)

Airbus A380 (triple in tandem + dual in-tandem)

Landing Gear Configurations and Dimensions

Boeing 717-200

	UNITS	717-200 BASIC				717-200 HGW OPTION
MAXIMUM DESIGN	LBS	111,000	115,000	117,000	119,000	122,000
TAXI WEIGHT	KG	50,349	52,163	53,070	53,977	55,338
WEIGHT ON MAIN GEAR	%	SEE SECTION 7.4				
NOSE GEAR TIRE SIZE	IN	26 x 6.6 TYPE VII 12 PR				
NOSE GEAR	PSI	118	122	124	127	130
TIRE PRESSURE	KG/CM^2	8.30	8.58	8.72	8.93	9.14
MAIN GEAR TIRE SIZE	IN	H41 x 15.0 – 19 24 PR				
MAIN GEAR	PSI	152	158	163	164	164
TIRE PRESSURE	KG/CM^2	10.69	11.11	11.46	11.53	11.53

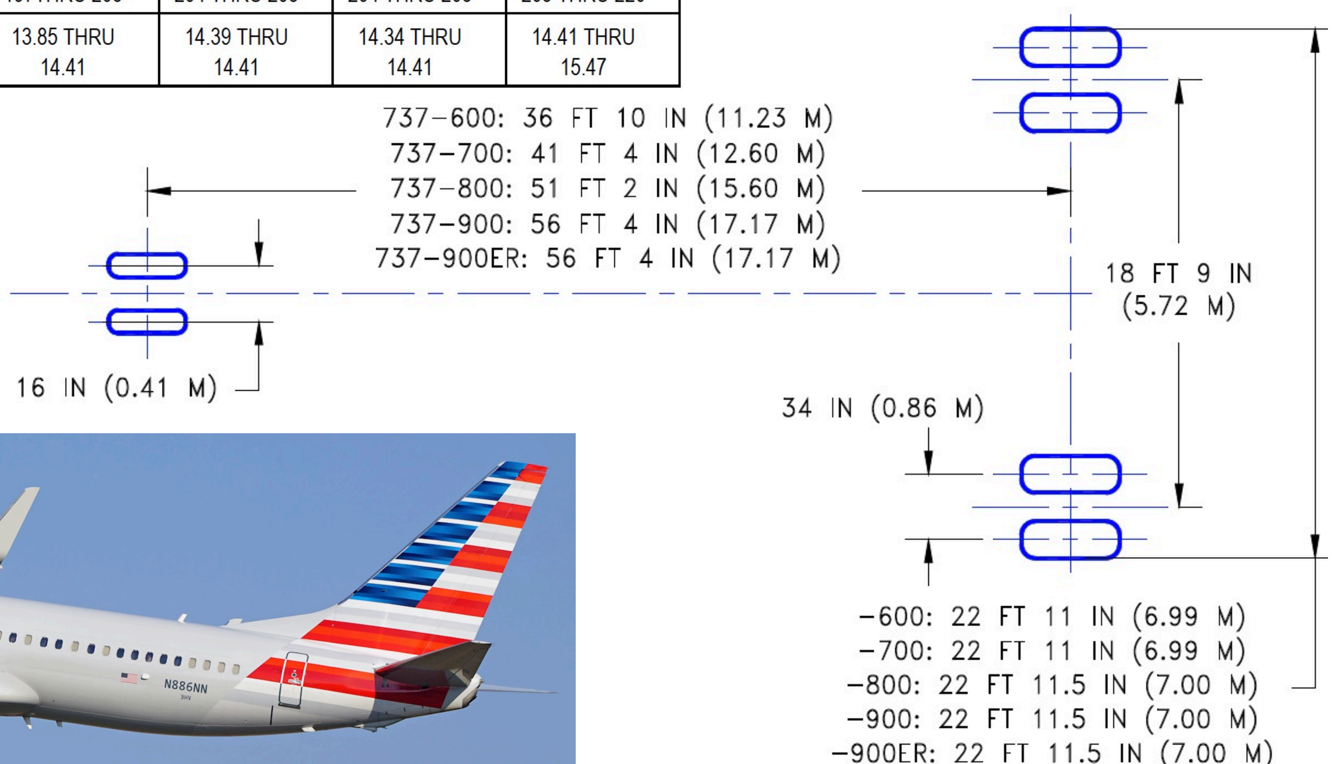


source: Boeing

Boeing 737 Family

	UNITS	737-600	737-700	737-800	737-900	737-900ER
MAXIMUM DESIGN TAXI WEIGHT	LB	124,500 THRU 145,000	133,500 THRU 155,000	156,000 THRU 174,700	164,500 THRU 174,700	164,500 THRU 188,200
	KG	56,472 THRU 65,771	60,554 THRU 70,307	70,760 THRU 79,242	74,616 THRU 79,242	74,616 THRU 85,366
NOSE GEAR TIRE SIZE	IN.	27 x 7.7 - 15 12 PR			27 x 7.75 - 15 12 PR	27 x 7.75 - 15 12 PR
NOSE GEAR TIRE PRESSURE	PSI	206	205	185	185	185
	KG/CM^2	14.50	14.44	13.03	13.03	13.03
MAIN GEAR TIRE SIZE	IN.	H43.5 x 16.0 - 21 24PR OR 26 PR	H43.5 x 16.0 - 21 26 PR	H44.5 x 16.5 - 21 28 PR	H44.5 x 16.5 - 21 28 PR	H44.5 x 16.5 - 21 30 PR
MAIN GEAR TIRE PRESSURE	PSI	182 THRU 205	197THRU 205	204 THRU 205	204 THRU 205	205 THRU 220
	KG/CM^2	12.80 THRU 14.41	13.85 THRU 14.41	14.39 THRU 14.41	14.34 THRU 14.41	14.41 THRU 15.47

