Chapter 11
Landing Gear and Subsystems

What kind of surface do you want to operate from?

Takeoff and Landing on Water

Source: Ahemd Nazim

de Havilland Canada DHC-6 Twin Otter

Source: www.bbc.co.uk

Shorts Sunderland Mk V

Landing on Sand or Grass

Source: 144airbattle.blogspot.com

Source: hushkit.net

Sud-Est Baroudeur

Source: 1000aircraftphotos.com

Air Launch + Landing on Packed Sand

Source: nasa.gov

Source: nasa.gov

North American X-15 launch from B-52, land at Rogers Dry Lake

Takeoff and Landing on Snow

Source: www.flytime.ca

LC-130 with rocket-assisted takeoff

Landing gear must be strong

Monarch A320 landing at BHX

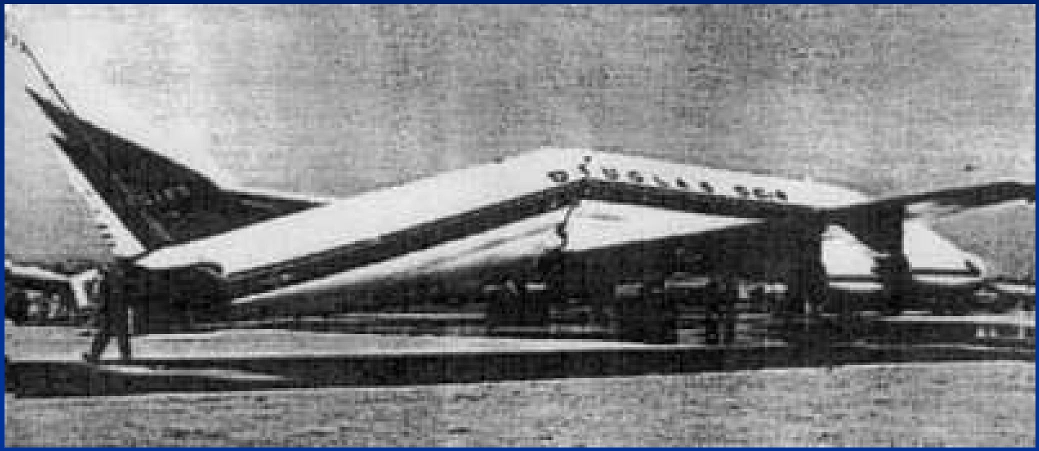
Landing gear must be strong (cont'd)

DC-9-80 Certification
Landing at Edwards AFB

Landing gear must be strong (cont'd)

Source: nycaviation.com

Aviaco DC-9 in Spain 1992/03/30
No fatalities



Source: www.aircrash.org

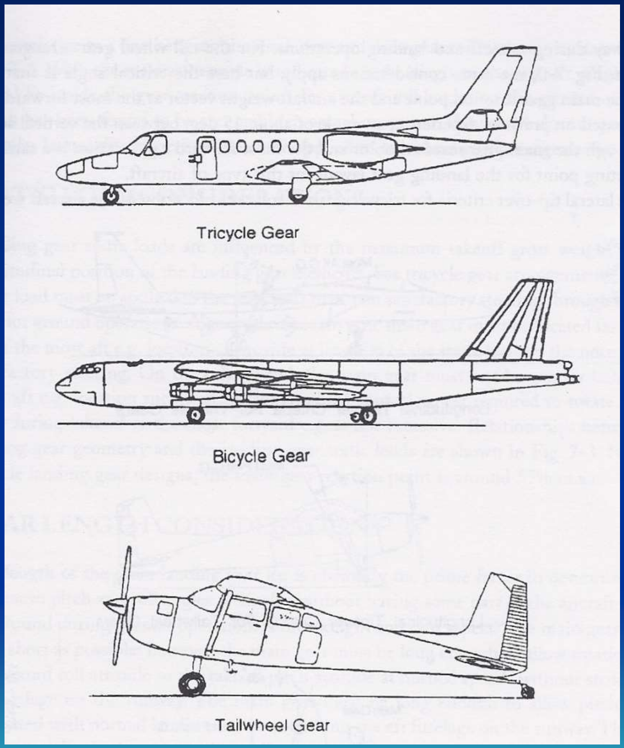
Douglas DC-8 at Edwards AFB 1959/04

Landing Gear Options

Tricycle – most popular, but retractable nose gear difficult with single-engine aircraft

Bicycle – can't rotate on TO, so need large flaps

Taildragger – good for soft field operations, but laterally unstable on ground



Source: Schaufele

B-52 Takeoff

Large flaps enable takeoff without rotation

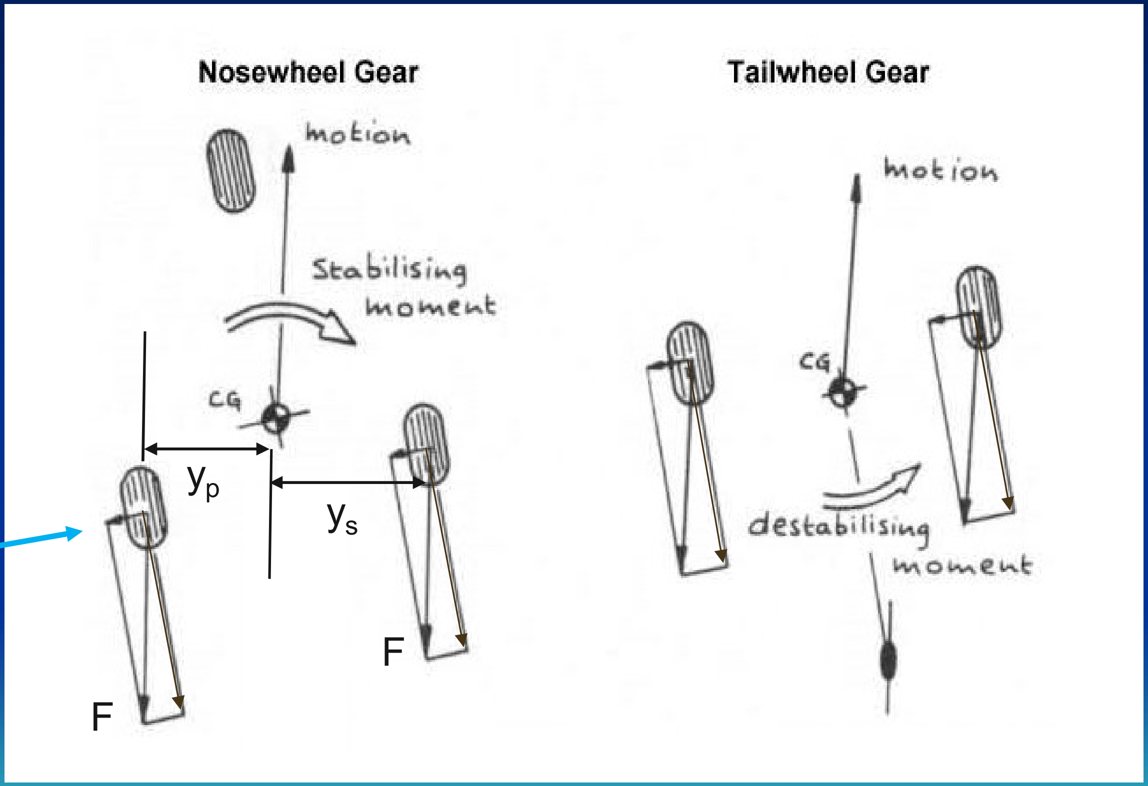
Forward and aft gear bogies caster for cross-wind landing

Yaw stability of tricycle vs. taildragger

Take moments about c.g., ignoring nosewheel or tailwheel loads

For nosewheel gear

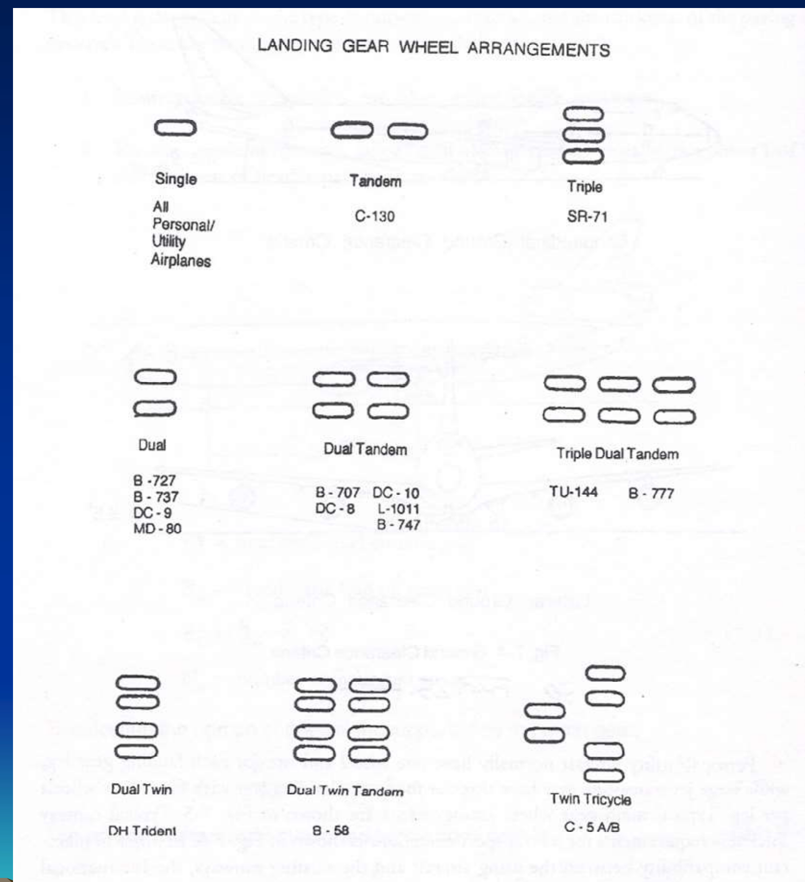
$F \times y_p < F \times y_s$



Source: Stinton, The Design of the Aeroplane

Typical MLG Wheel Arrangements

- Main Landing Gear (MLG) wheel arrangement is a function of
  - Available tire sizes
  - Runway strength/thickness
  - Landing loads
  - Available space for tires



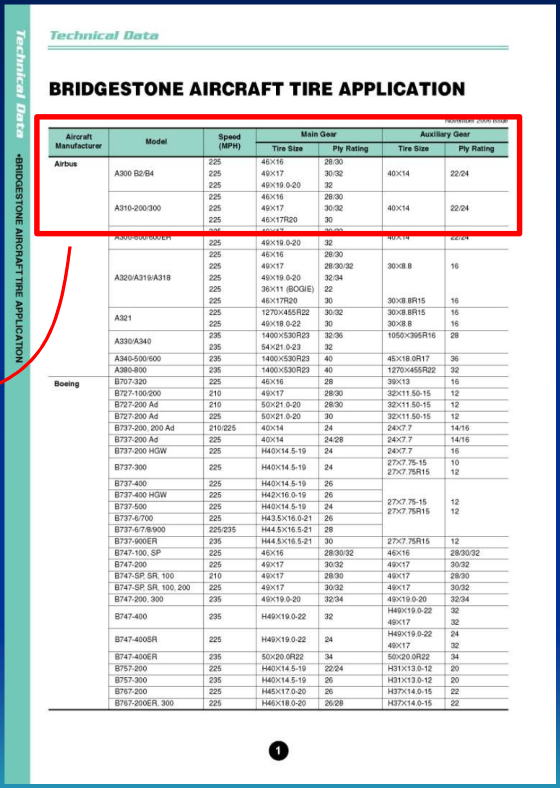
Source: Schaufele

Select Tire Size

- Select tire size for class and TOGW of aircraft from appropriate source, such as http://www.bridgestone.com/products/speciality_tires/aircraft/products/applications/pdf/tire_applications.pdf

November 2006 issue

Aircraft Manufacturer	Model	Speed (MPH)	Main Gear		Auxiliary Gear	
			Tire Size	Ply Rating	Tire Size	Ply Rating
Airbus	A300 B2/B4	225 225 225	46X16 49X17 49X19.0-20	28/30 30/32 32	40X14	22/24
	A310-200/300	225 225 225	46X16 49X17 46X17R20	28/30 30/32 30	40X14	22/24


Technical Data

BRIDGESTONE AIRCRAFT TIRE APPLICATION

November 2006 issue

Aircraft Manufacturer	Model	Speed (MPH)	Main Gear		Auxiliary Gear	
			Tire Size	Ply Rating	Tire Size	Ply Rating
Airbus	A300 B2/B4	225 225 225	46X16 49X17 49X19.0-20	28/30 30/32 32	40X14	22/24
	A310-200/300	225 225 225	46X16 49X17 46X17R20	28/30 30/32 30	40X14	22/24
	A300-600/600ER	[illegible] 225	[illegible] 49X19.0-20	[illegible] 32	40X14	22/24
	A320/A319/A318	225 225 225 225 225	46X16 49X17 49X19.0-20 36X11 (BOGIE) 46X17R20	28/30 28/30/32 32/34 22 30	30X8.8 30X8.8R15	16 16
	A321	225 225	1270X455R22 49X18.0-22	30/32 30	30X8.8R15 30X8.8	16 16
	A330/A340	235 235	1400X530R23 54X21.0-23	32/36 32	1050X395R16	28
	A340-500/600	235	1400X530R23	40	45X18.0R17	36
	A380-800	235	1400X530R23	40	1270X455R22	32
Boeing	B707-320	225	46X16	28	39X13	16
	B727-100/200	210	49X17	28/30	32X11.50-15	12
	B727-200 Ad	210	50X21.0-20	28/30	32X11.50-15	12
	B727-200 Ad	225	50X21.0-20	30	32X11.50-15	12
	B737-200, 200 Ad	210/225	40X14	24	24X7.7	14/16
	B737-200 Ad	225	40X14	24/28	24X7.7	14/16
	B737-200 HGW	225	H40X14.5-19	24	24X7.7	16
	B737-300	225	H40X14.5-19	24	27X7.75-15 27X7.75R15	10 12
	B737-400	225	H40X14.5-19	26	27X7.75-15 27X7.75R15	12 12
	B737-400 HGW	225	H42X16.0-19	26		
	B737-500	225	H40X14.5-19	24		
	B737-6/700	225	H43.5X16.0-21	26		
	B737-6/7/8/900	225/235	H44.5X16.5-21	28		
	B737-900ER	235	H44.5X16.5-21	30	27X7.75R15	12
	B747-100, SP	225	46X16	28/30/32	46X16	28/30/32
	B747-200	225	49X17	30/32	49X17	30/32
	B747-SP, SR, 100	210	49X17	28/30	49X17	28/30
	B747-SP, SR, 100, 200	225	49X17	30/32	49X17	30/32
	B747-200, 300	235	49X19.0-20	32/34	49X19.0-20	32/34
	B747-400	235	H49X19.0-22	32	H49X19.0-22 49X17	32 32
	B747-400SR	225	H49X19.0-22	24	H49X19.0-22 49X17	24 32
	B747-400ER	235	50X20.0R22	34	50X20.0R22	34
	B757-200	225	H40X14.5-19	22/24	H31X13.0-12	20
	B757-300	235	H40X14.5-19	26	H31X13.0-12	20
	B767-200	225	H45X17.0-20	26	H37X14.0-15	22
	B767-200ER, 300	225	H46X18.0-20	26/28	H37X14.0-15	22

•BRIDGESTONE AIRCRAFT TIRE APPLICATION

1

Leading Aircraft Tire Manufacturers

- Goodyear (United States)
  - Extensive tire data
- Michelin (France)
  - Data on Commercial/Regional Jets only
- Dunlop Aircraft Tyres (United Kingdom)
  - Limited aircraft types
- Bridgestone (Japan)
  - Good manual for selecting by aircraft type

Tire Sizing: Example 777-200LR/300ER

Tire dia. (inches)
Tire width (inches)
R = radial
Rim width (inches)

FAR 25.733 (c) (1)

MTOGW = 775,000 lb
Bridgestone highest rated radial tire
52x21.0R22 rated at 66,500 lb
(from Bridgestone website)

Assume:
MLG carries 90% of static load
FAR requires 7% margin
Number of wheels

$$= \frac{775{,}000 \times 0.90 \times 1.07}{66{,}500} = 11.2$$

(Note: 777-200 uses 50x20.0R22)

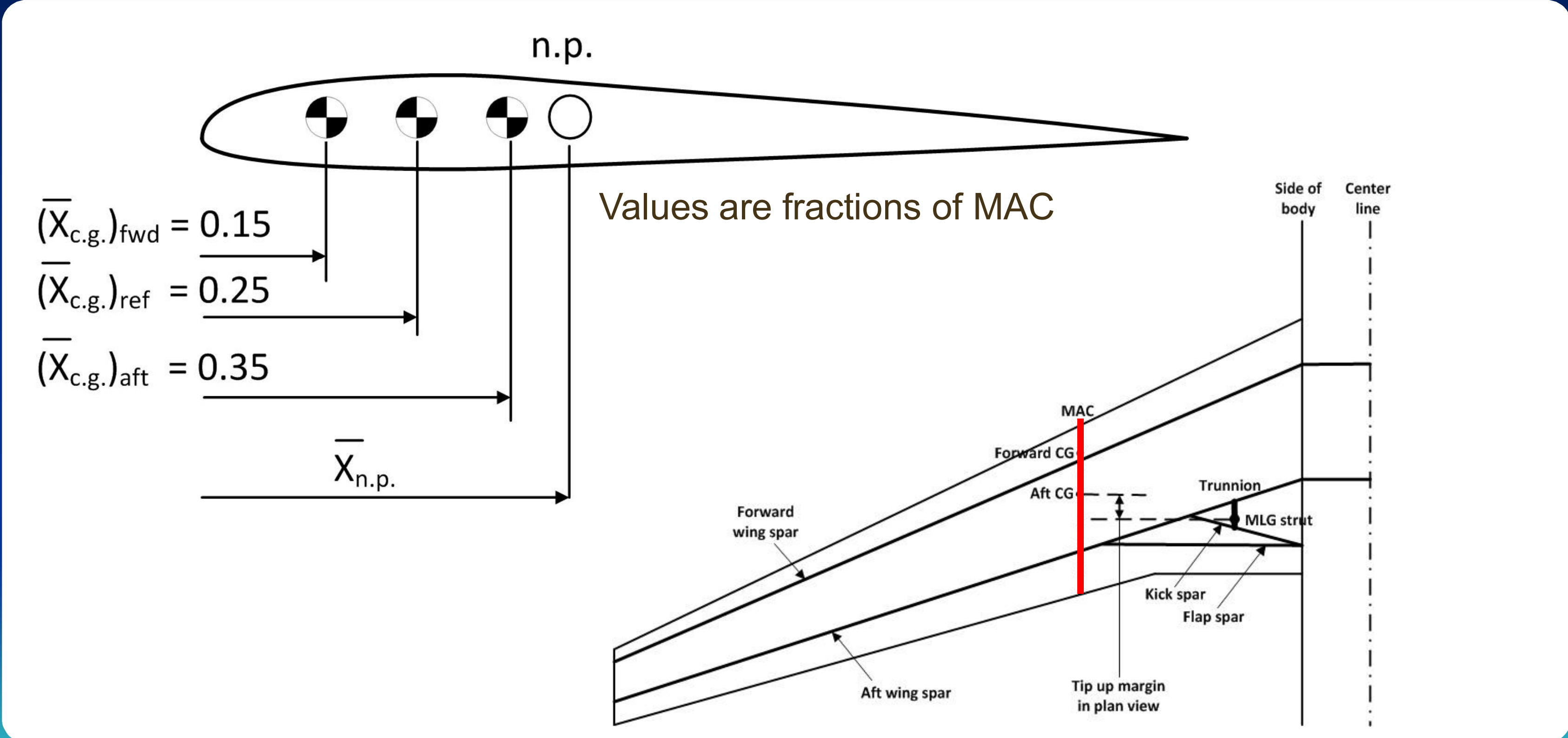
Runway Loading-Bearing Capacity

Concern for initial wide-body operations (747, L1011, DC-10)

LGA R/W 22 piers

LAX Sepulveda Blvd. tunnel

Nominal C.g. Locations for Commercial Aircraft



ADAC Aircraft Design & Consulting

Lateral Tip-over Margin

- This is what you don't want to have happen
- Engine run mishap at Eielson AFB (Feb 2003)
- Note axis of rotation (line between contact point on ground of NLG and starboard MLG)

Source: www.ar15.com

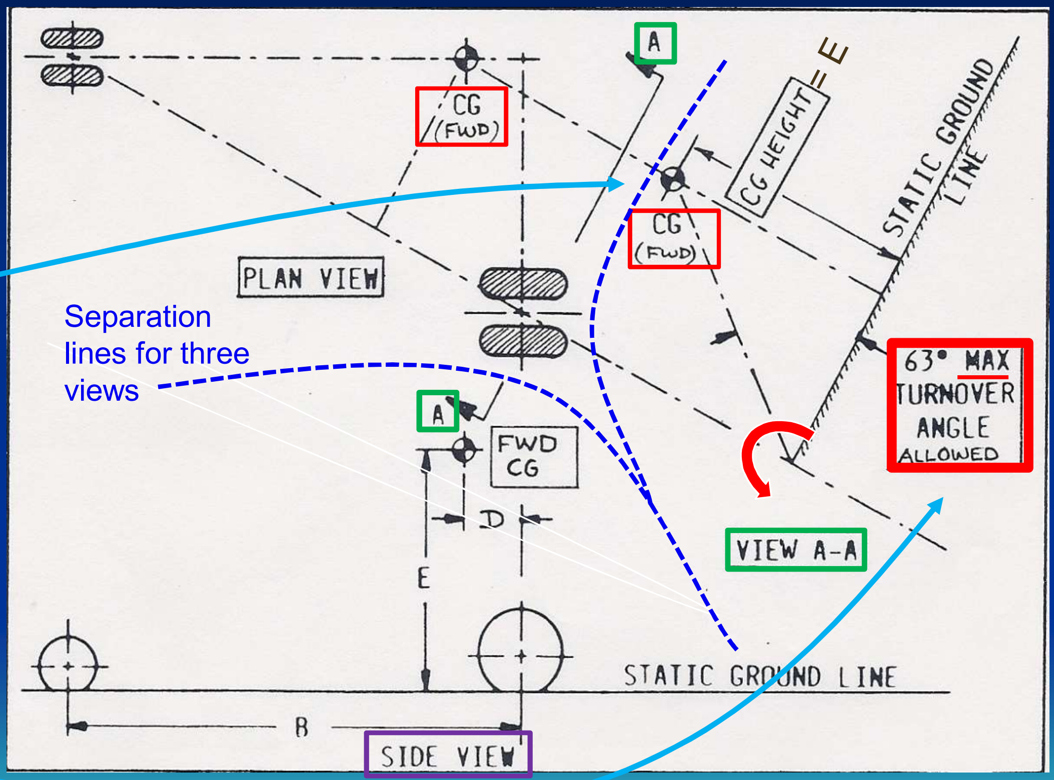
Lateral Tip-over Margin

- Make mirror image of original photo to be consistent with next slide

Source: www.ar15.com

Lateral Tip-over Margin

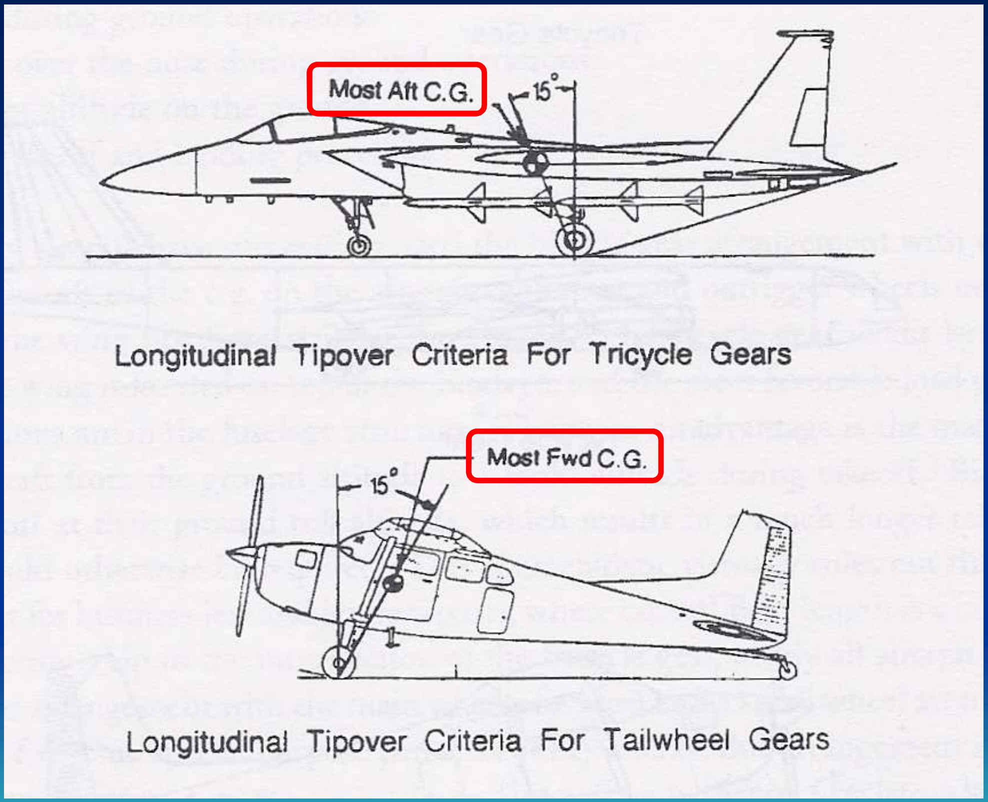
- Make scrap view in plane normal to line between ground location of NLG and MLG
- Assume c.g. height of commercial aircraft is at floor level
- Max elevation of forward c.g. from tip-over axis
  - 54^0 if carrier-based
  - 63^0 for all others (corresponds to lateral ½ g turn)



Source: Roskam

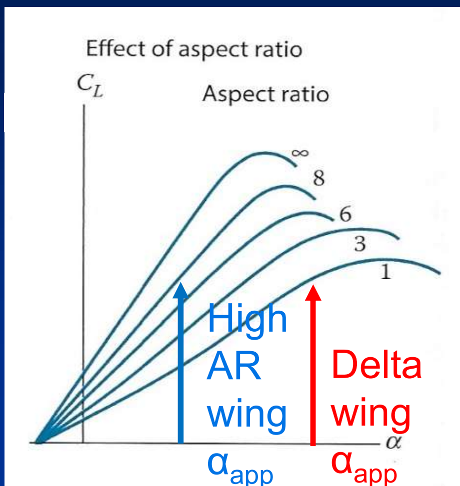
Longitudinal Tip-up Margin

- Margin for tricycle layout is approximate
  - Less for unswept wing
  - More for delta wing
- For taildragger
  - More for soft field ops



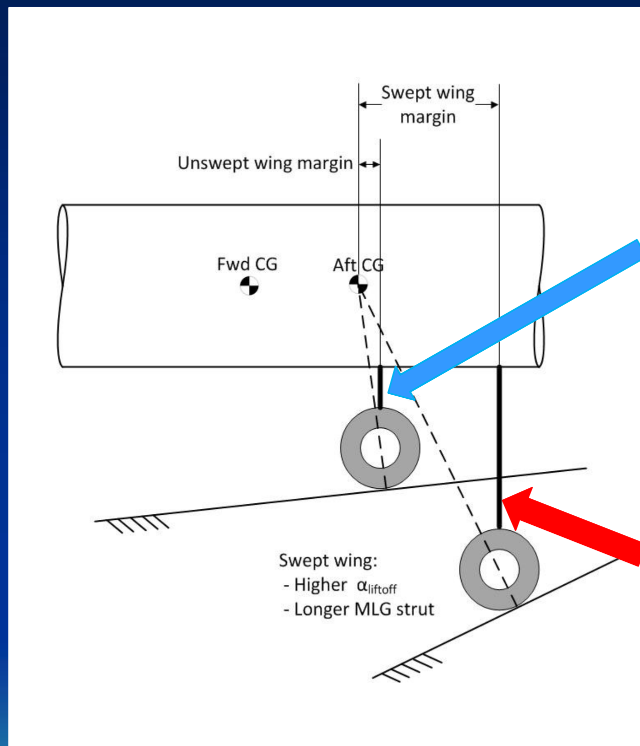
Source: Schaufele

Effect of AR on MLG Length and Location



For low AR planform, $C_{L_{max}}$ at much higher α

With horizontal tail, can use flaps, reduce α_{app}

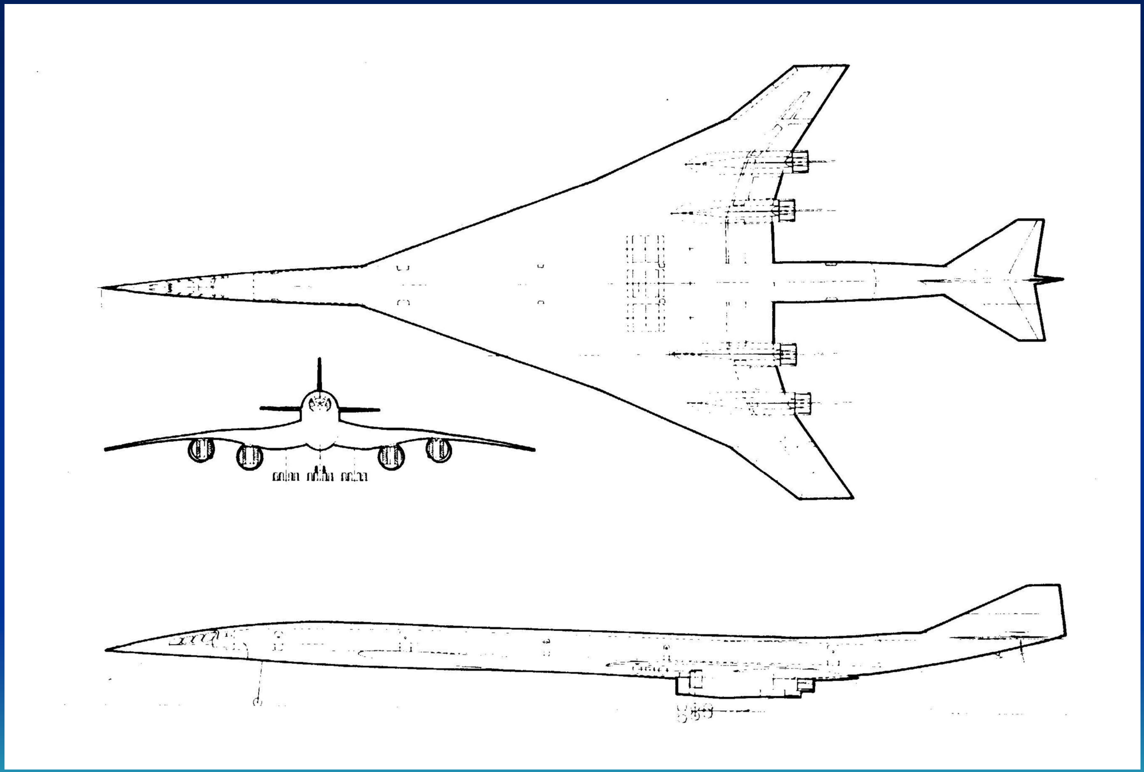


Embraer Phenom

BAC/Sud Concorde

CL-1611 Supersonic Transport

Horizontal stabilizer permits use of wing flaps, thus reduced attitude at t/o and landing, thus shorter landing gear (less weight, less drag)



Establishing V_{MU}

FAR 25.107 (d) defines V_{MU} as lowest CAS at which aircraft can safely lift off the ground

FAR 25.107 (e) (1) (iv) defines related flight speeds

For AEO $V_{LO} \geq 1.10\ V_{MU}$

For OEI $V_{LO} \geq 1.05\ V_{MU}$

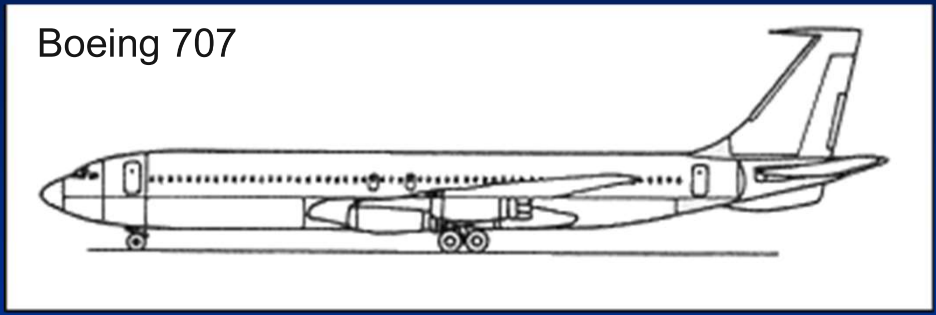
Boeing Moses Lake Flight Test Center

Design for Growth

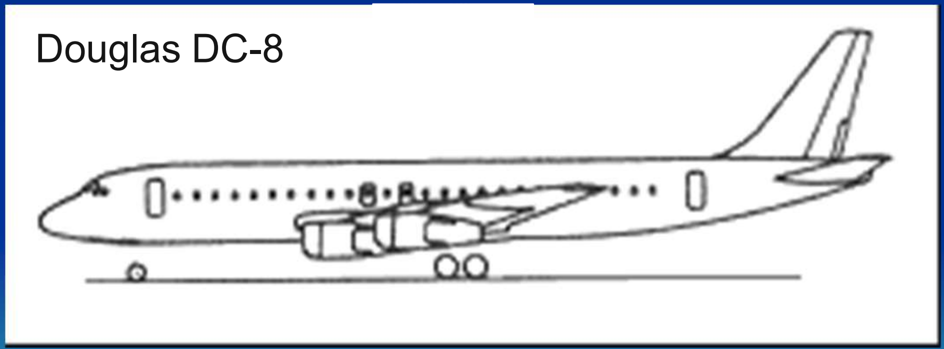
Comment from Ed Wells (Boeing Sr. VP and on BoD, helped design B-17, 707, 747) to Phil Condit (Boeing CEO):

"Be careful how long or how short you make the landing gear"

Source: Bloomberg Business Week, Feb 19, 2018

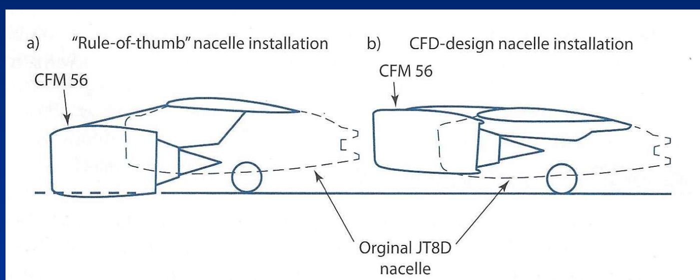


http://www.aviastar.org/air/usa/boeing-707.php



http://www.aviastar.org/air/usa/mcdonnel_dc-8.php

Design for New Technology



Boeing failed to leave space for HBPR engines, such as CFM-56

http://www.aviastar.org/air/usa/boeing-737.php

http://www.aerospaceweb.org/aircraft/jetliner/a320/

Observe aft C.g. Limit when on Ground

- Easy to exceed aft c.g. limit when loading or unloading cargo
- Should install tail strut to prevent tip-up

Landing Gear Reaction Forces

$$\frac{R_m}{W} = \frac{L_n}{L_m + L_n}$$

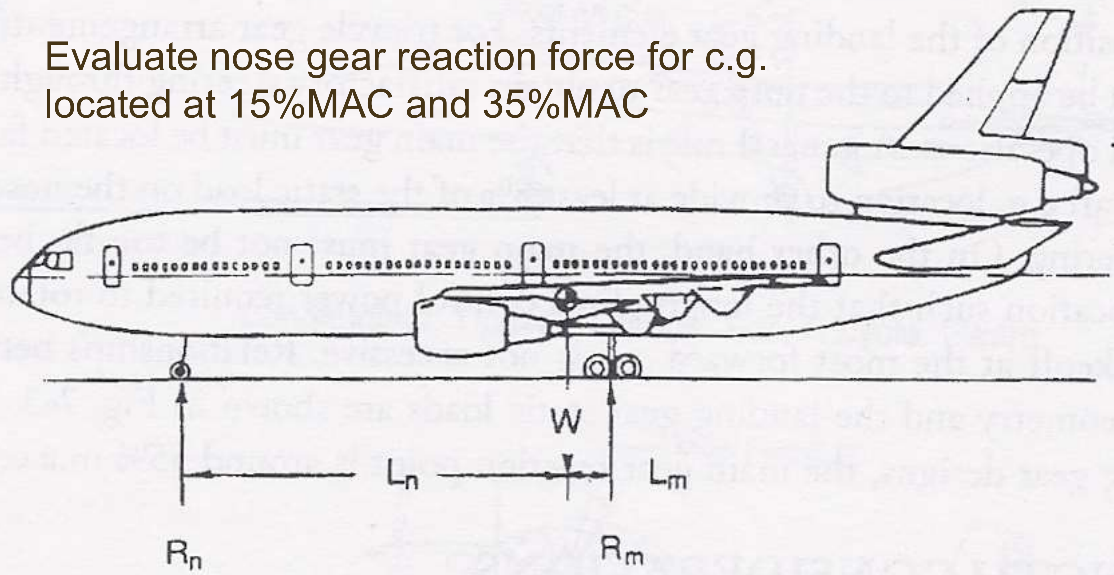
$$\frac{R_n}{W} = \frac{L_m}{L_m + L_n}$$

Currey suggests

$$0.08 \leq \frac{R_n}{W} \leq 0.15$$

Aft c.g. Fwd c.g.