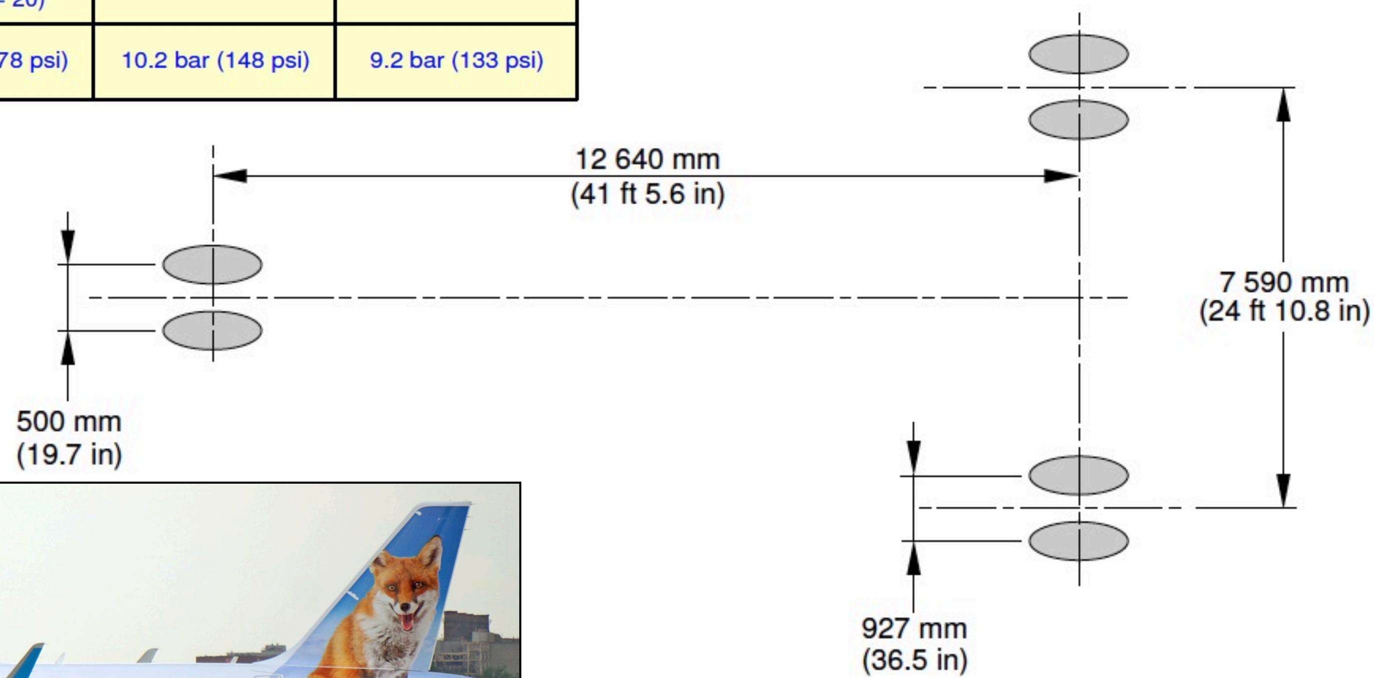
source: Boeing



Airbus A320-200

source: Airbus

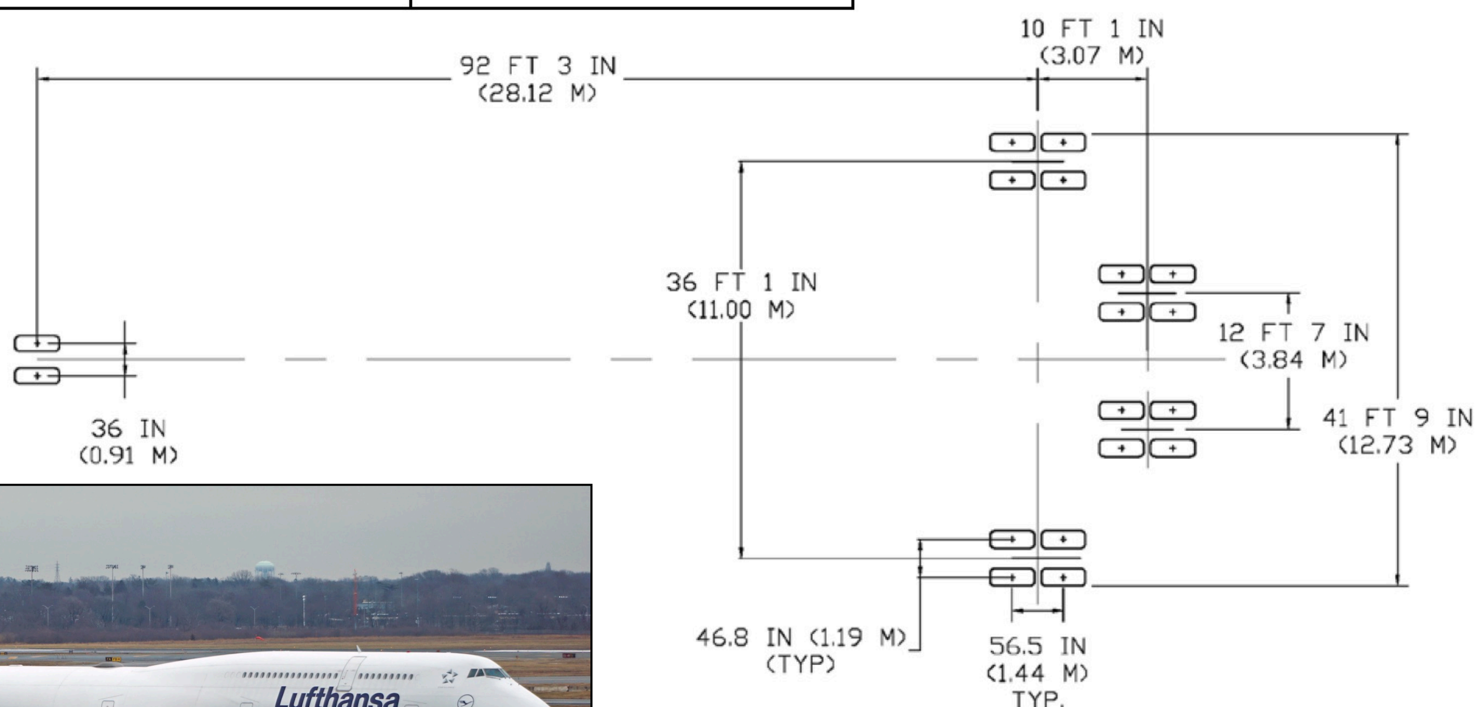
A/C CODE	E		
PERCENTAGE OF WEIGHT ON MAIN GEAR GROUP	SEE SECTION 7–4–1		
NOSE GEAR TIRE SIZE	30 x 8.8 R15 (30 x 8.8 – 15)		
NOSE GEAR TIRE PRESSURE	11 bar (160 psi)		
MAIN GEAR TIRE SIZE	46 x 17 R20 (46 x 16 – 20)	49 x 17 – 20	49 x 19 – 20
MAIN GEAR TIRE PRESSURE	12.3 bar (178 psi)	10.2 bar (148 psi)	9.2 bar (133 psi)



Boeing 747-8

	UNITS	747-8F	747-8, 747-8F
MAXIMUM DESIGN TAXI WEIGHT	LB KG	978,000 443,613	990,000 449,056
PERCENT OF WEIGHT ON MAIN GEAR	%	SEE SECTION 7.4	
NOSE GEAR TIRE SIZE	IN.	50 X 20.0 R 22, 26 PR	50 X 20.0 R22, 26 PR
NOSE GEAR TIRE PRESSURE	PSI KG/CM^2	167 11.74	167 11.74
MAIN GEAR TIRE SIZE	IN.	52 X 21.0 R22, 36 PR	52 X 21.0 R22, 36 PR
MAIN GEAR TIRE PRESSURE	PSI KG/CM^2	221 15.54	221 15.54

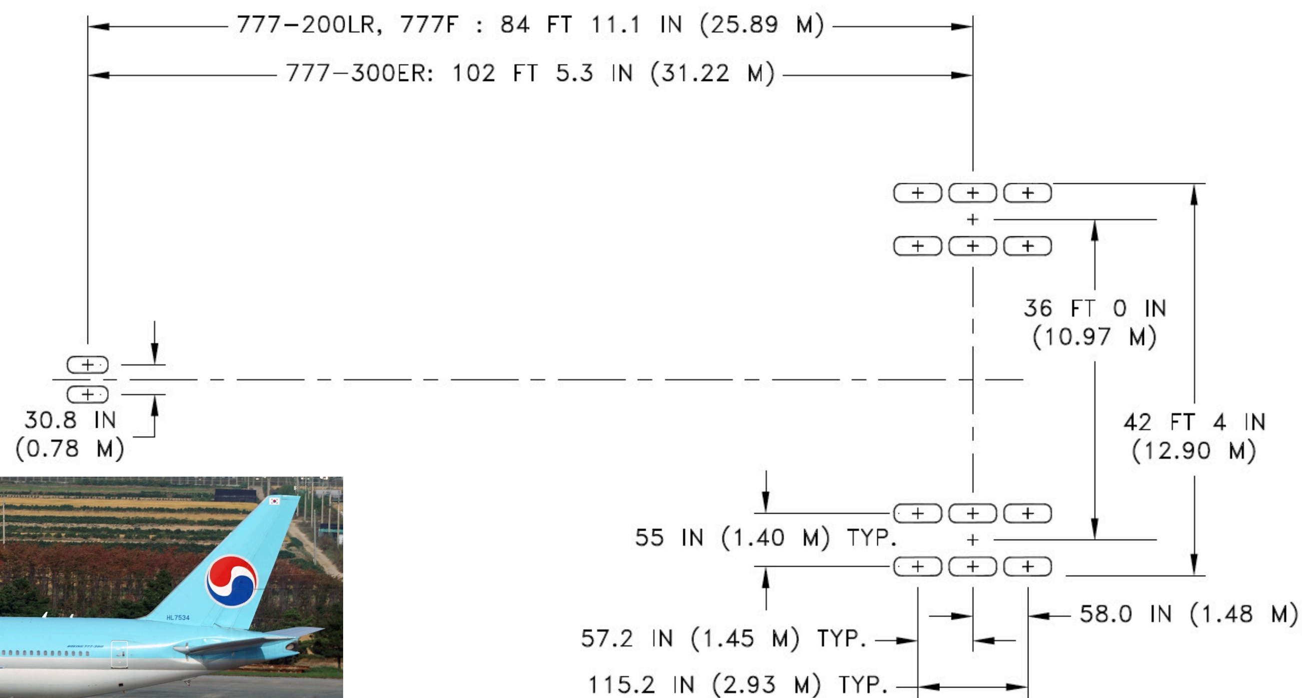
source: Boeing



Boeing 777 Family

	UNITS	777-200LR	777F	777-300ER
MAXIMUM DESIGN	LB	768,000	768,800	777,000
TAXI WEIGHT	KG	348,358	348,722	352,441
PERCENT OF WT ON MAIN GEAR		SEE SECTION 7.4		
NOSE GEAR TIRE SIZE	IN.	43 X 17.5 R 17, 32 PR		
NOSE GEAR	PSI	218	218	
TIRE PRESSURE	KG/CM^2	15.3	15.3	
MAIN GEAR TIRE SIZE	IN.	52 X 21 R 22, 36 PR		
MAIN GEAR	PSI	218	221	
TIRE PRESSURE	KG/CM^2	15.3	15.5	