Evaluate nose gear reaction force for c.g. located at 15%MAC and 35%MAC



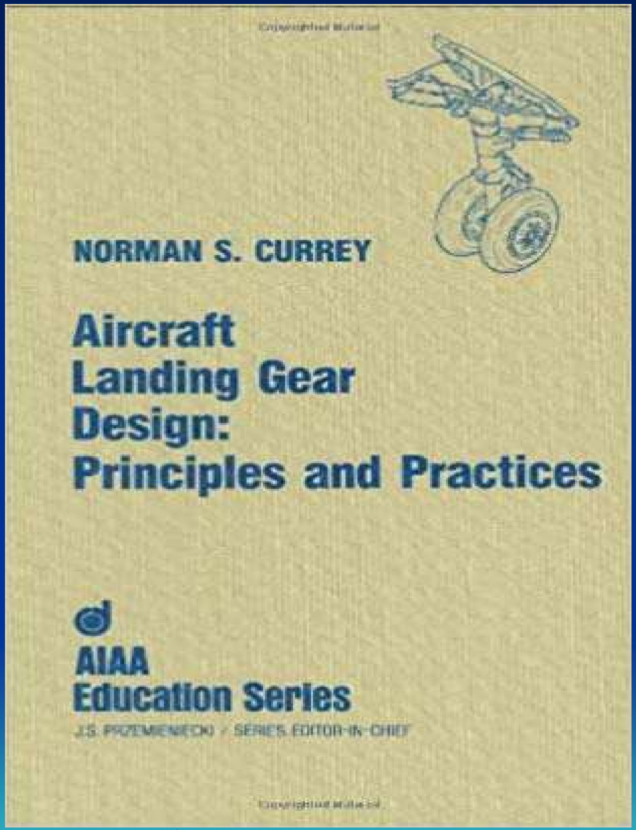
Source: Schaufele

If nose gear load is below limit at aft c.g., it may have to be moved aft

Short Commercial Break

Also worked at Lockheed (in Georgia) and also British

Excellent book on landing gear design

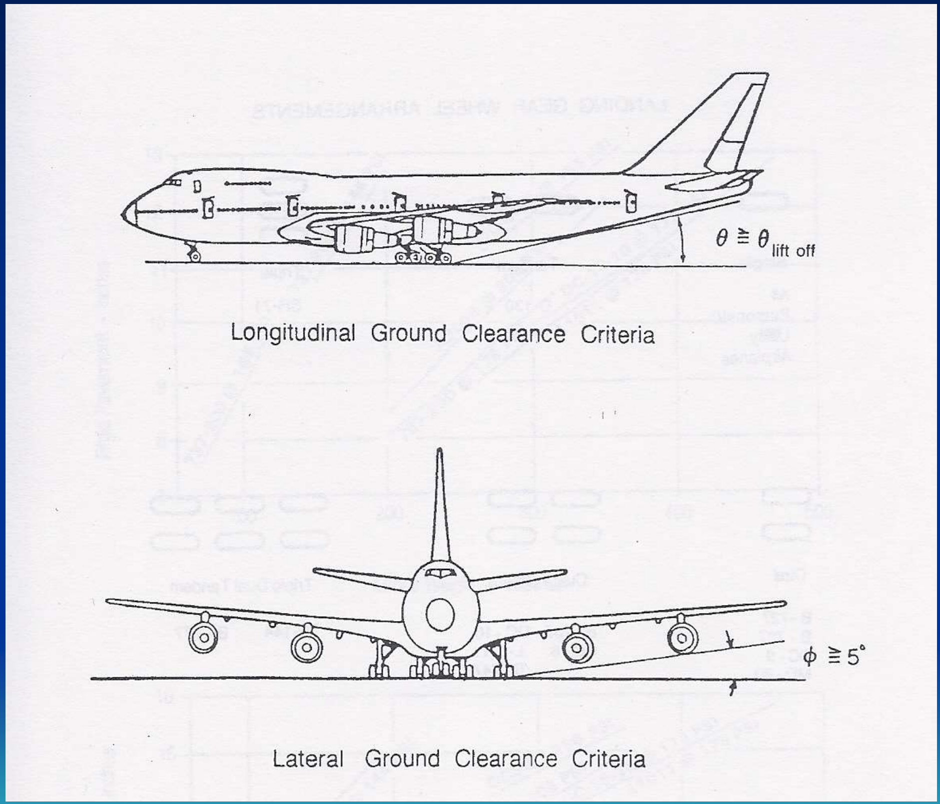


Ground Clearance Criteria

Allowable bank angle with OEI is

Φ = 5 deg,

set by FAR 25.149(b)



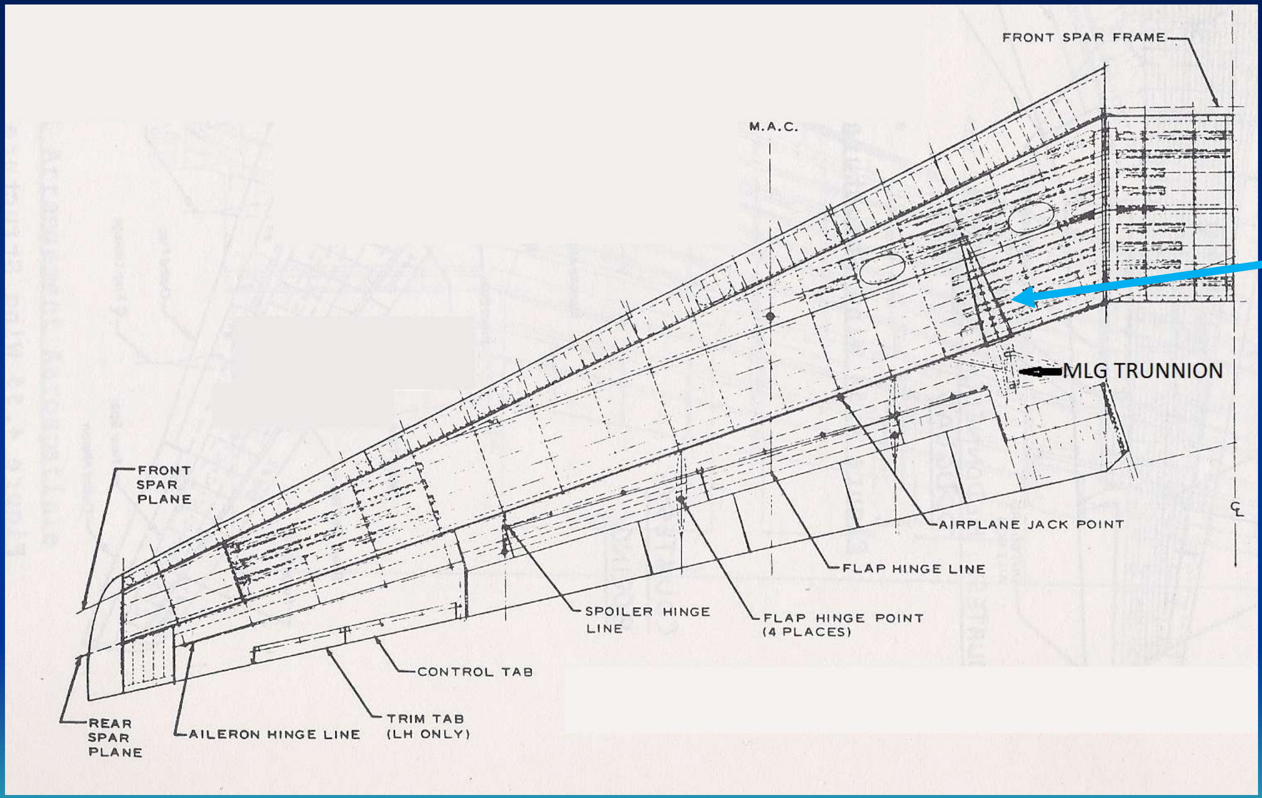
Source: Schaufele

You Don’t Want This To Happen

Source: Av Herald.com

KE A380 at NRT, Jul 11, 2011. The aircraft continued on its flight.

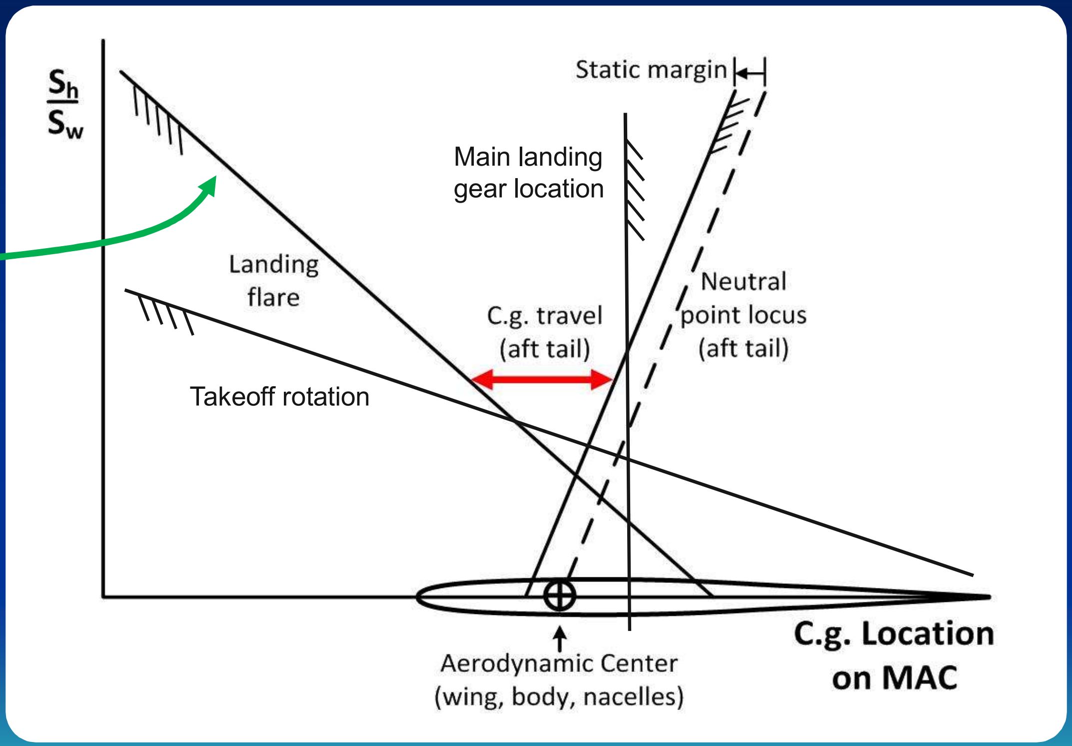
DC-9 Wing Structure



MLG trunnion cantilevered off wing box

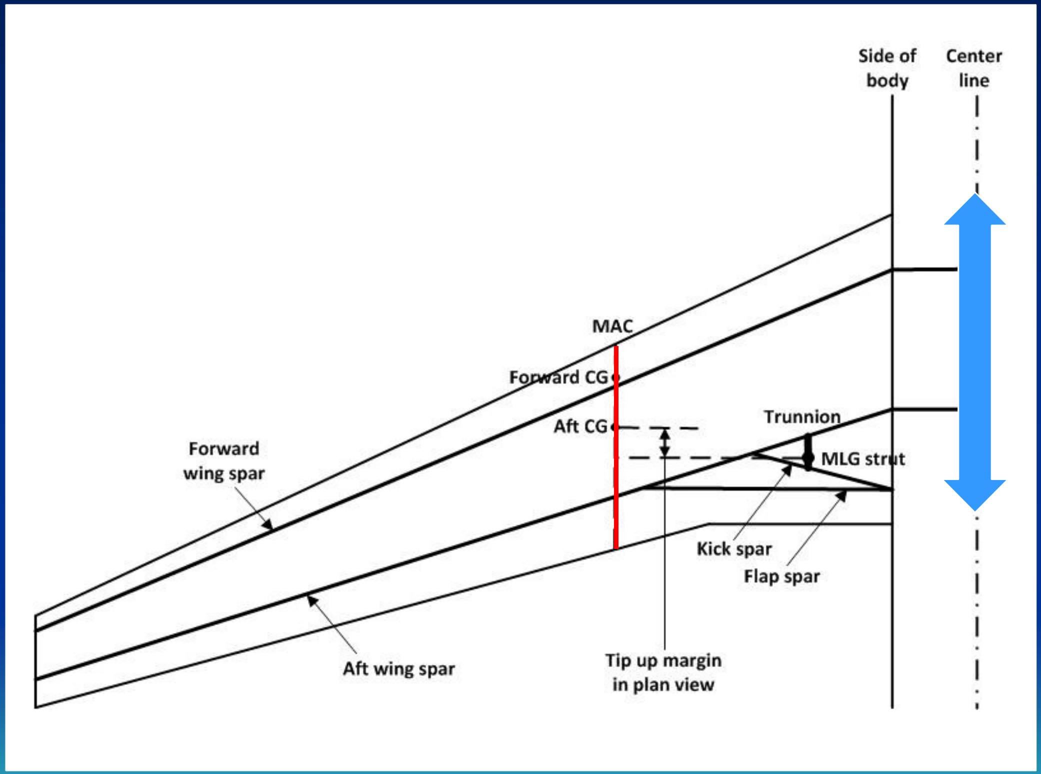
Notch Chart

- For aft tail configuration
- Landing flare line moves to right with increasing C_{m_0} (e.g. flaps)



Effect of Λ or AR on MLG Design

- Typical CG limits:
  - Fwd: 15% MAC
  - Aft: 35% MAC
- As Λ or AR increase, aft CG limit moves further aft relative to MLG
- As Λ increases, $\alpha_{liftoff}$ also increases, forcing MLG further aft



- Move fuselage forward or aft wrt wing to get CG in correct location

Canting 787 MLG Strut Aft

- Additional bending moments induced in strut
- Maximum aft cant of about 15^0

Forward

B787 MLG (starboard)

ADAC Aircraft Design & Consulting

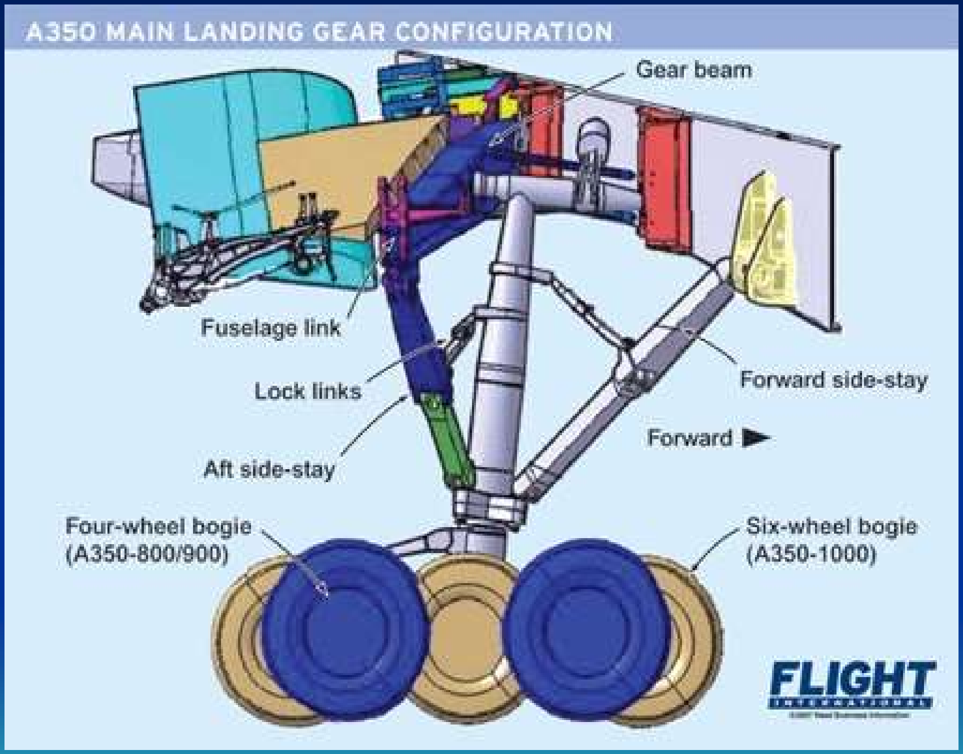
787 MLG Trunnion Attachment

- Most vertical loads carried through trunnion to rear spar and kick spar
- Single lever arm for retraction

B787 MLG (port)

A350 MLG Trunnion Attachment

- Most vertical loads carried through trunnion to rear spar and gear beam
- Single lever arm for retraction



A350 MLG – port side

Wing Design Study Λ = 25 deg

- Unconstrained wing design
  - Block fuel = 59.1 Klb
- Constrained wing design
  - Block fuel = 59.4 Klb

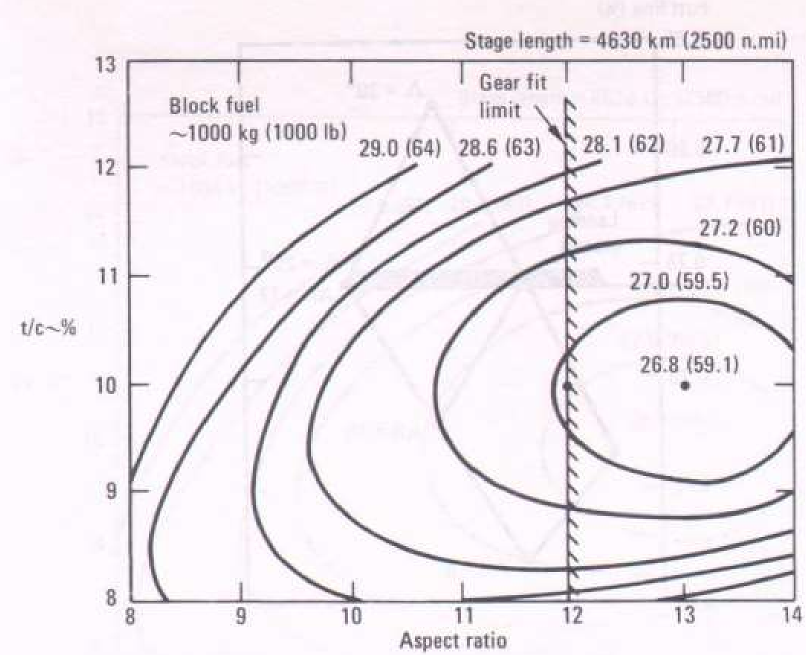


Figure 156. - Configuration P16 - block fuel knothole, $\Lambda = 25^o$, with landing gear constraint.

Source: NASA CR 3586

ADAC Aircraft Design & Consulting

Wing Design Study Λ = 30 deg

- Unconstrained wing design
  - Block fuel = 58.5 Klb

  (30° sweep is better)

- Constrained wing design
  - Block fuel = 61.7 Klb

  (30° sweep is worse)

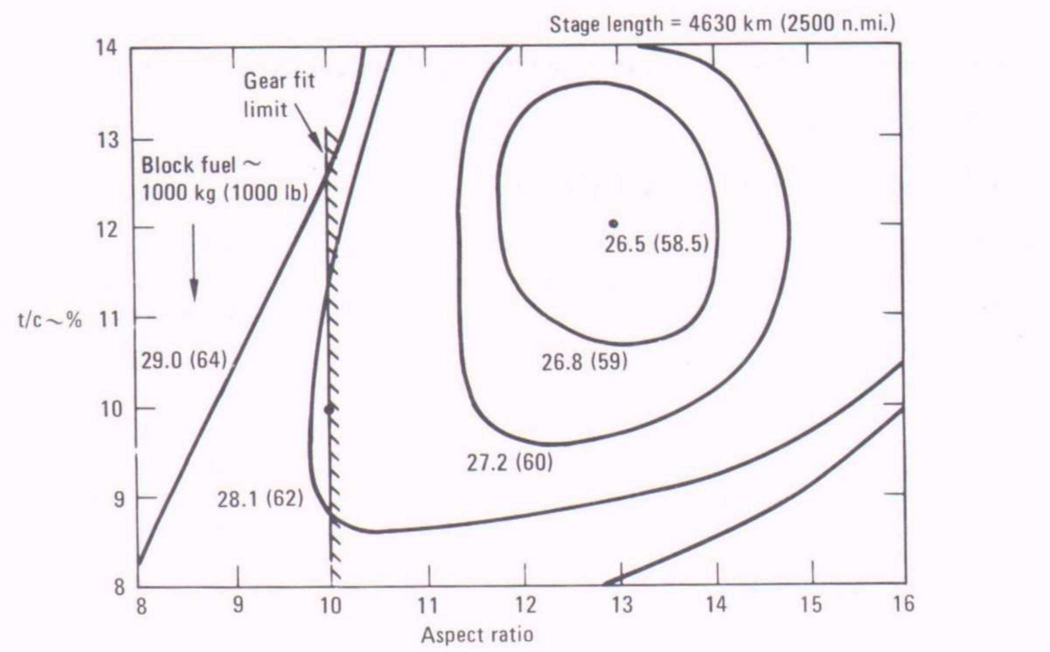
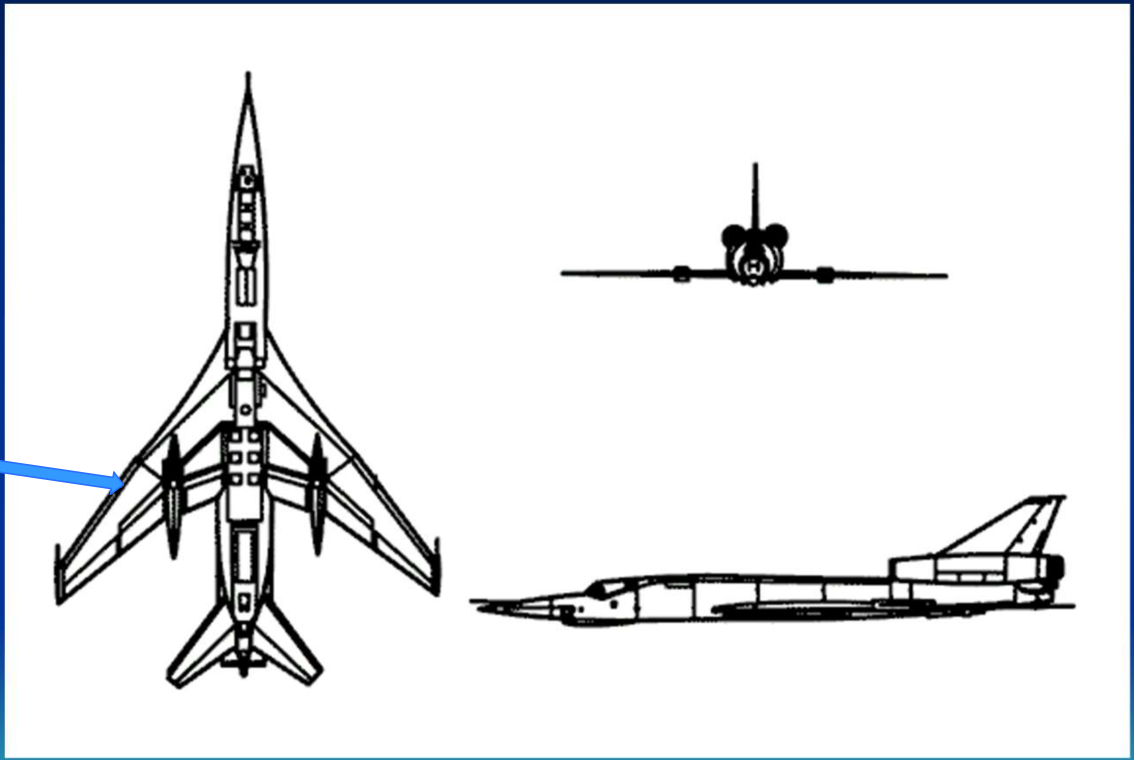


Figure 157. - Configuration P16 - block fuel knothole, Λ = 30°, with landing gear constraint.

Source: NASA CR 3586

Tupolev Tu-22

- If wing has high sweep:
  - Put MLG in wing pods
  - If lucky, pods may smooth out area distribution

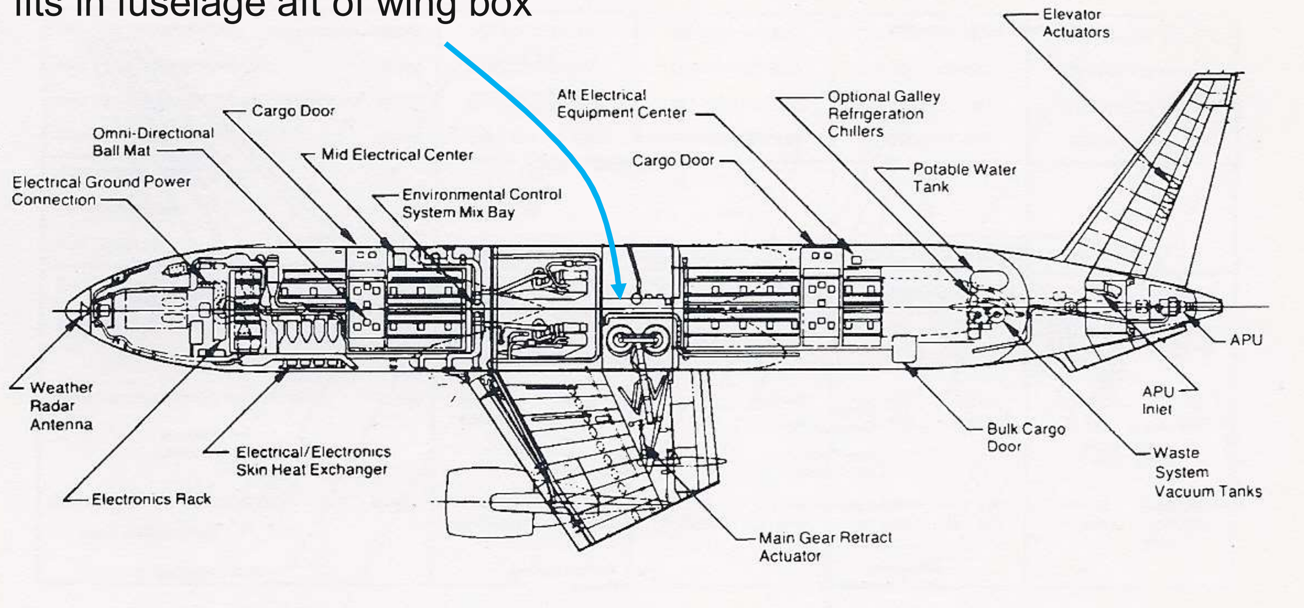


787 Gear Swing

- Adjust trunnion angles, and gear will still swing up behind wing box

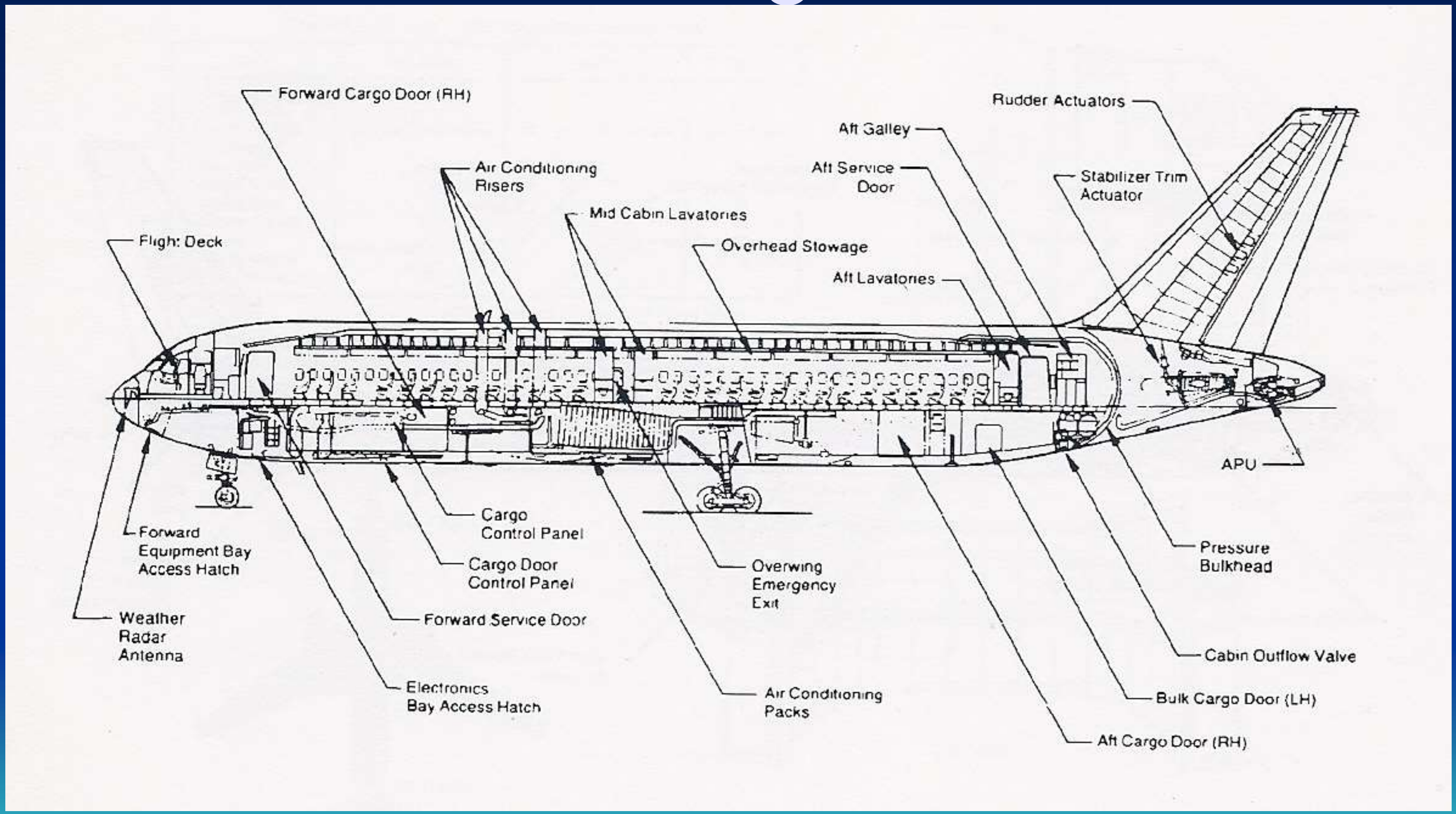
767 Fuselage Plan View

On swept wing commercial airliners, main landing gear fits in fuselage aft of wing box



Source: Roskam

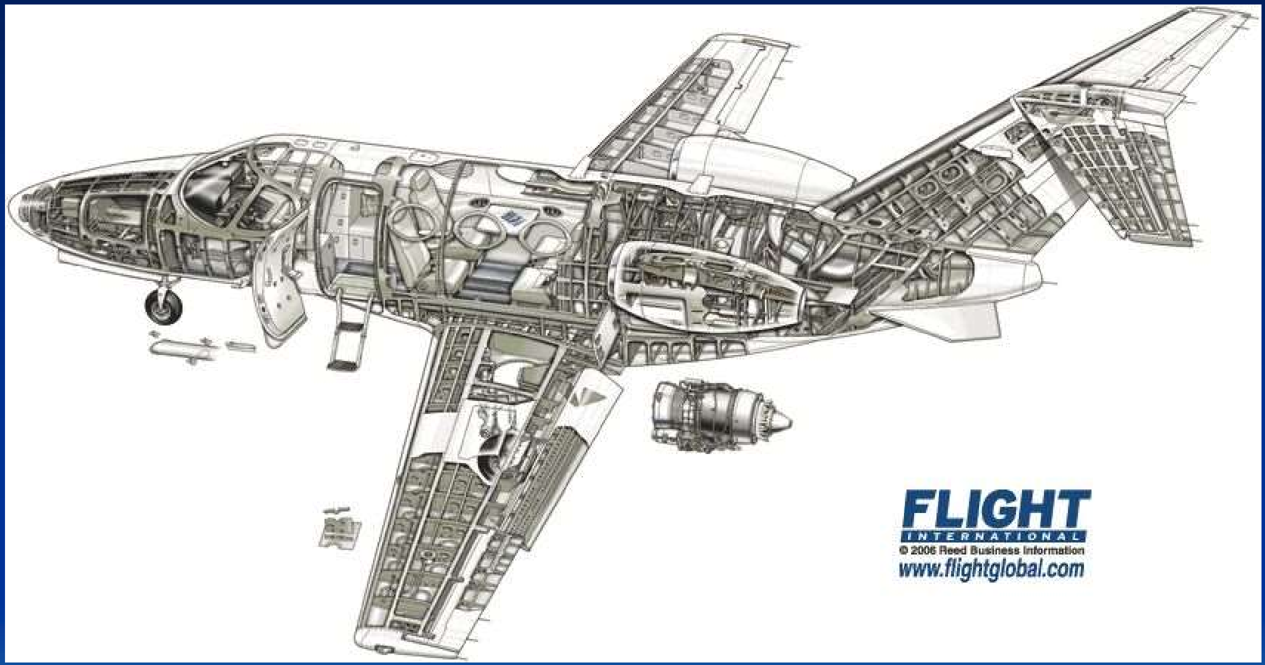
767 Fuselage Profile



Source: Roskam

MLG Location On Unswept Wing

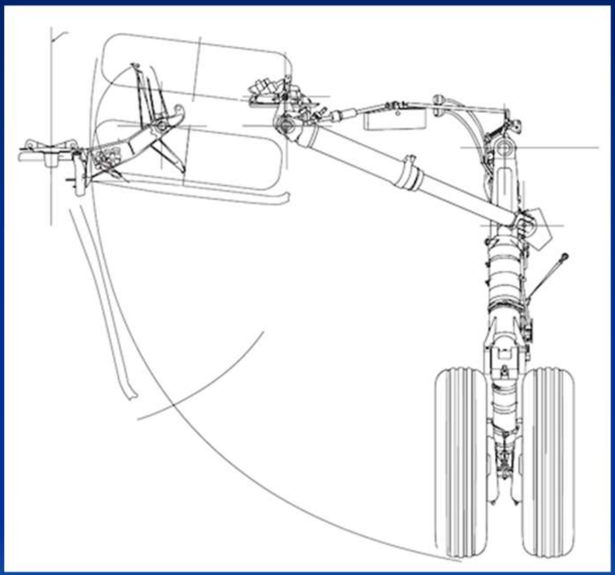
Trunnion located between front and rear spar, with MLG assembly also fitting between spars