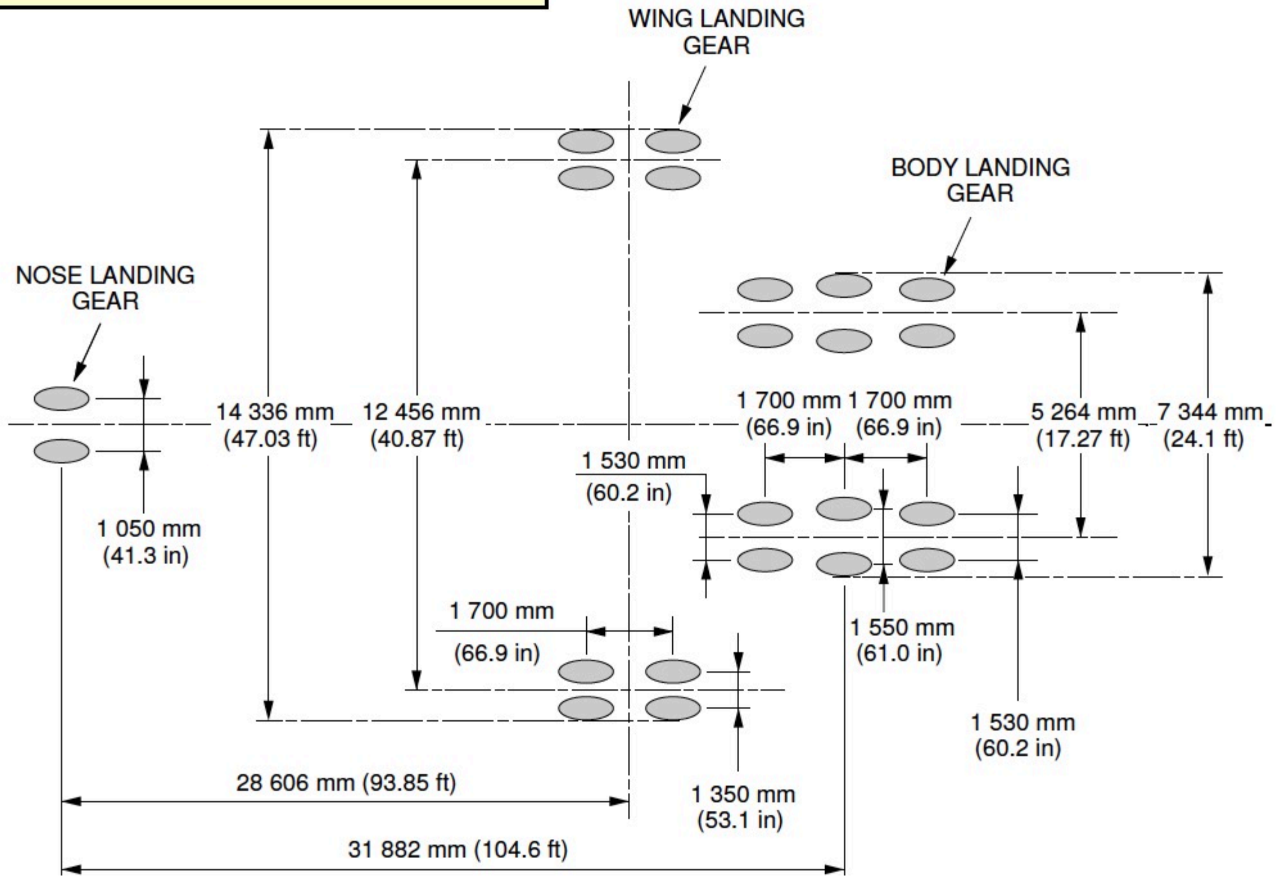
source: Boeing



Airbus A380-800

source: Airbus

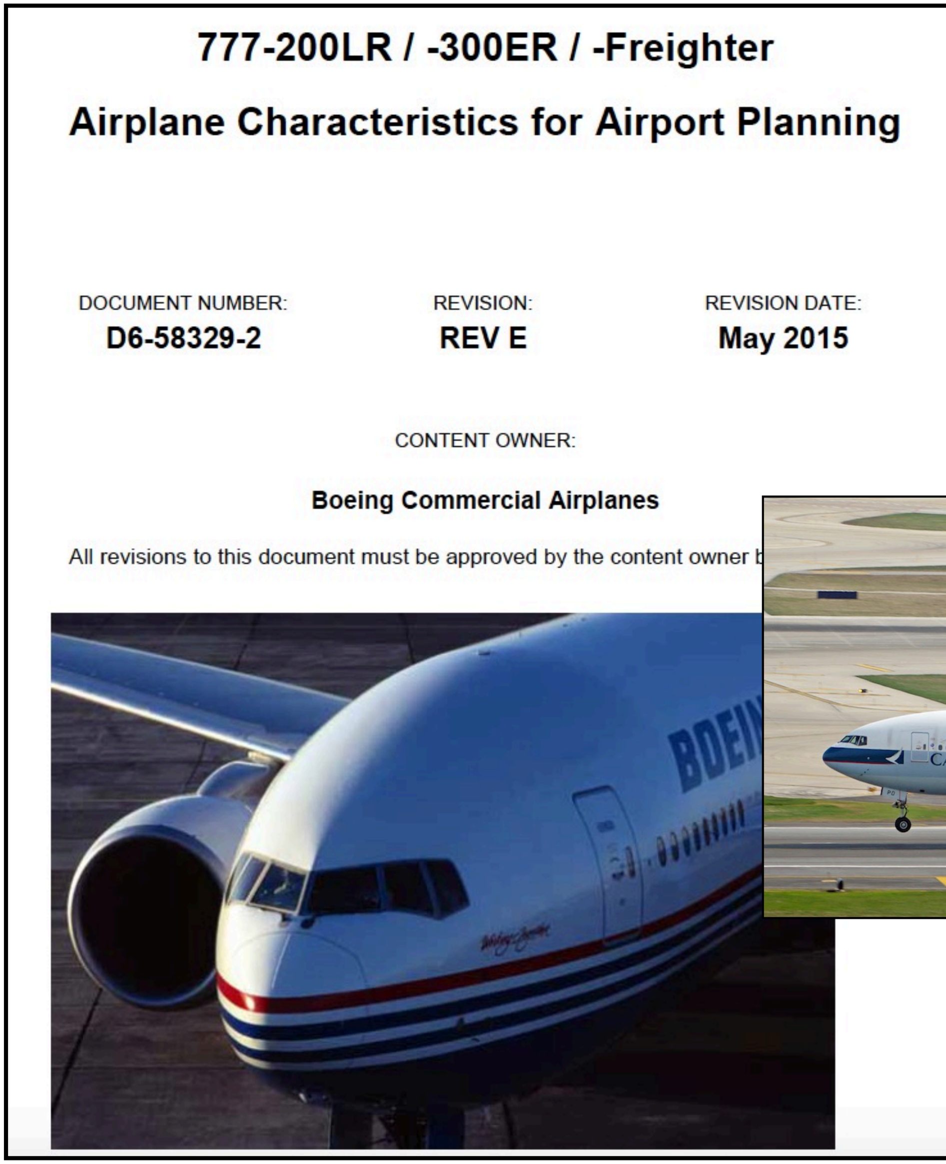
MAXIMUM RAMP WEIGHT	571 000 kg (1 258 850 lb)
PERCENTAGE OF WEIGHT ON MAIN GEAR GROUP	See Section 7–4–1 Figure: Landing Gear Loading on Pavement – MRW 571 000 kg – A380–800 Models
NOSE GEAR TIRE SIZE	1270 x 455R22 32PR or 50 x 20R22 34PR
NOSE GEAR TIRE PRESSURE	14.1 bar (205 psi)
WING GEAR TIRE SIZE	1400 x 530R23 40PR
WING GEAR TIRE PRESSURE	15 bar (218 psi)
BODY GEAR TIRE SIZE	1400 x 530R23 40PR
BODY GEAR TIRE PRESSURE	15 bar (218 psi)



Pavement Design Methods

- Flexible Pavement Requirements - U.S. Army Corps of Engineers Method (S-77-1) and FAA Design Method (CBR Method)
- Flexible Pavement Requirements - LCN Method
- Rigid Pavement Requirements - Portland Cement Association Design Method
- Flexible Iterative Elastic Layer Design (FAA using FAARFIELD model)

Sample Airport Pavement Charts



777-200LR / -300ER / -Freighter

Airplane Characteristics for Airport Planning

DOCUMENT NUMBER:	REVISION:	REVISION DATE:
D6-58329-2	REV E	May 2015

CONTENT OWNER:

Boeing Commercial Airplanes

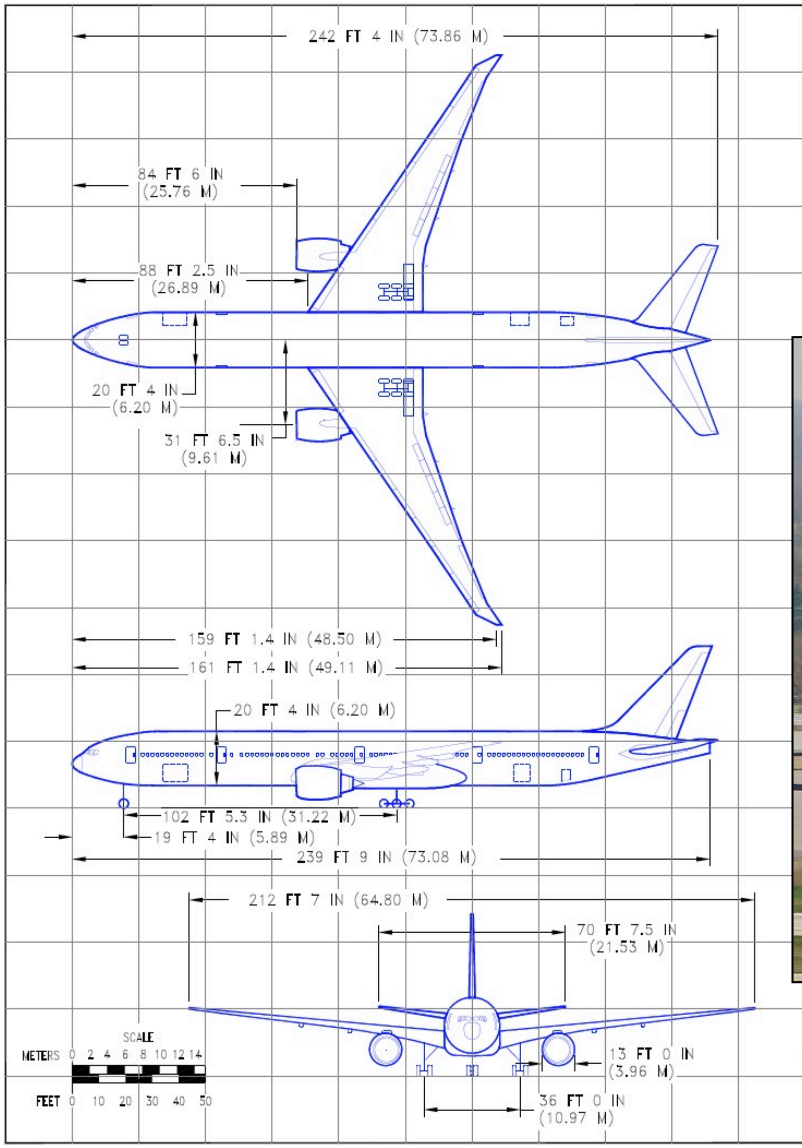
All revisions to this document must be approved by the content owner b

Aircraft manufacturers provide ready-made charts for quick verification of pavement design solutions

Boeing 777-300ER Taking Off at Chicago O'Hare Airport

http://www.boeing.com/commercial/airports

Sample Airport Pavement Charts



Boeing 777-300ER Dimensions in Airport Design Document

Boeing 777-300ER Taking Off at Chicago O'Hare Airport

http://www.boeing.com/commercial/airports

California Bearing Ratio (CBR)

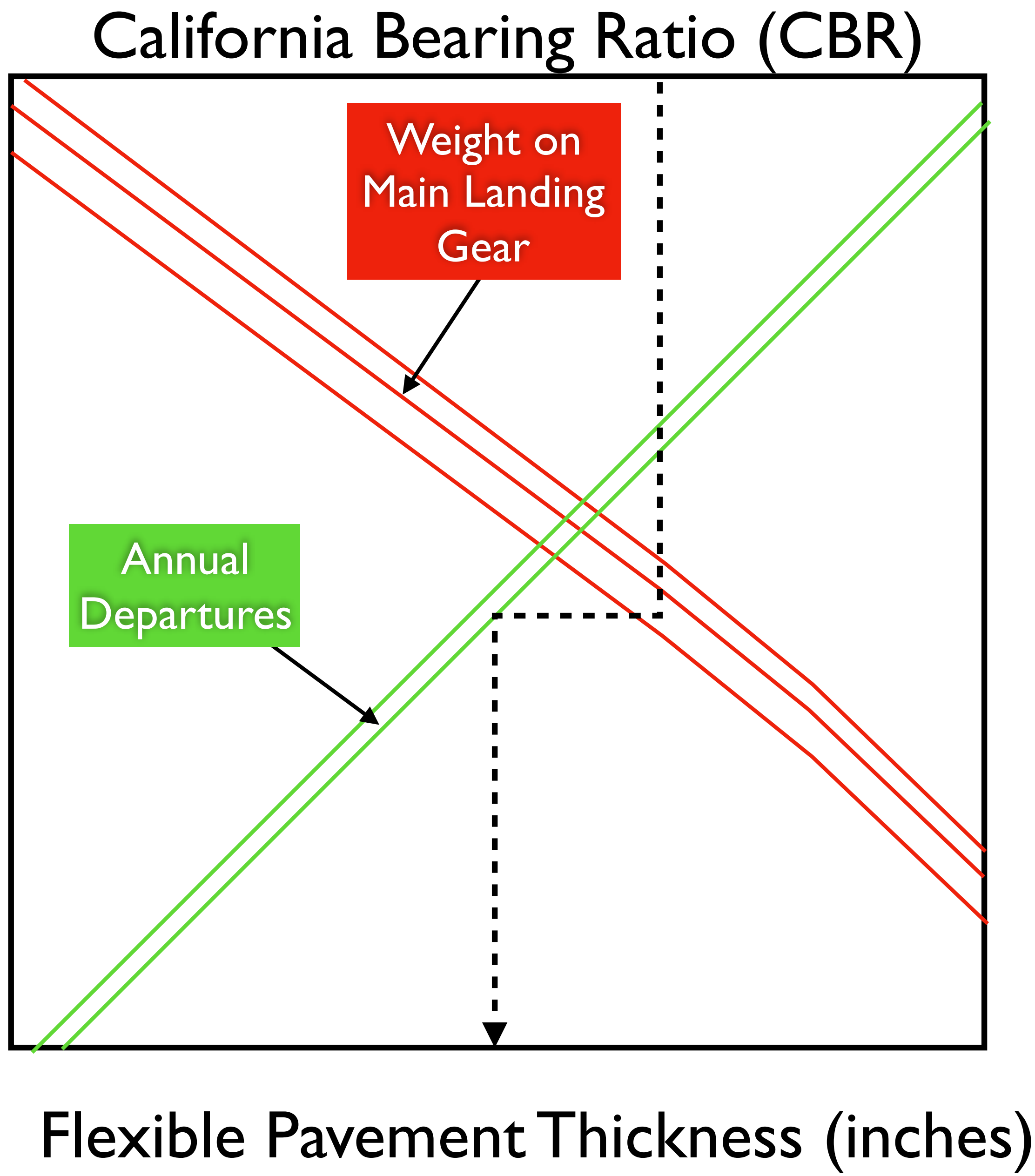
- A measure of the load-bearing capacity (or strength) of natural soil
- Strength of soil compared to crushed California limestone (assumed to have a CBR value of 100)
- CBR is a standard described in ASTM Standard D1883-05 (for laboratory samples)
- D4429 (for soils in the field)
- AASHTO T193

Check out information in : http://www.pavementinteractive.org/california-bearing-ratio/

Sample Airport Pavement Charts

Flexible Pavement Design Chart

U.S. Army Corps of Engineers Design Method (S-77-1):

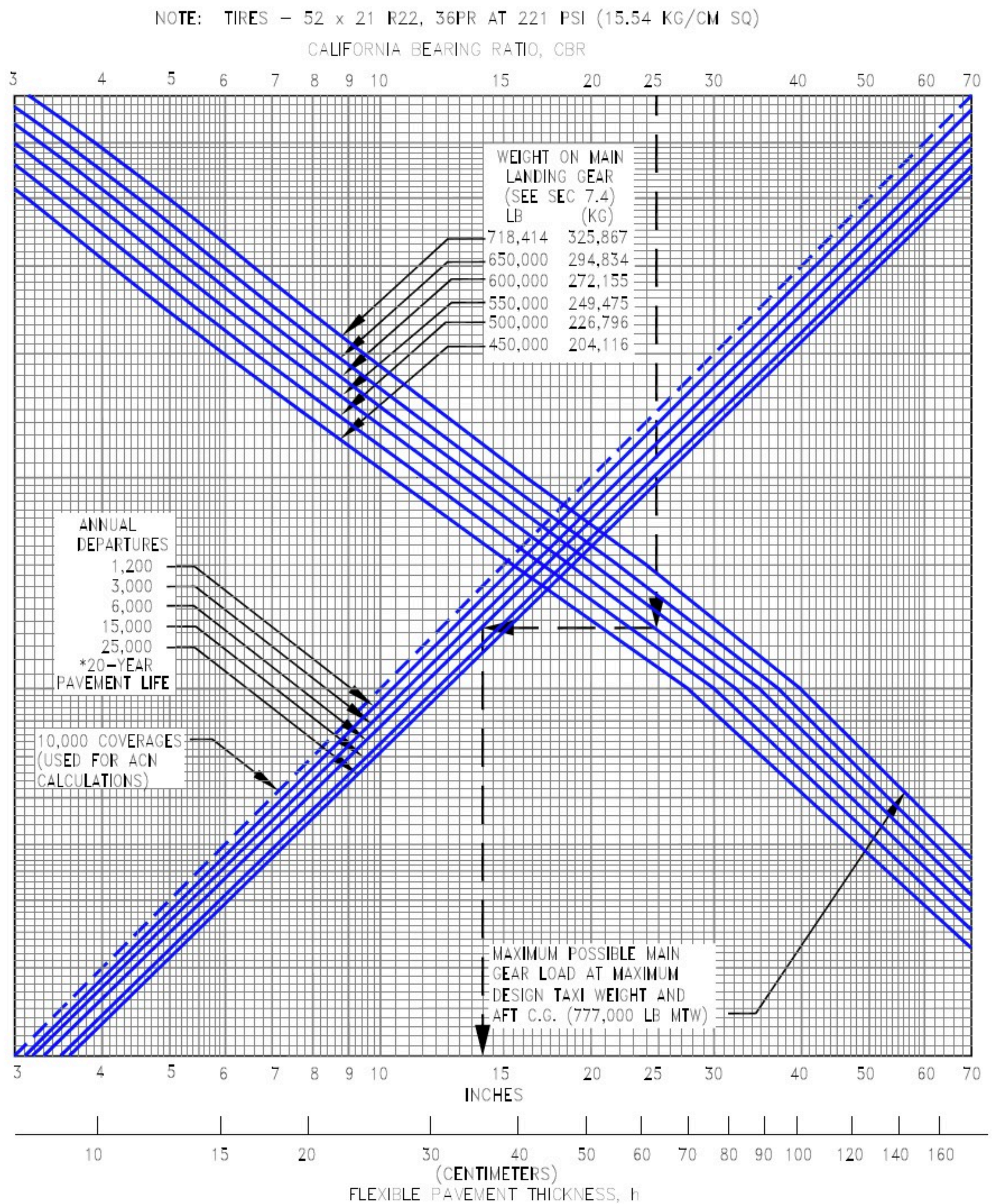


Source:
777-200LR / -300ER / -Freighter
Airplane Characteristics for Airport Planning