Cessna Citation Mustang

G450 Main Landing Gear

http://www.acjetexpert.com/gulfstream-g450/



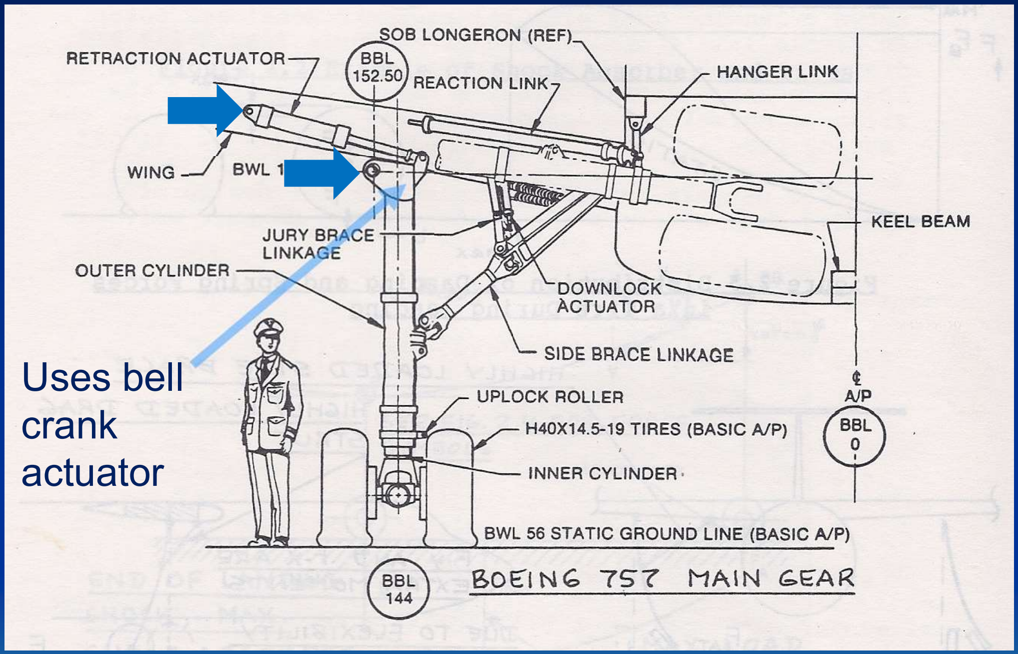
http://code7700.com/g450_landing_gear.htm

757 Main Landing Gear

Attachment to wing

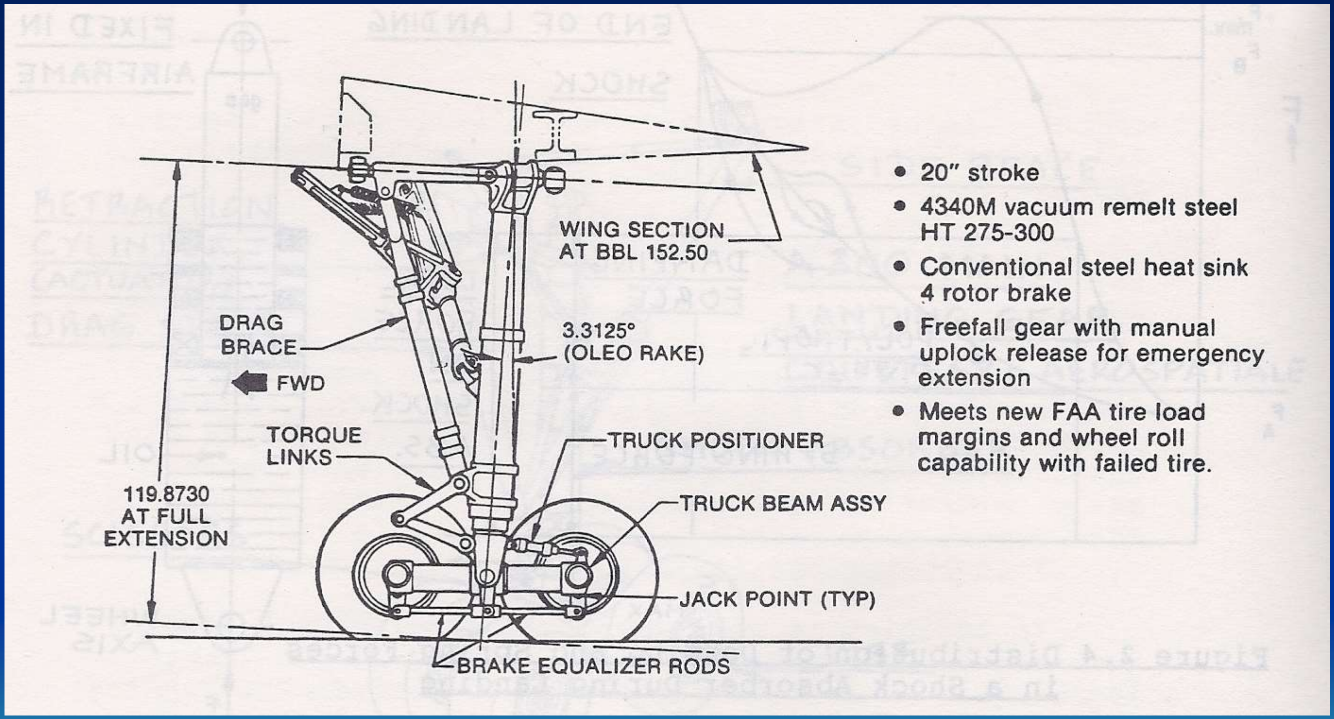
Why use bell crank? Possibly not enough wing thickness at location of MLG actuator

Uses bell crank actuator



Source: Roskam Vol IV

757 Main Landing Gear



Source: Roskam Vol IV

737 Main Landing Gear

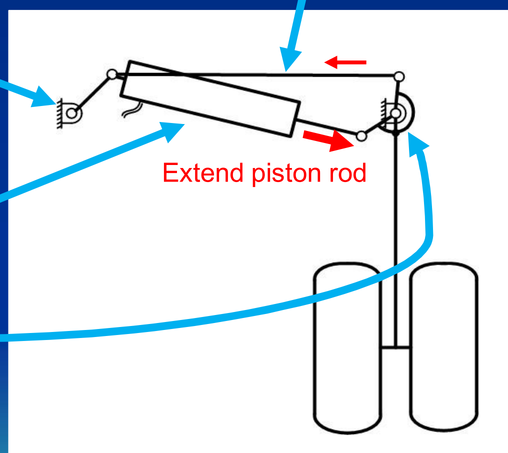
- Uses “walking beam” to rotate main strut
- Piston motion doubled
- Piston force halved
- Small load on beam hanger

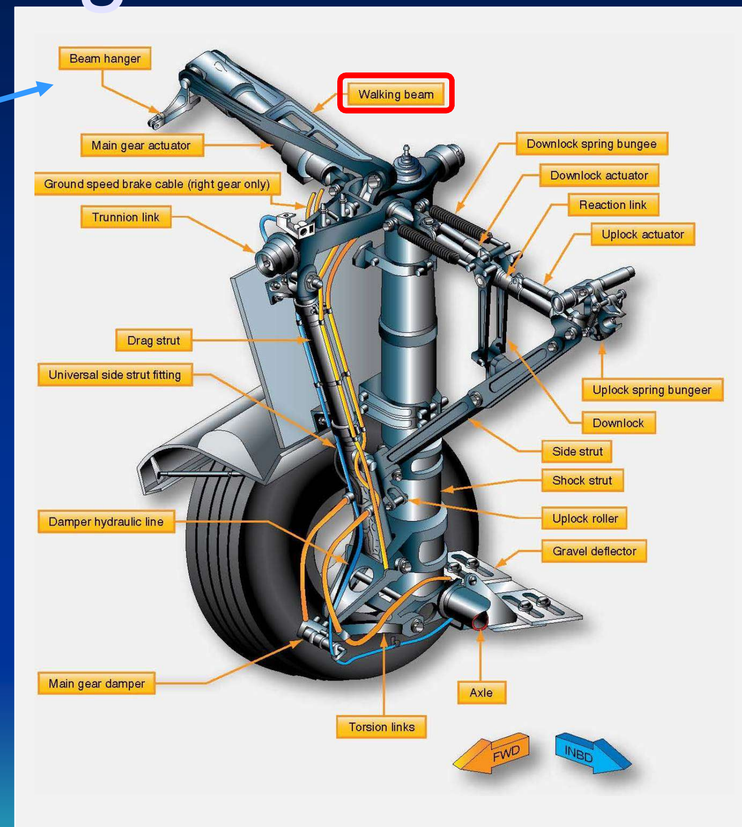
Walking beam

Beam hanger

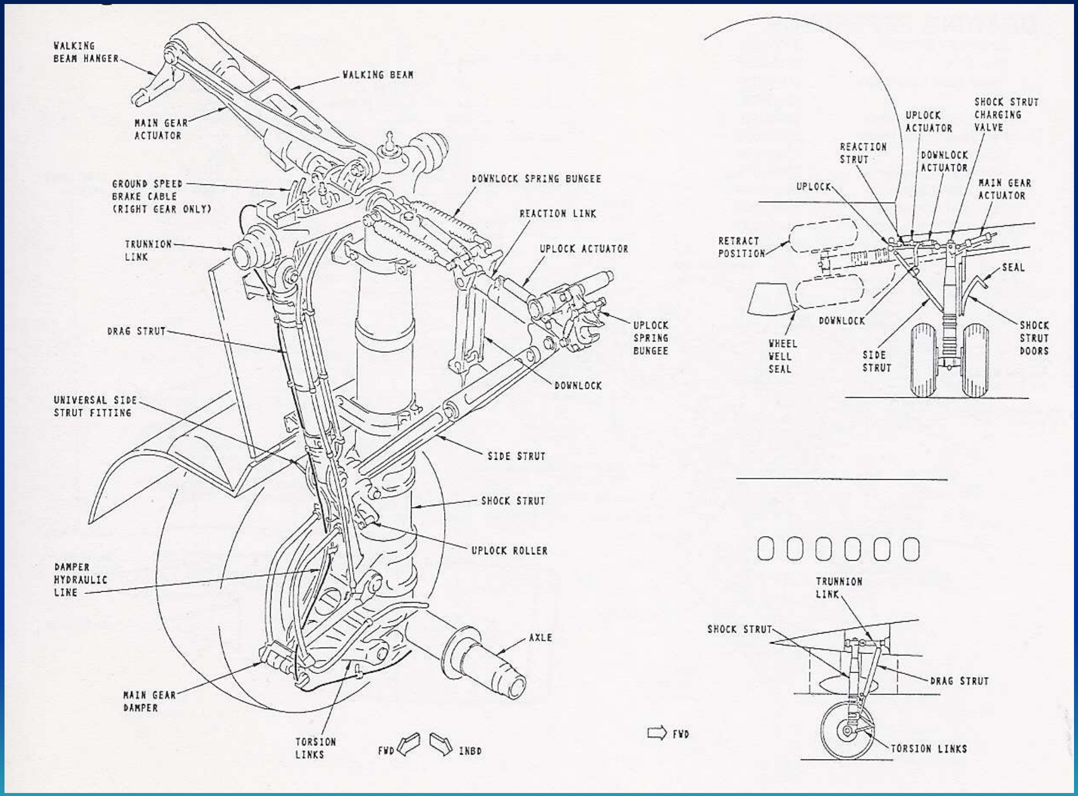
Main gear actuator

Trunnion link





737 Main Landing Gear

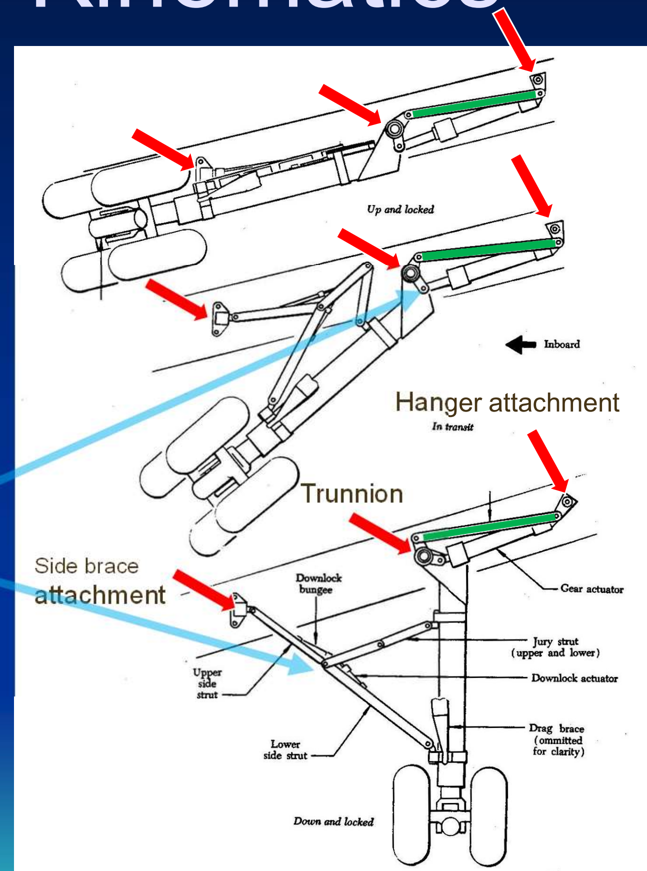


Walking Beam Kinematics

Attachment to structure

Walking beam

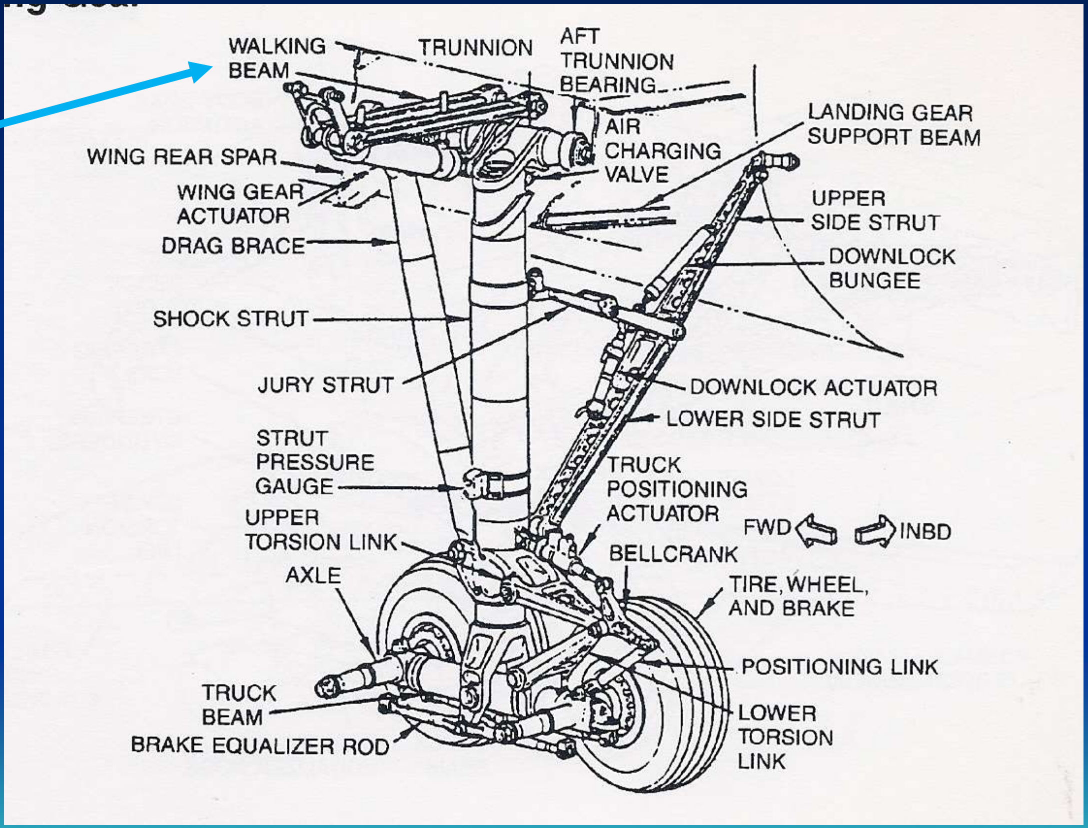
- Retraction sequence
  - Open MLG doors
  - Release downlock actuator
    - Breaks jury strut
  - Extend main gear actuator
    - MLG retracts
  - Operate uplock actuator
  - Close MLG doors



Source: Great War Replicas

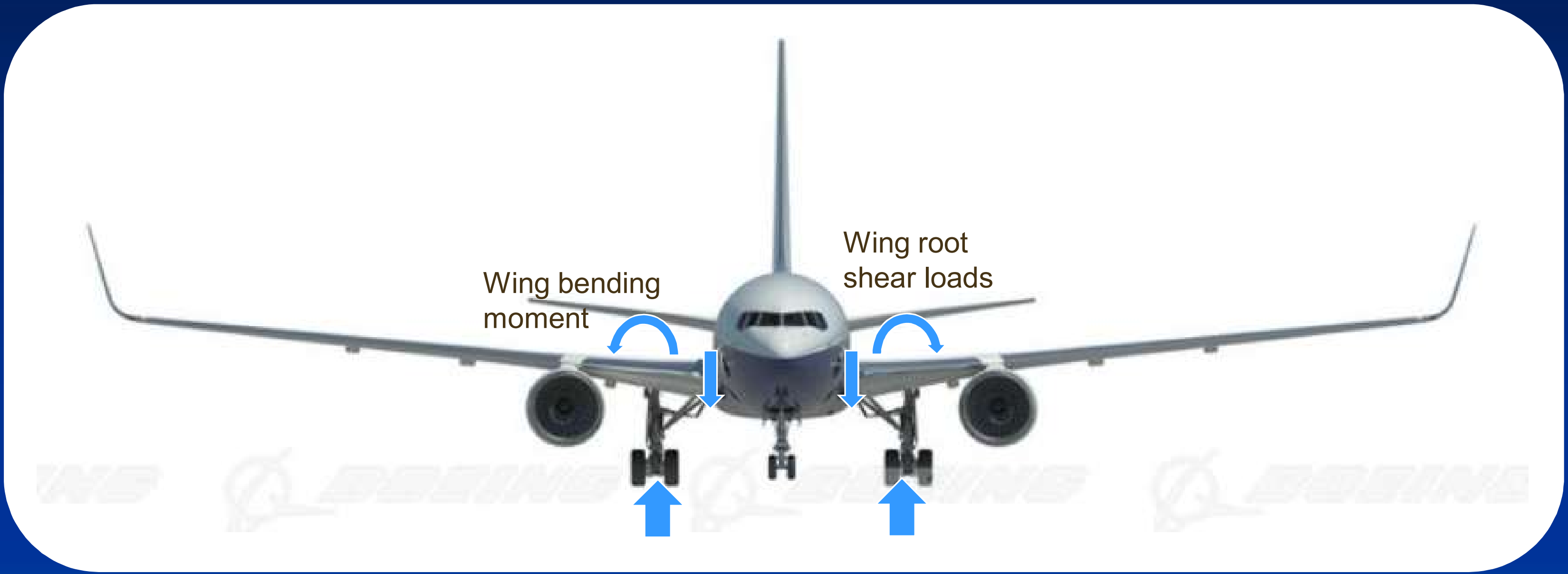
747 Wing Landing Gear

Also uses walking beam actuator



ADAC
Aircraft Design & Consulting

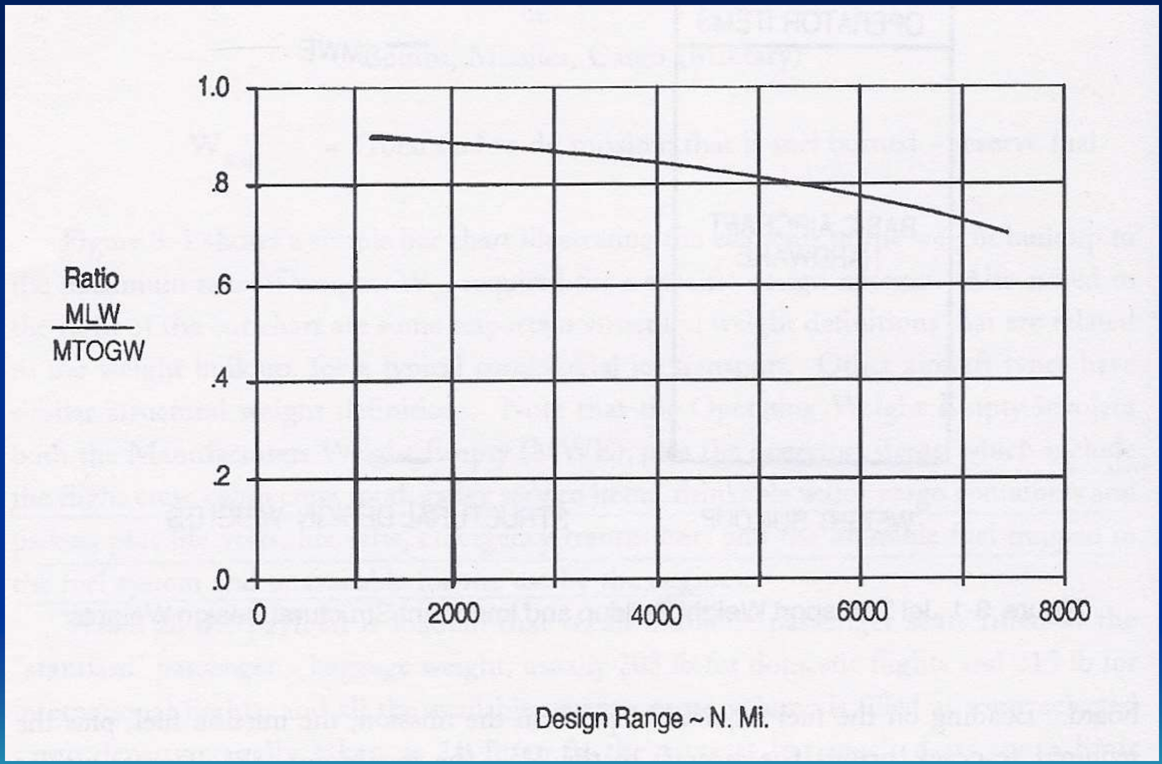
767-300ER MLG Landing Loads



Source: boeing.com

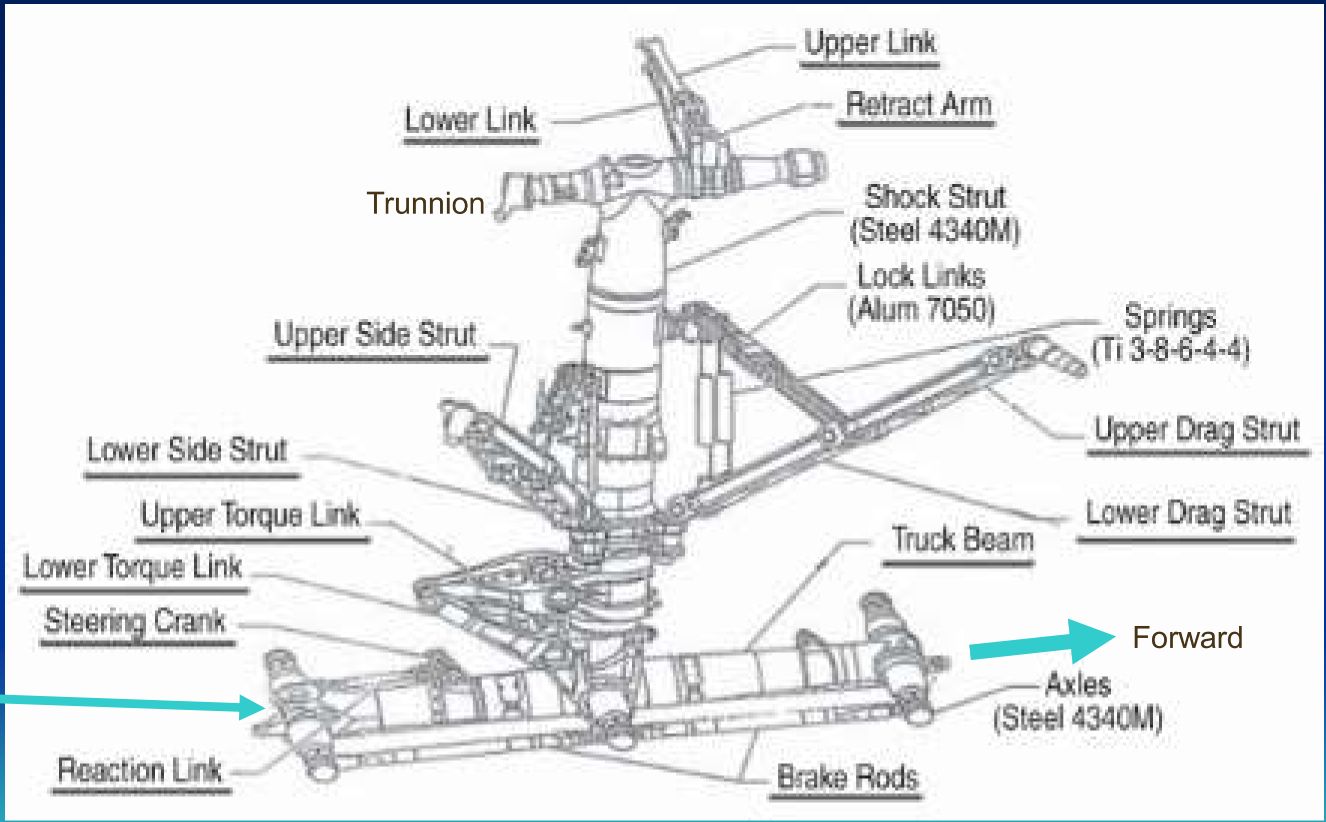
For long range aircraft, MLW < MTOGW

Trends in MLW/MTOGW



Source: Schauflele

777 Articulated MLG Bogey



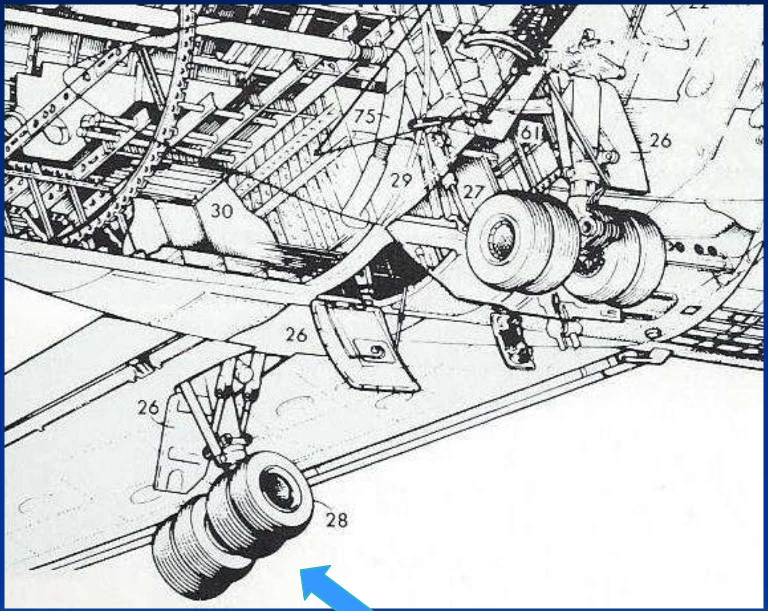
Wheels removed from axles

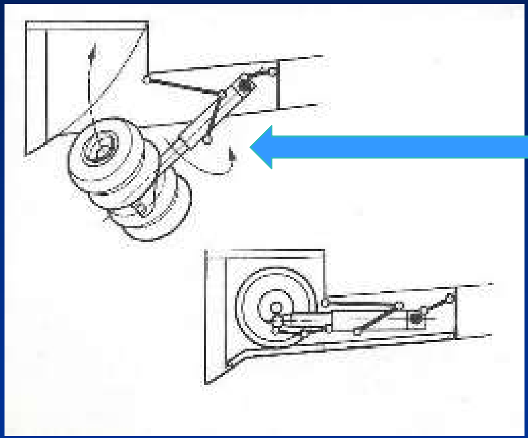
Rear axle pivots on truck beam

Tu-154 MLG

- MTOGW = 229,000 lb
- Smaller wheels
- Gravel or rough field operation

DH Trident Main Landing Gear





MLG bogie rotates during retraction

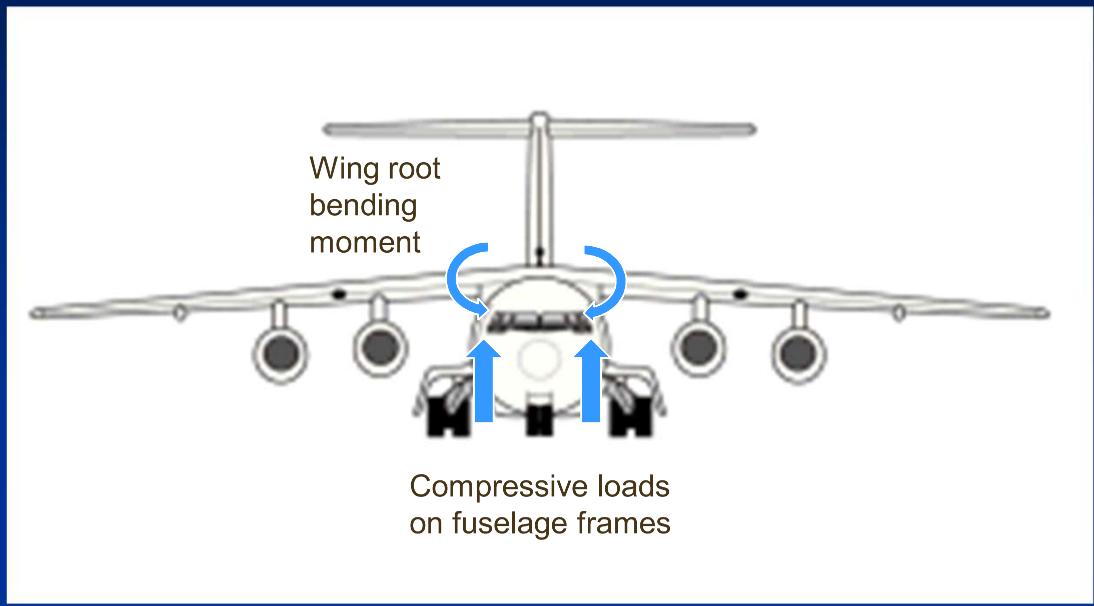
Compact stowage

Engines are at the rear, so short landing could be used. So trunnion fitted into the wing root, not fuselage, requiring innovative design

Higher aerodynamic drag when lowered

MLG in locked position

BAe 146 MLG Landing Loads



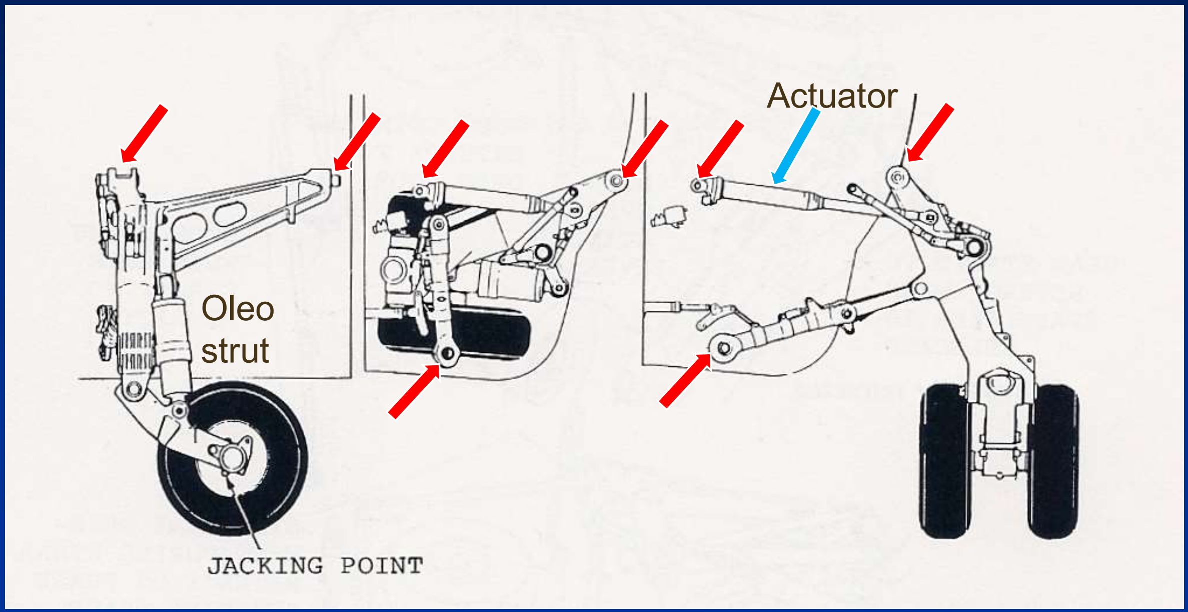
Source: aviastar.org

BAe 146 Main Landing Gear

- Trailing link often used for body-mounted MLG

Source: Luigi Rosa

BAe 146 Main Landing Gear



Source: Dowty Rotol

- Compact retraction requires small blister

CASA/ITPN CN-219 Main Landing Gear

- Trailing link often used for body-mounted MLG

Source: IPTN

ADAC Aircraft Design & Consulting

ITPN N-219 Fixed Main Landing Gear

- Trailing link often used for body-mounted MLG

Source: IPTN

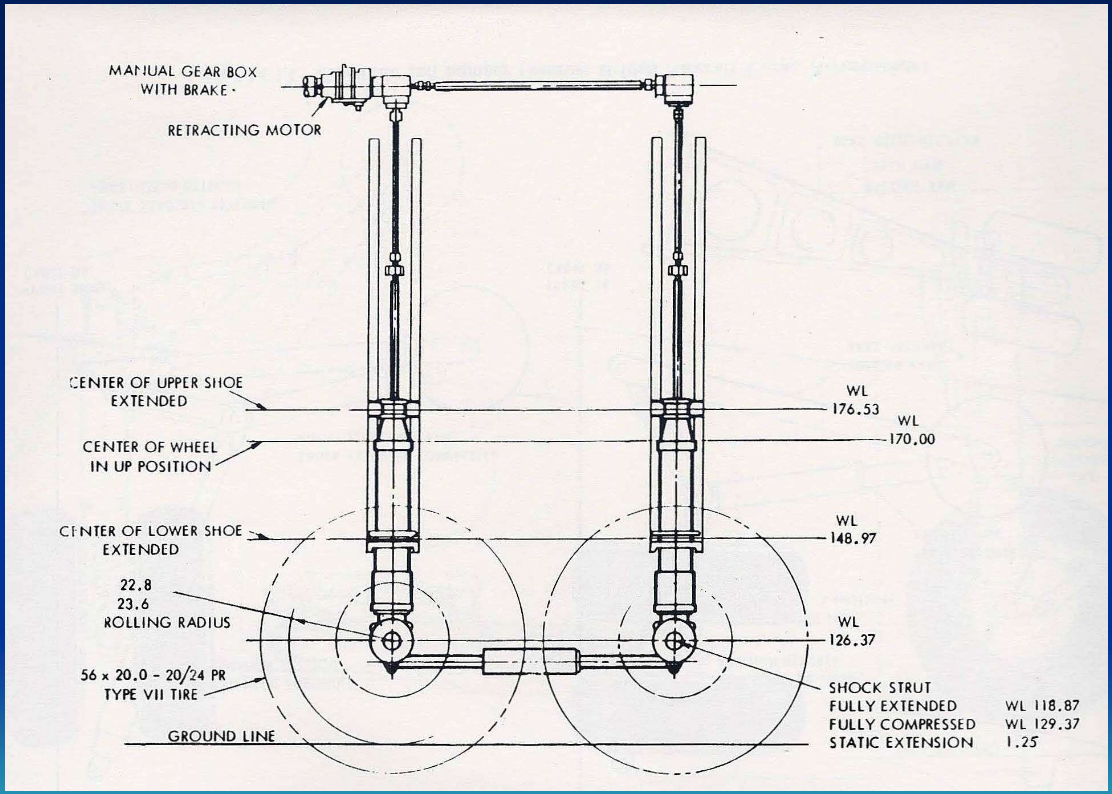
An 225 Main Landing Gear

- Repeat as necessary

C.g. must be far enough aft for airplane to rotate on aft wheels. Forward wheels probably not taking much load.