Sample Airport Pavement Charts

Flexible Pavement Design Chart

U.S. Army Corps of Engineers Design Method (S-77-1):



Source:
777-200LR / -300ER / -Freighter
Airplane Characteristics for Airport Planning

Example: Quick Design Estimate

Flexible Pavement

Boeing 777-300ER

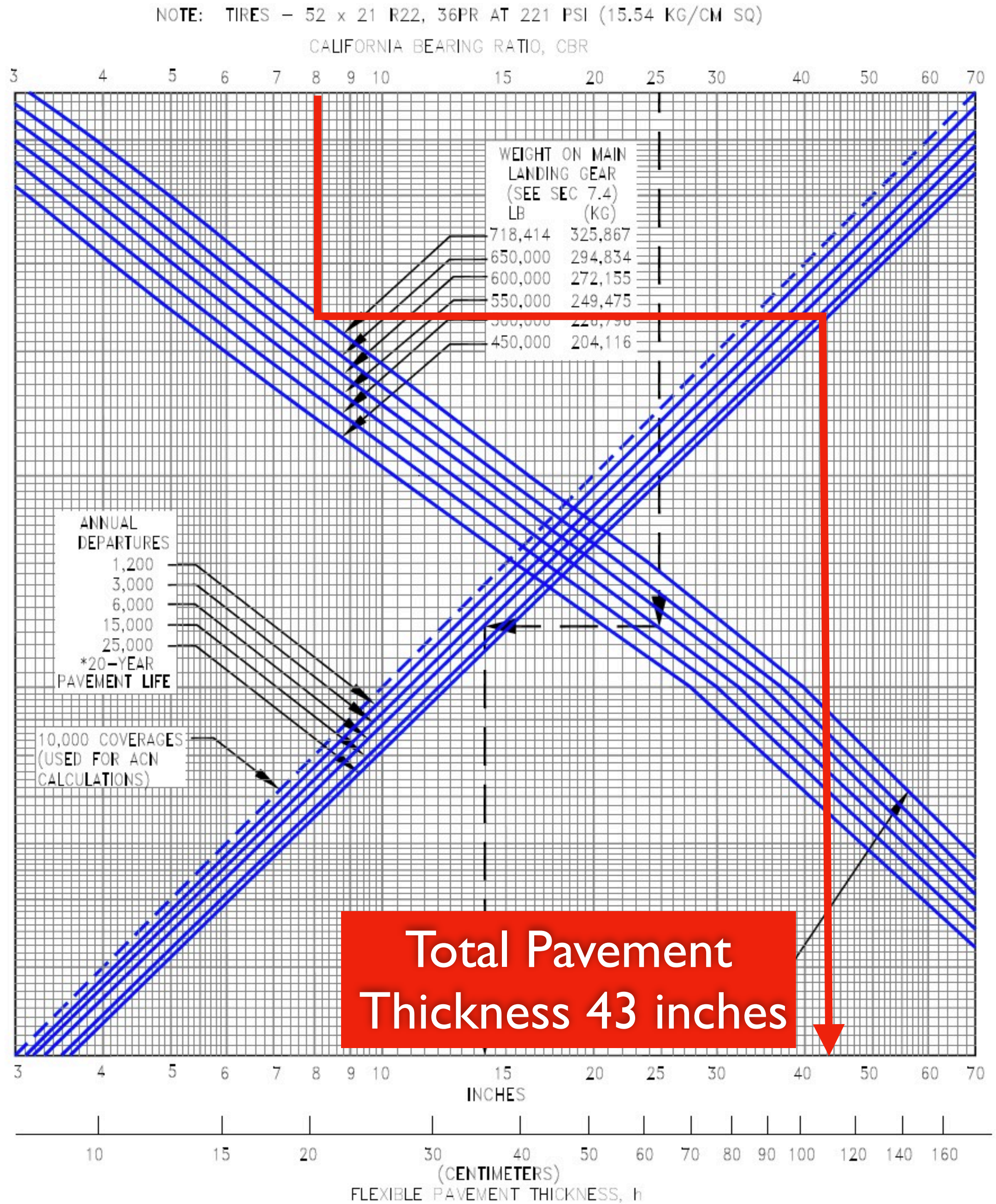
MTOW - 718,414 lb

CBR Subbase - 25

CBR Subgrade - 8

20 year design

U.S. Army Corps of Engineers Design Method (S-77-1):



Source:
777-200LR / -300ER / -Freighter
Airplane Characteristics for Airport Planning

Example: Quick Design Estimate

Flexible Pavement

Boeing 777-300ER

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CBR Subgrade - 8

20 year design

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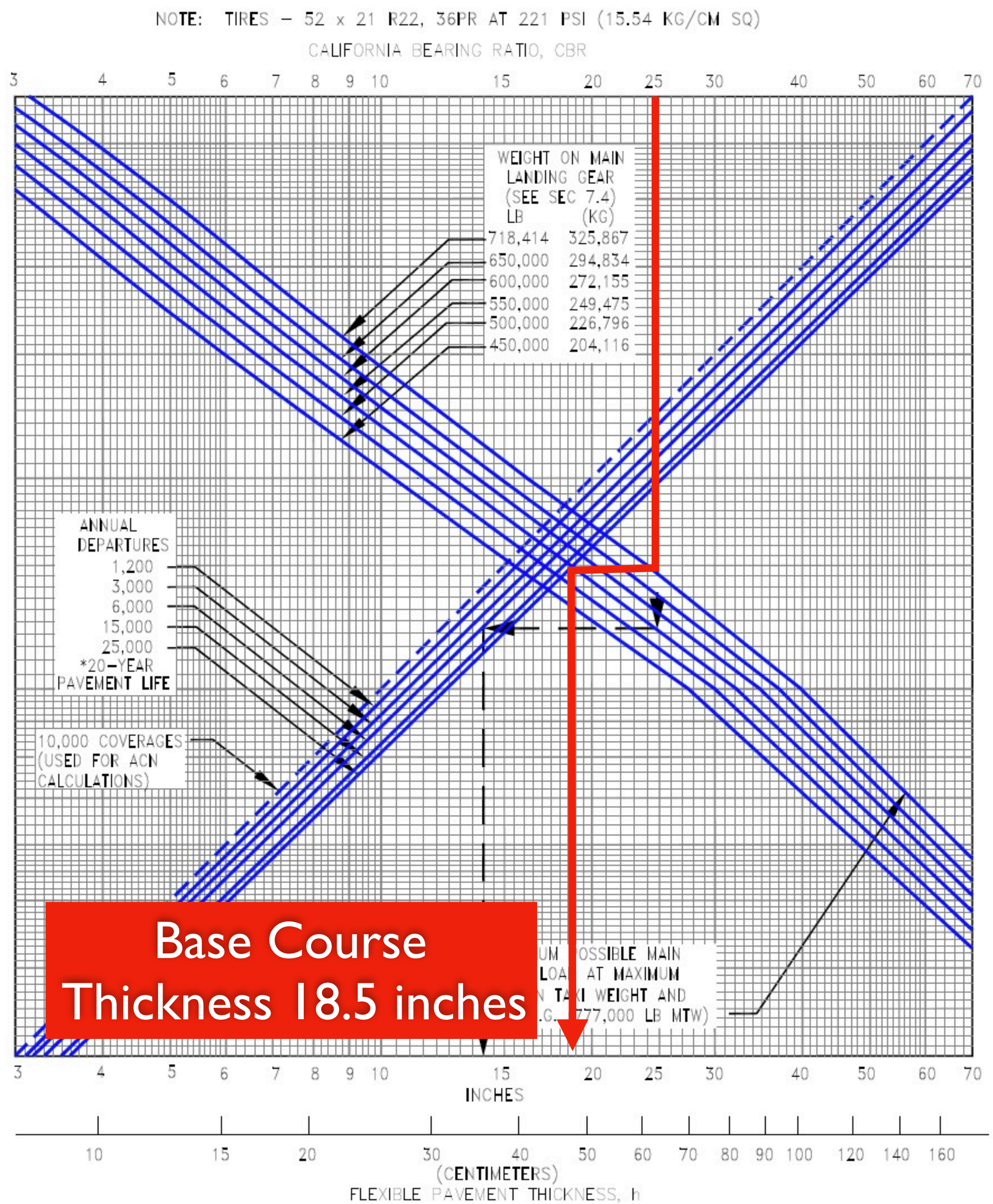


Source:
777-200LR / -300ER / -Freighter
Airplane Characteristics for Airport Planning

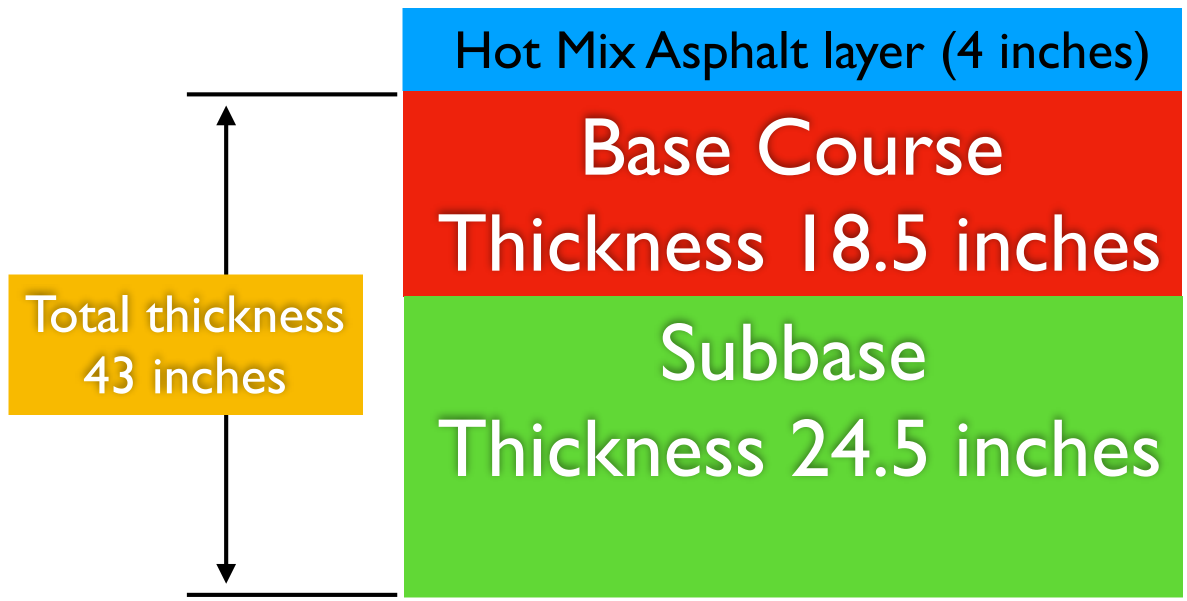
Example: Quick Design Estimate

Flexible Pavement

Boeing 777-300ER
CBR Subbase - 25
CBR Subgrade - 8
20 year design

U.S. Army Corps of Engineers Design Method (S-77-1)

Assumption: No credit given to HMA layer

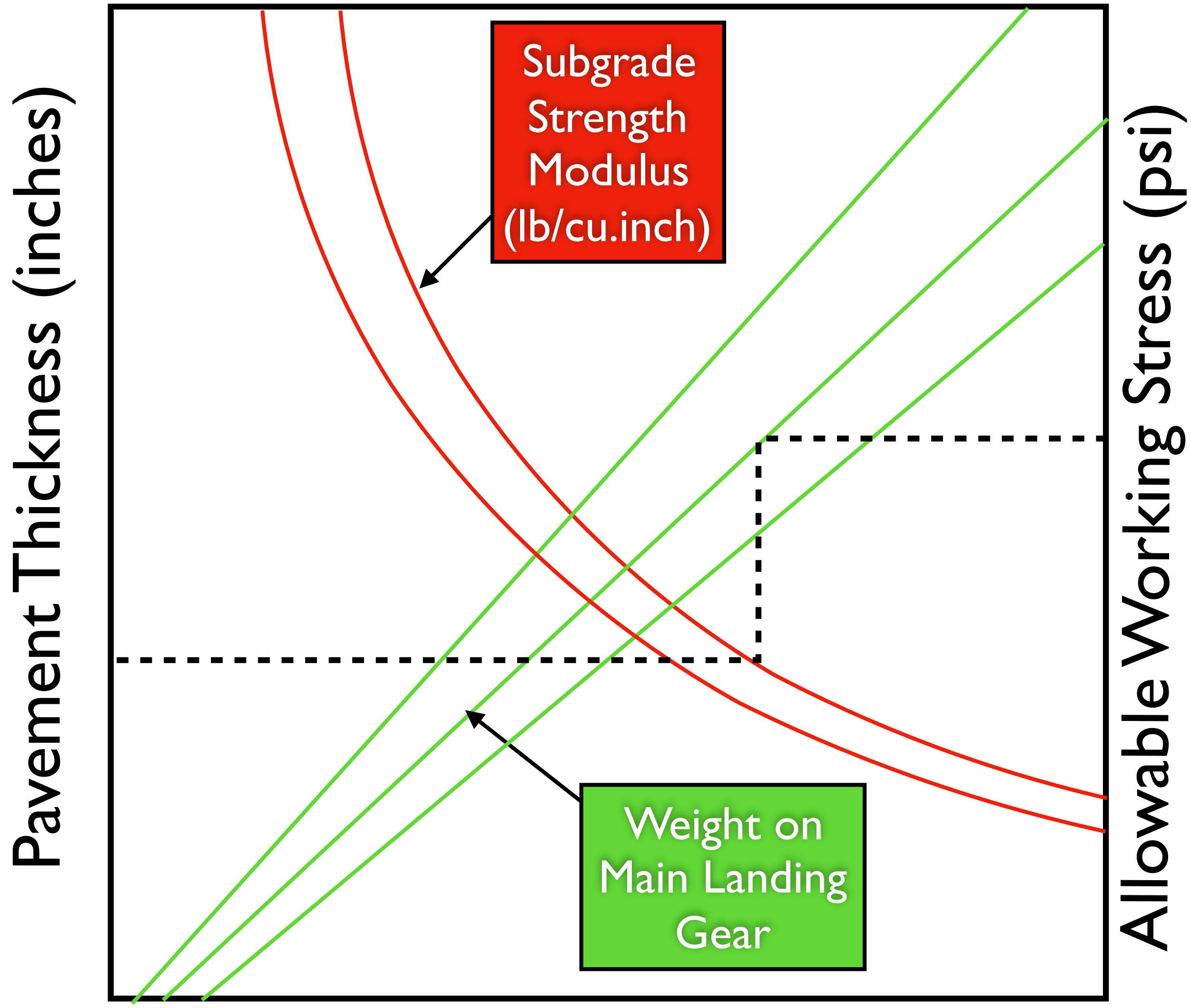


Source:
777-200LR / -300ER / -Freighter
Airplane Characteristics for Airport Planning