C-130 Main Landing Gear

Raised and lowered by parallel jackscrews driven by hydraulic motor



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Aircraft Design & Consulting

F-22 Main Landing Gear

Conventional strut and drag brace on trunnion

Fokker F-27

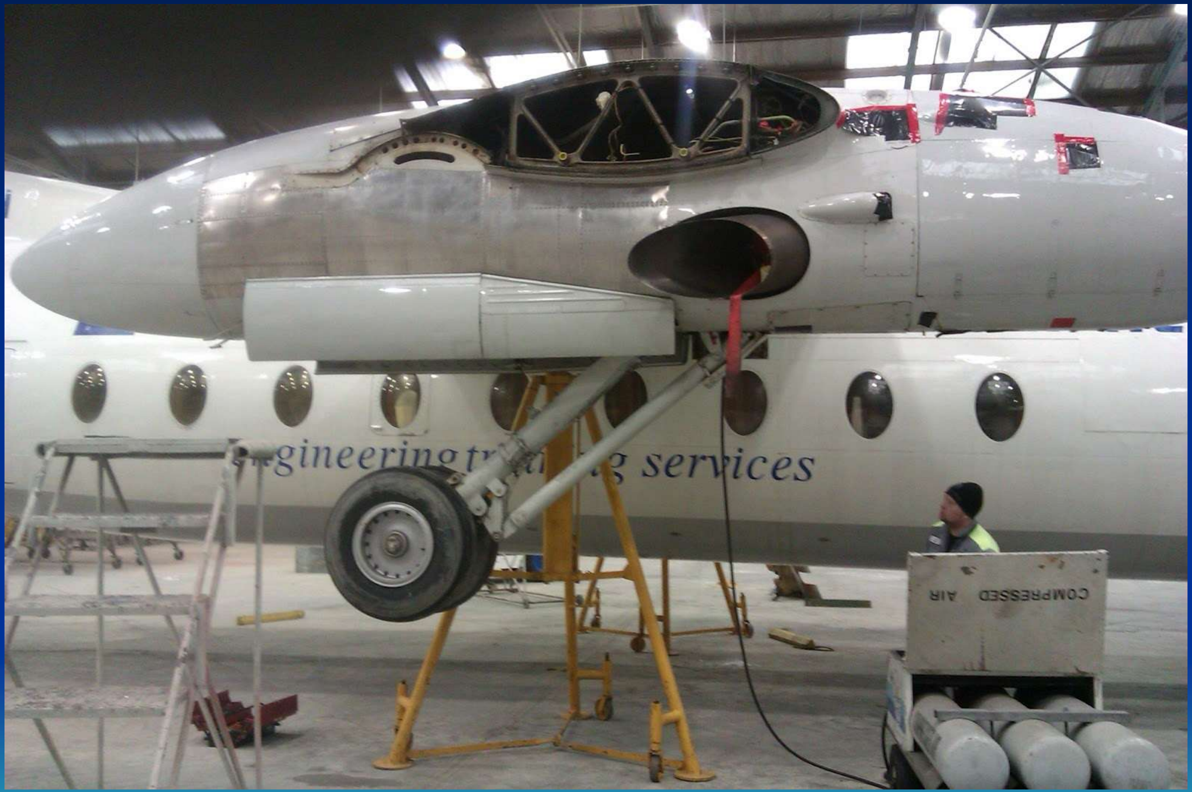
Long strut with no side-brace

Crosswind limit is 29 kt.

Source: defense-studies.blogspot.com

Fokker F-27

Long strut with
no side-brace



Source: thelearnedturtle.blogspot.com

De Havilland DHC-4 Caribou

Gull wing reduces MLG oleo strut length

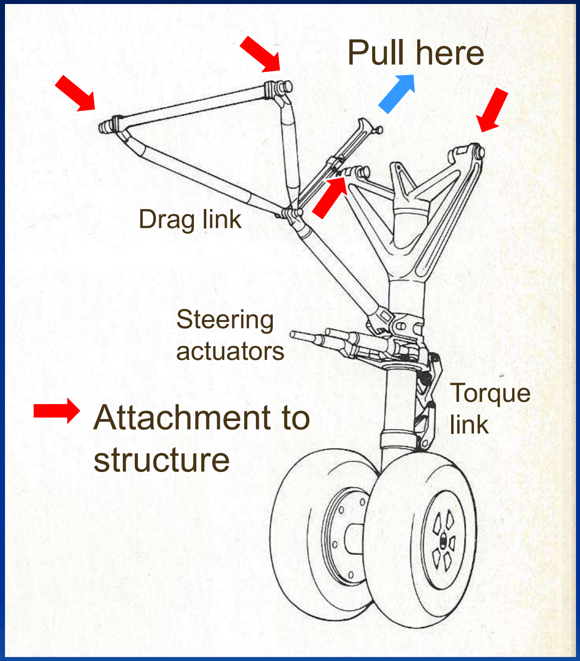
Source: © Alexander Watts

Vought F4U Corsair

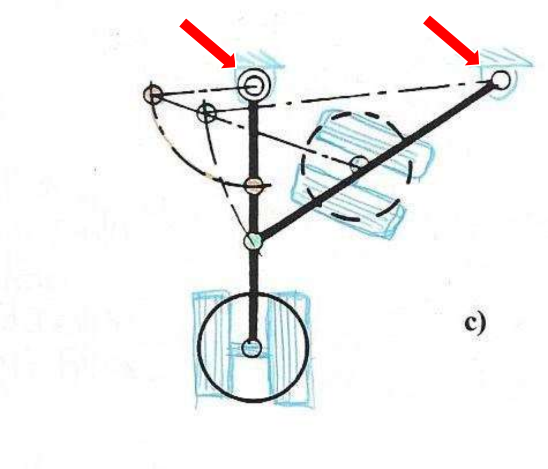
Source: www.cybermodeler.com

MLG retracts rearward into wing

Nose Landing Gear

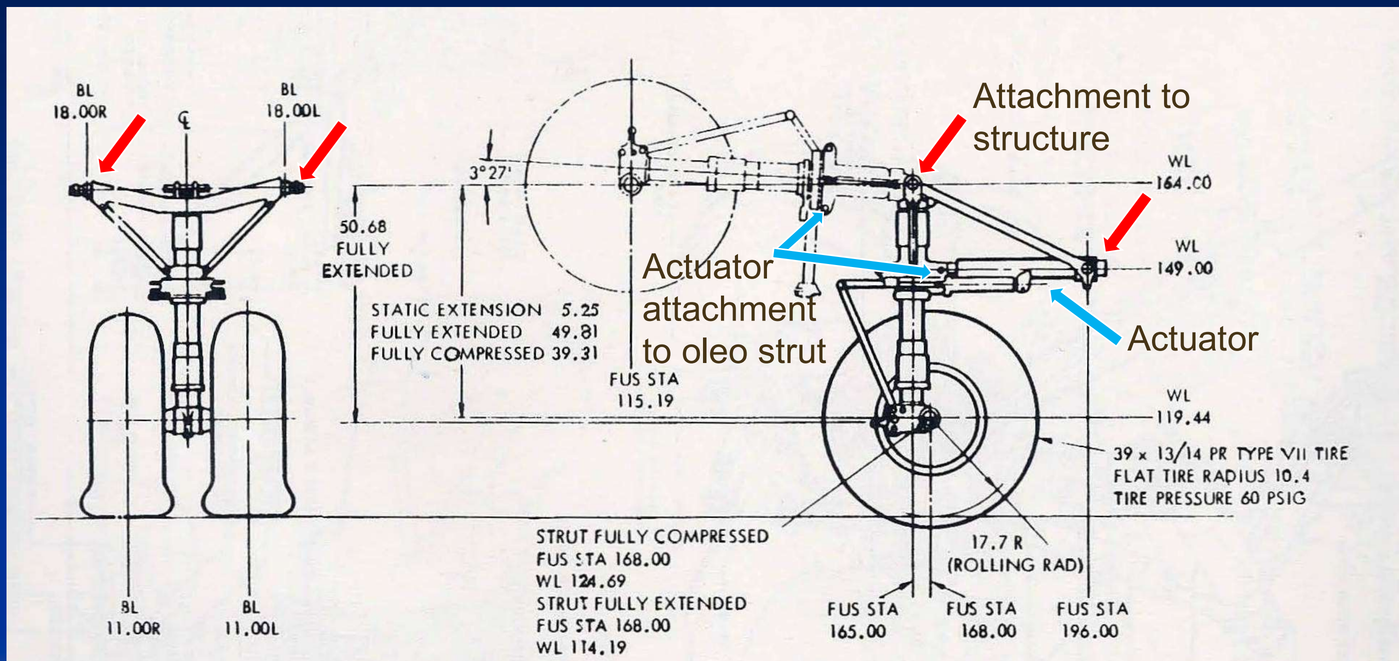


Abex/Dowty NLG on DC-10



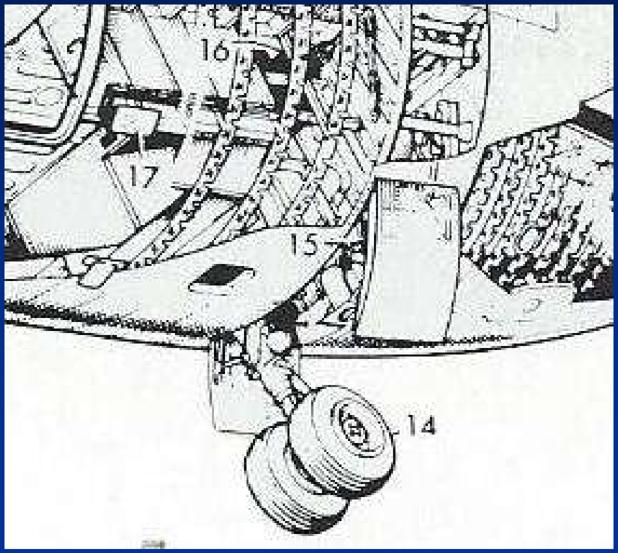
Alternative retraction kinetics with broken main strut

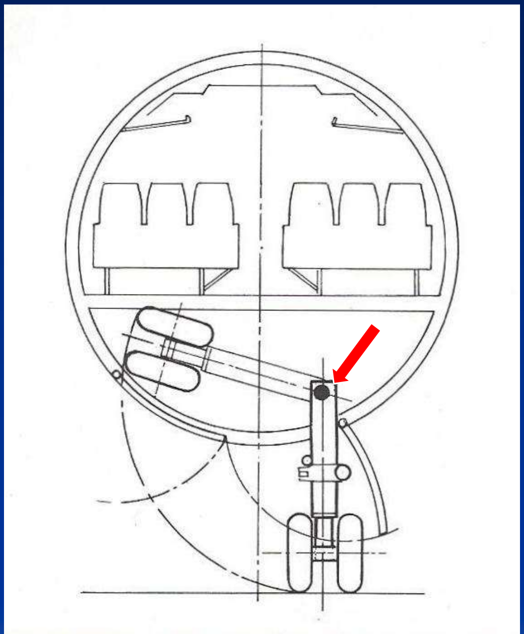
C-130 Nose Landing Gear



Nose gear steering operated by tiller in cockpit

DH Trident Nose Landing Gear





- Offset from centerline by 2 ft
- NLG fits between fuselage frames

F-22 Nose Landing Gear

Conventional strut and torque link (shown as mockup)

Landing Gear

Summary

- Need for Strength
- Types of gear
- Tire size and selection
- Landing gear location wrt. c.g.
- Types of landing gear actuation
- Attachment to structure

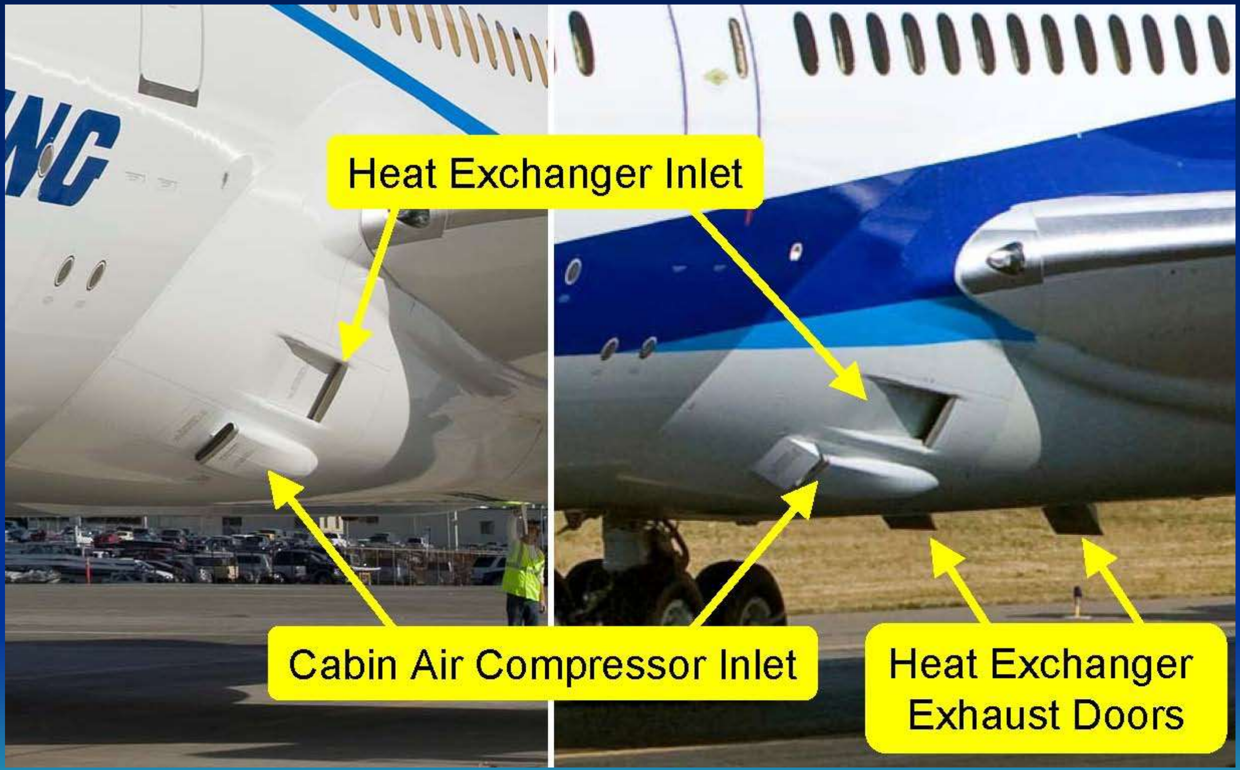
Chapter 11
Subsystems

Aircraft Subsystems

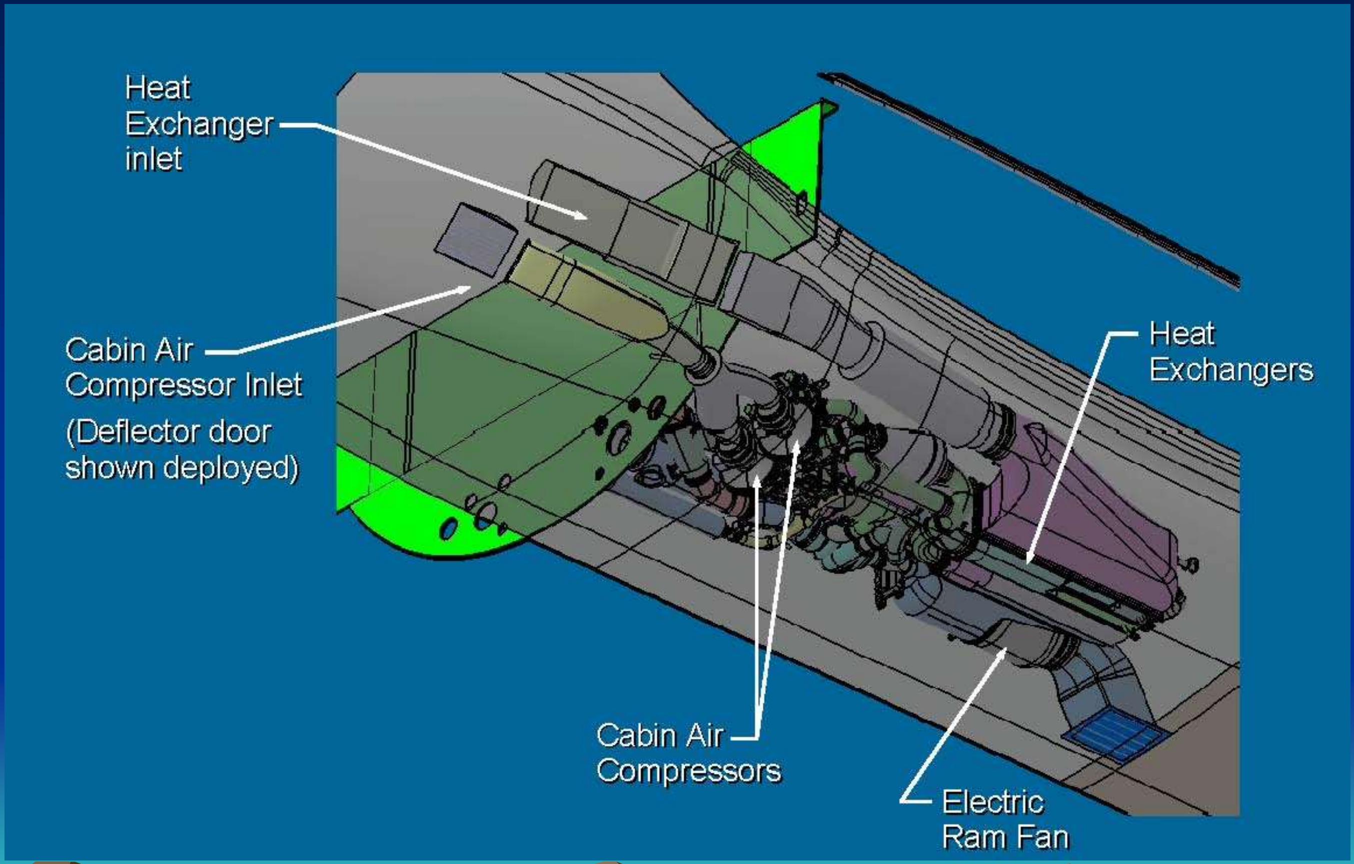
- Pneumatic
  - Pressurization
  - Environmental Control System (ECS)
- Electrical
- Hydraulic
  - Flaps
  - Landing gear
- Flight Controls
- Avionics