Sample Airport Pavement Charts

Rigid Pavement Design Chart

Portland Cement Association Design Method

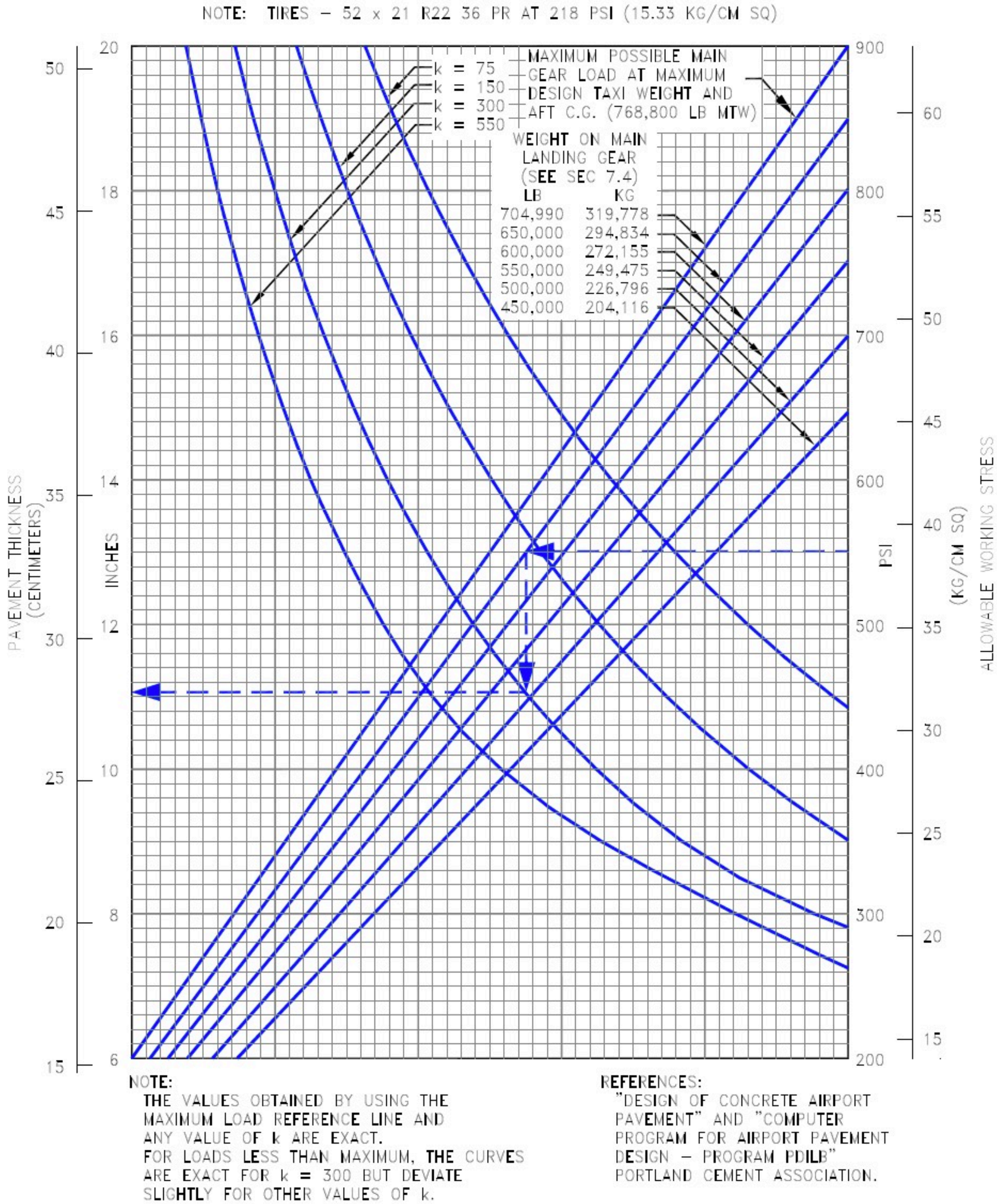


Source:
777-200LR / -300ER / -Freighter
Airplane Characteristics for Airport Planning

Sample Airport Pavement Charts

Rigid Pavement Design Chart

Portland Cement Association Design Method



Source:
777-200LR / -300ER / -Freighter
Airplane Characteristics for Airport Planning

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Invent the Future

Computer Model FAARFIELD v. 1.42

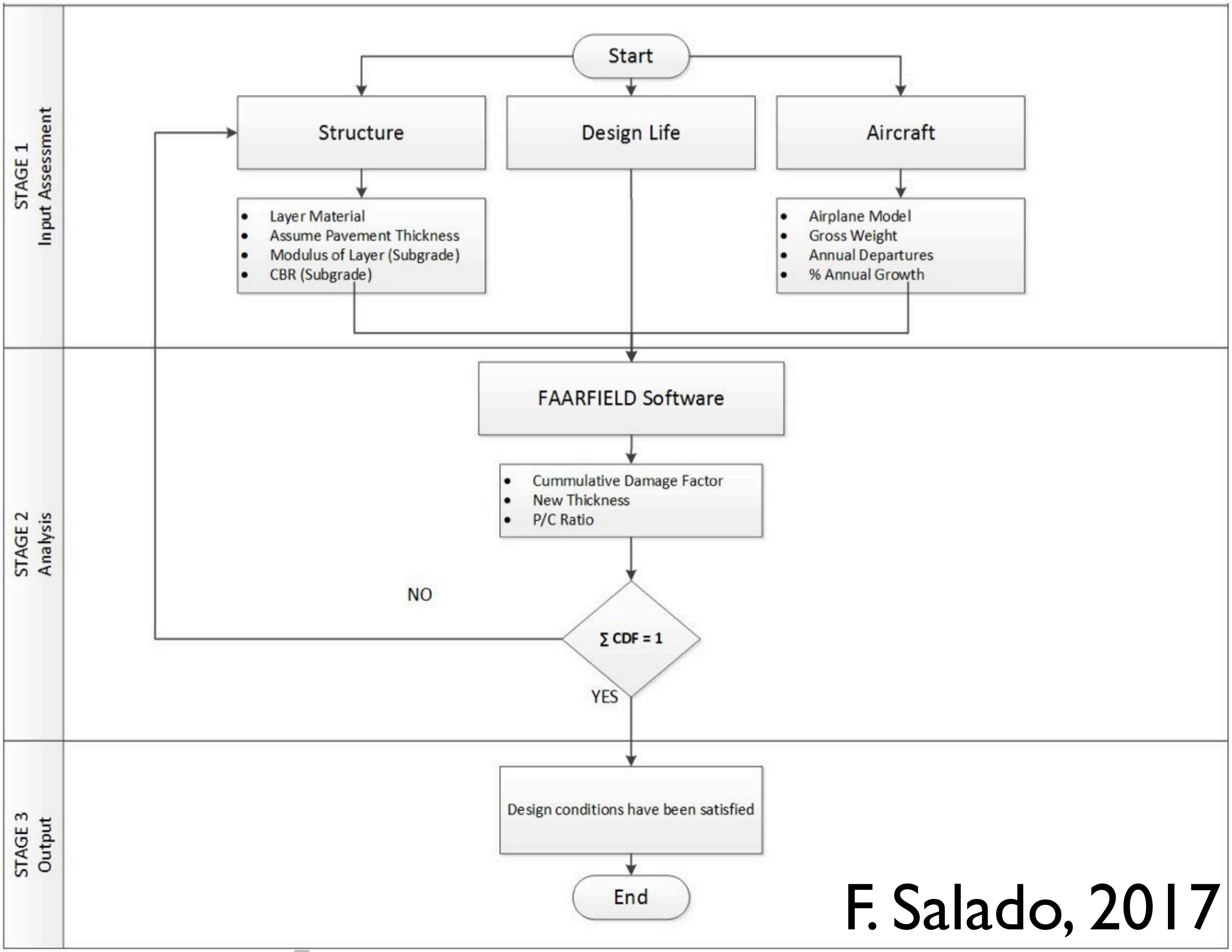
- Companion software to FAA AC 150/5320-6F Airport Pavement Design and Evaluation
- FAARFIELD 1.42 uses the NIKE3D, a 3D finite-element program developed by the U.S. Dept. of Energy Lawrence Livermore National Laboratory (LLNL)
- Employs the Cumulative Damage Factor (CDF) to estimate the contribution of each aircraft for the design of the pavement
- No critical aircraft is used like in the old method
- Pass to Coverage Ratio (P/C) expressed as the number of passes required to apply a full load to a unit area

Computer Model FAARFIELD v. 1.42 Sample Material Specifications

Layer	Materials
Flexible Surface Course	P-401 Plant Mix Bituminous Pavement P-403 Plant Mix Bituminous Pavement (Base, Leveling)
Flexible Base Course	P-209 Crushed Aggregate Base Course P-219 Recycled Concrete Aggregate Base Course
Rigid Base Course	P-301 Soil-Cement Base Course P-304 Cement-Treated Base Course P-306 Econocrete Base Course
Rigid Surface Course	P-501 Portland Cement Concrete Pavement

source: Brill, D. , Standards for Specifying Construction of Airports, 2013

Computer Model FAARFIELD v. 1.42



F. Salado, 2017

Example Problem (F. Salado, 2017)

- Design a Rigid Pavement for a Boeing 777-300ER
  - Pavement Type: Rigid
  - Tires: 220 psi
  - Subgrade Strength (K): 150 lb/in^3
  - Aircraft Maximum Takeoff Weight: 774,600 lb
  - 1200 annual passes
  - 2% growth factor in number of passes
  - 20 year design condition

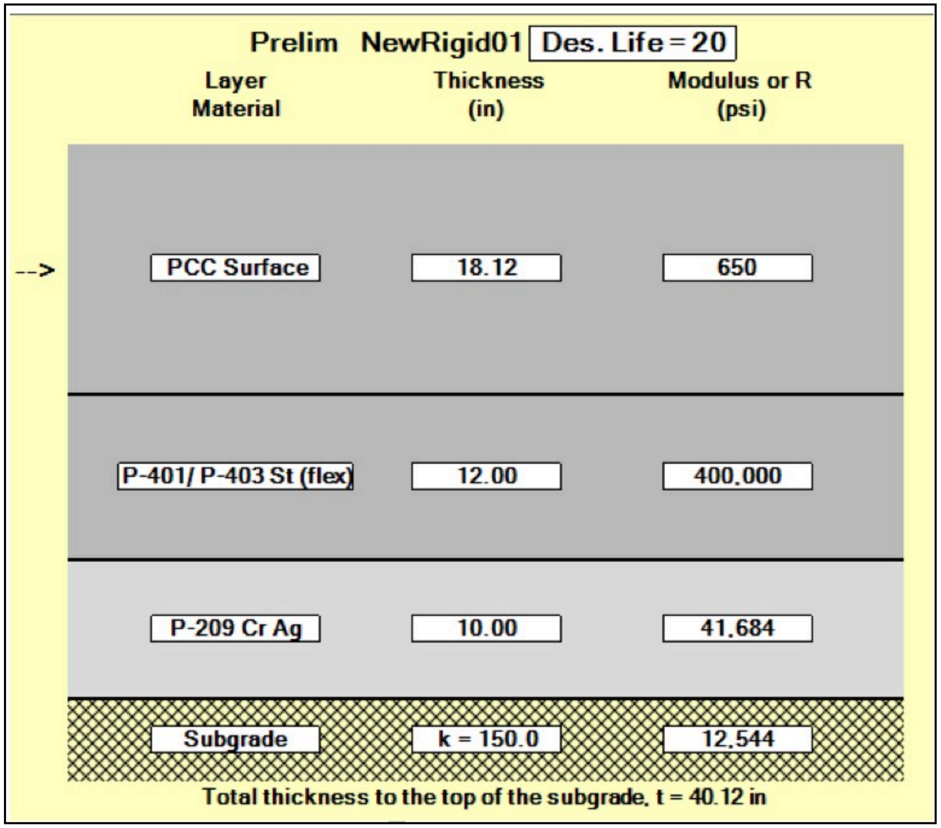
Steps in the Solution (F. Salado)

- Select the design life of 20 years
- For aircraft with MTOW > 100,000 lb, a stabilized base layer below the Portland Cement Concrete (PCC) is required
- HMA P-401 was selected as stabilized base material as recommended from FAA with a thickness of 12 in.
- Material P-209 was selected for crushed aggregate (10 inches)
- The subgrade K value is 150 lb/in^3 with an Elastic Modulus of 12.5 psi.

Example Problem (F. Salado, 2017)

Layer	Type	Thickness in	Modulus psi	Poisson's Ratio	Strength R,psi
1 (top)	PCC Surface	18.12	4,000,000	0.15	650
2	P-401/ P-403 St (flex)	12.00	400,000	0.35	0
3	P-209 Crushed Aggregate	10.00	41,684	0.35	0
4 (bottom)	Subgrade	0.00	12,544	0.40	0

FAA FAARFIELD Model Output



ACN Reporting System

- **ACN = Aircraft Classification Number**
  - Single number expressing the relative effect of an aircraft on a pavement for a specified subgrade strength (ICAO)
  - ACN values are reported for flexible and rigid pavements
- **Flexible pavements** have four subgrade categories:
  - High Strength – CBR 15
  - Medium Strength – CBR 10
  - C. Low Strength – CBR 6
  - Ultra Low Strength – CBR 3

ACN Reporting System

- **ACN = Aircraft Classification Number**
  - Single number expressing the relative effect of an aircraft on a pavement for a specified subgrade strength (ICAO)
  - ACN values are reported for flexible and rigid pavements
- **Rigid pavements** have four subgrade categories:
  - High Strength – Subgrade k = 150 MN/m^3 (550 lb/in^3)
  - Medium Strength – Subgrade k = 80 MN/m^3 (300 lb/in^3)
  - Low Strength – Subgrade k = 40 MN/m^3 (150 lb/in^3)
  - Ultra Low Strength – Subgrade k = 20 MN/m^3 (75 lb/in^3)

ACN Reporting System: Boeing 747-400F

				ACN FOR RIGID PAVEMENT SUBGRADES – MN/m³				ACN FOR FLEXIBLE PAVEMENT SUBGRADES – CBR			
AIRCRAFT TYPE	MAXIMUM TAXI WEIGHT/ MINIMUM WT (1) LB (KG)	LOAD ON ONE MAIN GEAR LEG (%)	TIRE PRESSURE PSI (MPa)	HIGH 150	MEDIUM 80	LOW 40	ULTRA LOW 20	HIGH 15	MEDIUM 10	LOW 6	ULTRA LOW 3
747-400, -400F	877,000(397,800) 395,000(179,200)	23.33	200(1.38)	53 19	62 21	74 25	85 29	53 20	59 21	73 23	94 30
747-400ER, -400 ER FREIGHTER	913,000(414,130) 362,400(164,400)	23.40	230 (1.58)	59 19	69 20	81 23	92 27	57 18	63 19	78 21	100 26

ACN Reporting System Values (source: Wikipedia)

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Aircraft Classification Numbers (ACNs)

Aircraft	Weight Maximum (kN)	Tire Pressure (MPa)	Flexible pavement sub-grades CBR%				Rigid pavement sub-grades k (MPa/m^3)			
			High	Medium	Low	Very low	High	Medium	Low	Ultra low
			A	B	C	D	A	B	C	D
			15	10	6	3	150	80	40	20
A330-200 (Configuration 1)	2,137	1.34	57	62	72	98	48	56	66	78
A330-200 (Configuration 2)	2,264	1.42	62	67	78	106	53	61	73	85
A330-300 (Configuration 1)	2,088	1.31	55	60	70	94	46	54	64	75
A330-300 (Configuration 2)	2,137	1.33	57	61	71	96	47	55	65	77
A330-300 (Configuration 3)	2,264	1.42	62	68	79	107	54	62	74	86
A380-800 (6 Wheel Main Gear)	5,514	1.47	56	62	75	106	55	67	88	110
A380-800 (4 Wheel Wing Gear)	5,514	1.47	62	68	80	108	55	64	76	88
B737-800	777	1.47	44	46	51	56	51	53	55	57
B737-900	777	1.47	44	46	51	56	51	53	55	57
B737-BBJ	763	1.47	43	45	50	55	50	52	54	56
B747-400, 400F, 400M	3,905	1.38	53	59	73	94	53	62	74	85
B747-400D (Domestic)	2,729	1.04	36	39	47	65	30	36	43	51
B747-400ER	4,061	1.58	57	63	78	100	59	69	81	92
B747-SP	3,127	1.26	45	50	61	81	40	48	58	67
B777-300	2,945	1.48	53	59	72	100	54	68	88	108
B777-300ER	3,345	1.52	64	71	89	120	66	85	109	131

ACN Reporting System (source: Wikipedia)

Aircraft Classification Numbers (ACNs)

Aircraft	Weight Maximum (kN)	Tire Pressure (MPa)	Flexible pavement sub-grades CBR%				Rigid pavement sub-grades k (MPa/m^3)			
			High	Medium	Low	Very low	High	Medium	Low	Ultra low
			A	B	C	D	A	B	C	D
			15	10	6	3	150	80	40	20
B787-8	2,240	1.57	60	66	81	106	61	71	84	96
BAC-111 Series 400	390	0.97	23	24	27	29	25	27	28	29
BAC-111 Series 475	440	0.57	23	28	29	32	26	28	29	31
BAC-111 Series 500	467	1.1	29	31	33	35	33	34	35	36
BAe-146-100	376	0.84	18	20	23	26	20	22	24	25
BAe-146-200	416	0.97	22	23	26	29	24	26	27	29
BAe-146-300	436	1.1	24	25	28	31	27	28	30	31
Bae-ATP	232	0.85	12	13	14	16	13	14	15	16
Beech 1900C, 1900D	76	0.67	3	4	4	5	4	4	5	5
Beech 2000 Starship	65	0.54	2	3	4	4	3	4	4	4
Beech Jet 400, 400A	73	0.86	6	7	7	7	6	6	6	6
Beech King Air 100, 200 Series	56	0.73	2	3	3	4	3	3	3	4
Beech King Air 300, 300C, 350, 350C	67	0.73	3	3	4	4	4	4	4	4
Bombardier 415 (Canadair CL-215, 415)	196	0.53	12	14	17	17	14	14	15	15
Bombardier BD-700, Global Express, XRS	437	1.15	26	28	31	32	30	31	32	33
Bombardier Challenger 300	168	1.21	9	9	11	12	11	11	12	12
Bombardier Challenger 800	237	1.12	13	14	16	17	16	16	17	18
Bombardier Challenger CL 600, 601, 604	215	1.21	12	13	15	16	15	15	16	16
Bombardier CRJ100, CRJ200, CRJ440	237	1.12	13	14	16	17	16	16	17	18
Bombardier CRJ700 Series	335	1.06	18	18	21	24	20	21	22	23
Bombardier CRJ900 Series	377	1.06	21	21	24	27	23	24	26	27
Bombardier Dash 8 Q100, Q200 Series	162	0.9	8	8	9	11	9	9	10	10

Operation Conditions

- ICAO recognizes that:
  - *Aircraft can safely operate on a pavement if their ACN is less than or equal to the pavement load bearing capacity or Pavement Classification Number (PCN)*
- *An aircraft having an ACN equal to or less than the PCN can operate without weight restrictions on a pavement (Wikipedia)*
- *PCN is published in an Aeronautical Information Publication (AIP) (Wikipedia)*

Pavement Classification Number (PCN)

- Published in the Aeronautical Information Publication (AIP)
- Published in Airnav

Runway 10C/28C

Chicago ORD Airport Data

Dimensions:	10801 x 200 ft. / 3292 x 61 m
Surface:	concrete/grooved, in excellent condition
Weight bearing capacity:	PCN 96 /R/C/W/T
	Single wheel: 75.0
	Double wheel: 135.0
	Double tandem: 375.0
	Dual double tandem: 902.0