787 Pneumatic Systems

- Wing LE Anti-Ice
- Air Conditioning
- Cabin Pressure
- Engine Start



787 Environmental Control System



787 Environmental Control System

- Overhead cabin air distribution
- Upper and lower air recirculation
- HEPA Filters and Gaseous Air Purification* for recirculated air
- Personal Air Outlet (Gasper) System* - Basic
- Optional Flight Deck Humidification System

- Forced air cooling for essential E/E equipment
- Draw-thru cooling for minor E/E equipment
- Liquid cooling for Power Electronics*

- Electric Air Conditioning*
- 6,000 foot maximum cabin altitude*
- Integrated galley refrigeration*
- Conventional cabin pressure control – two outflow valves

- Electric heating for door floor areas*
- Draw-thru ventilation for Lavatories, Galleys, and Crew Rests

- Supplemental electric heating for Forward and Bulk Cargo compartments*
- Forward* and Bulk Cargo heating and ventilation for animal carriage
- Optional Forward Cargo air conditioning

* Different from 777

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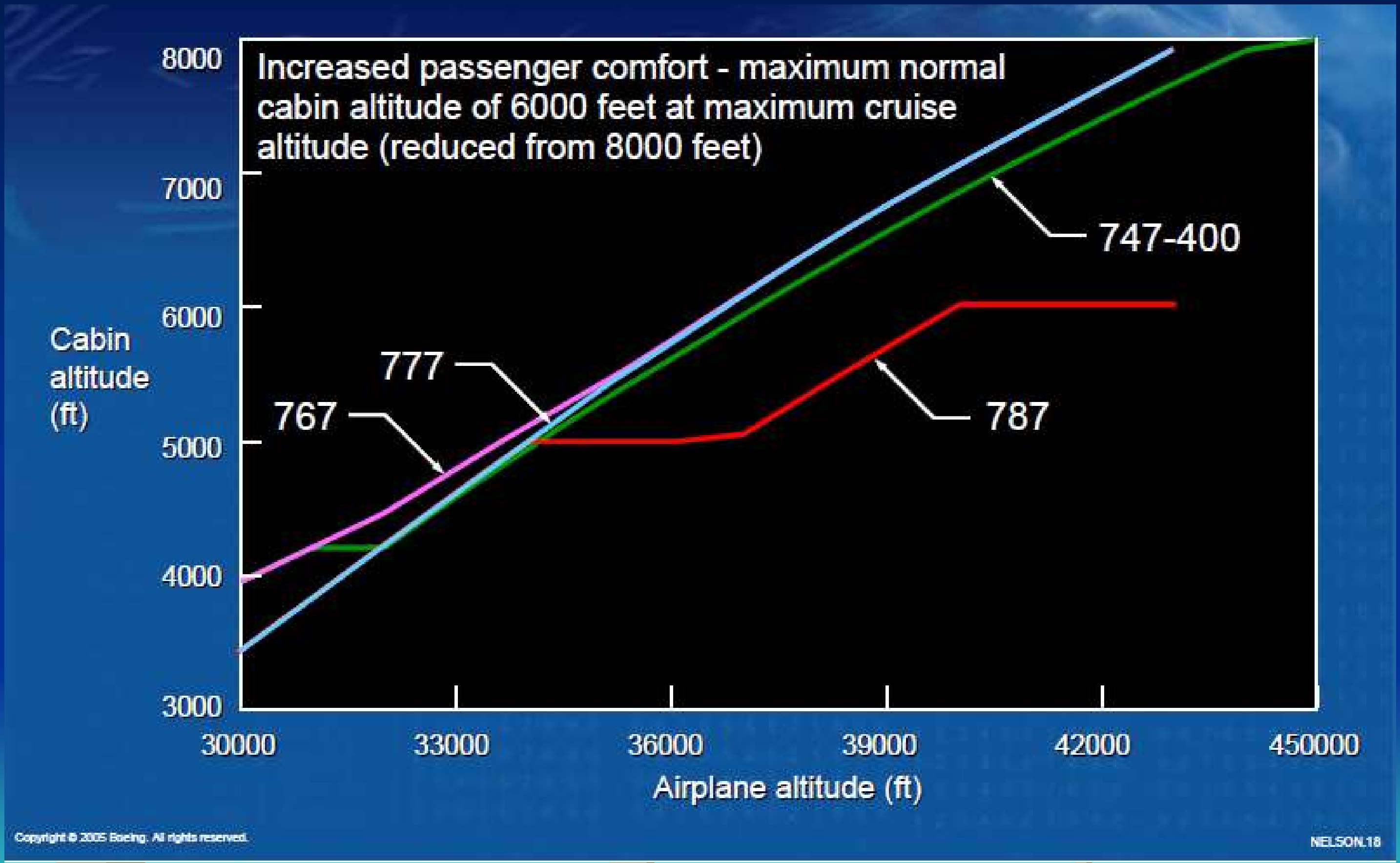
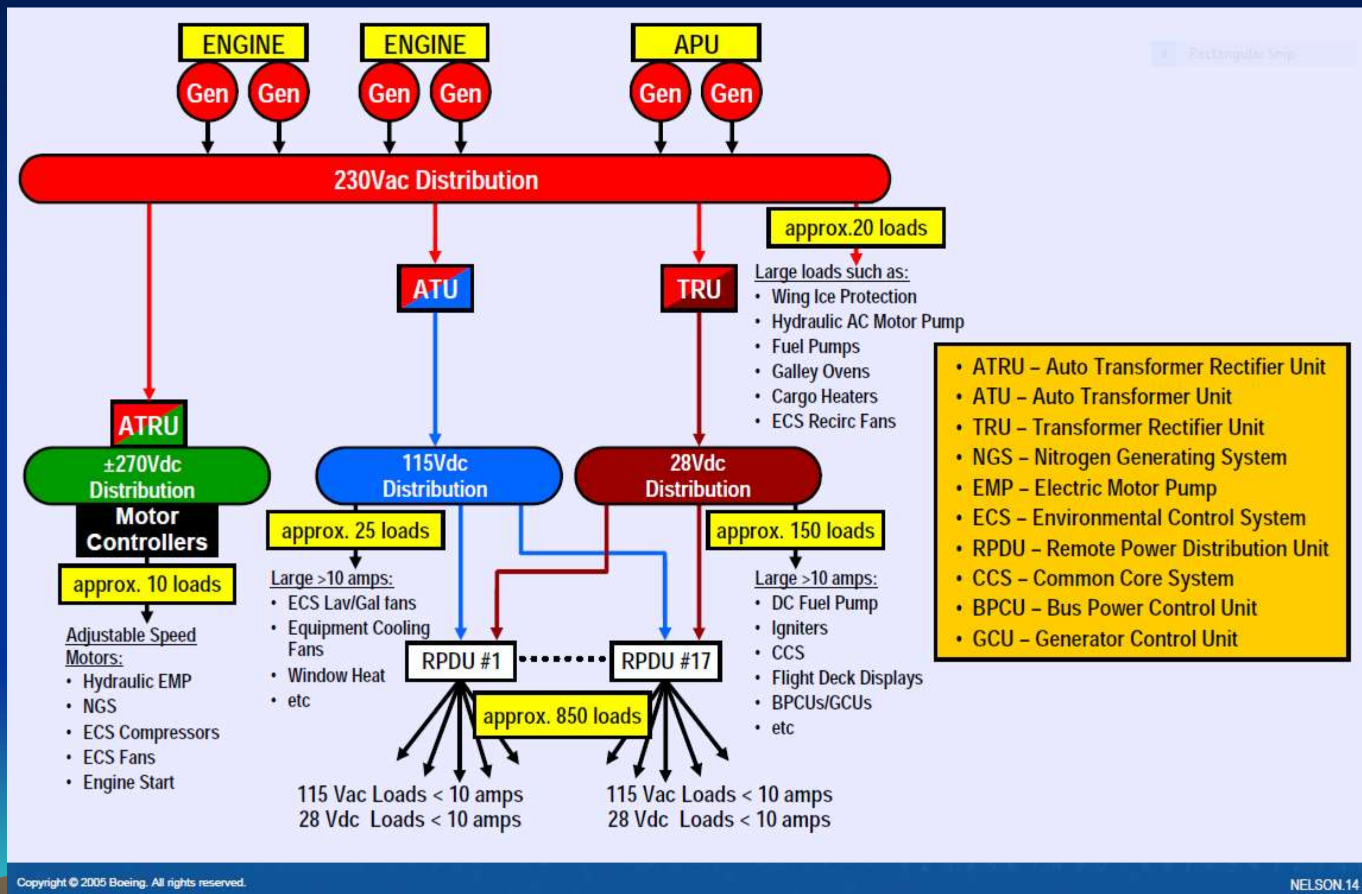
787 Pressurization Schedule



787 Electrical System Overview



Auxiliary Power Unit (APU)

787 uses P&W AP
S5000 APU

Source: Simon Chandler

APU inlet

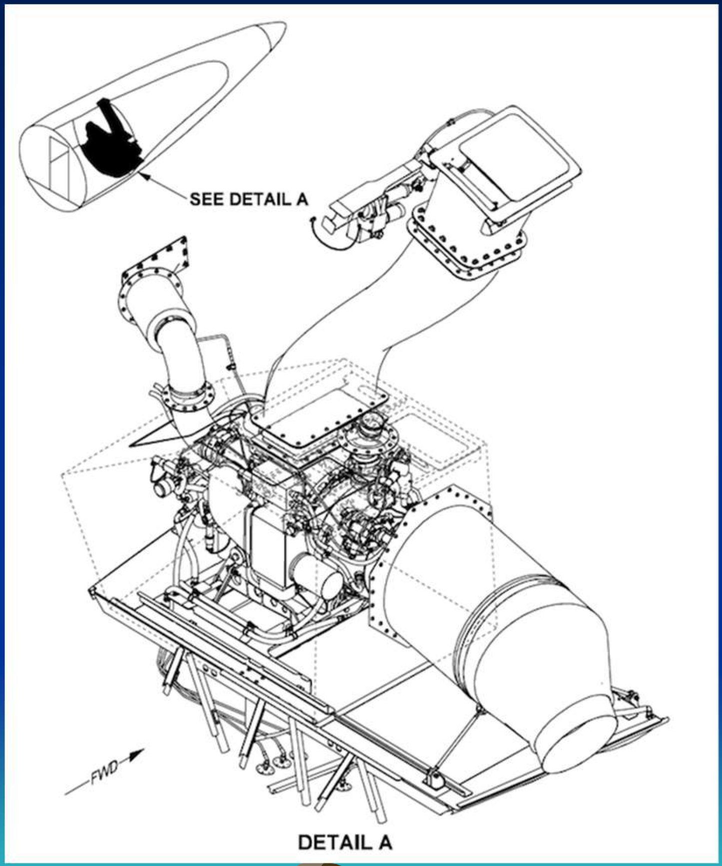
https://aviationweek.com/awin/boeing-tackles-787-apu-overheating-issue

Auxiliary Power Unit (APU)

Gulfstream G450 APU

This website has much good information on G450 and other aircrcraft

http://code7700.com/g450.htm



http://code7700.com/g450_apu.htm

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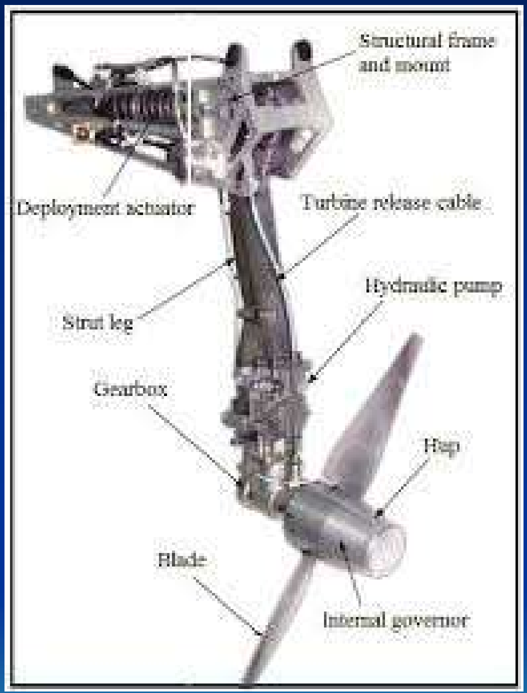
Ram Air Turbine (RAT)



A-380 RAT (1.63 m dia. propeller)

- Deploys automatically if all engines fail
- Provides emergency electrical and hydraulics

RAT on F-105 fighter-bomber

https://lessonslearned.faa.gov/ll_main.cfm?TabID=1&LLID=44&LLTypeID=2

787 Ram Air Turbine

RAT deployed for test

http://code7700.com/g450_apu.htm

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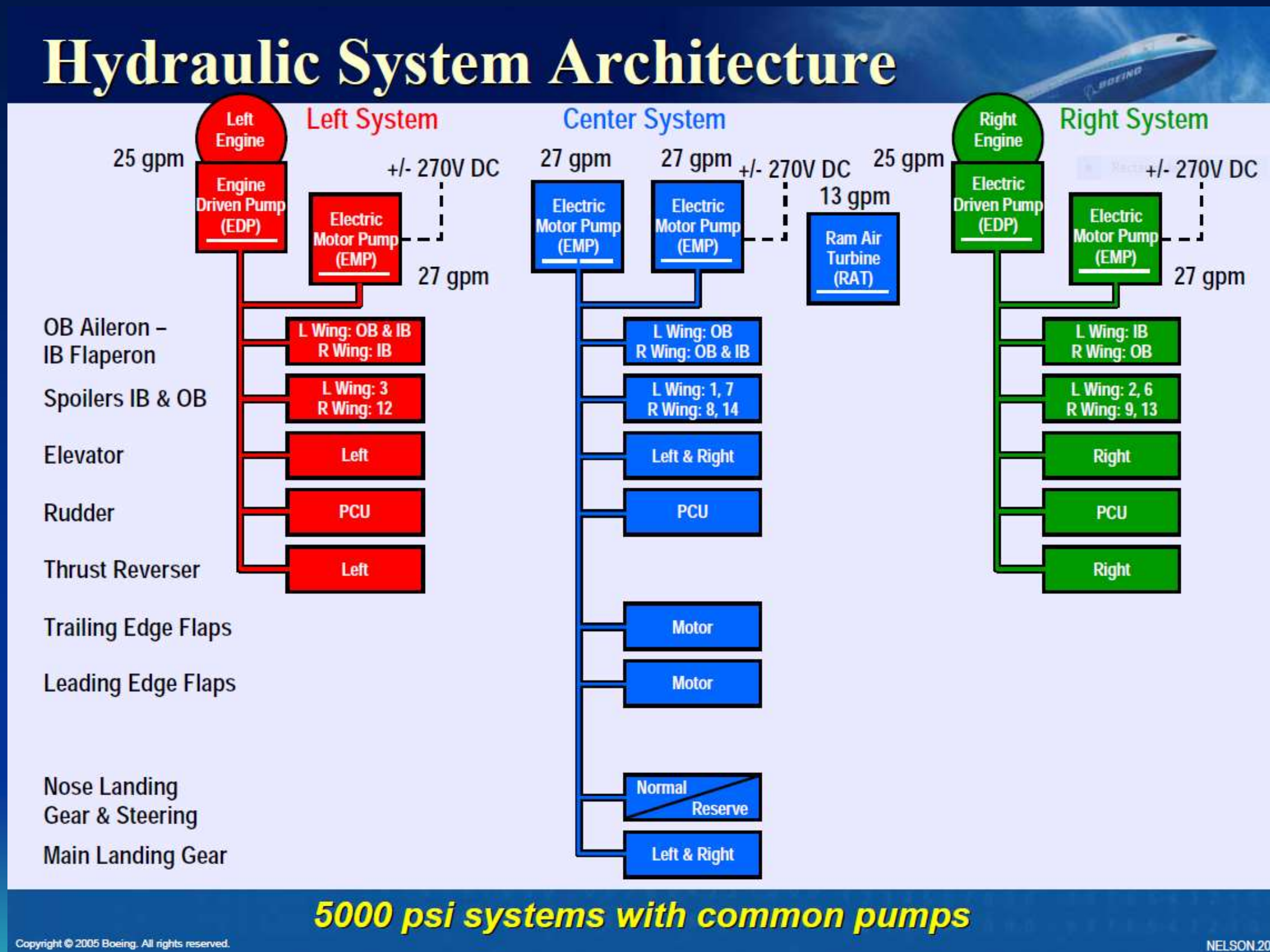
Hydraulic System Architecture
Left System
Center System
Right System
Left Engine
Right Engine
25 gpm
Engine Driven Pump (EDP)
+/- 270V DC
Electric Motor Pump (EMP)
27 gpm
27 gpm
27 gpm
Electric Motor Pump (EMP)
Electric Motor Pump (EMP)
+/- 270V DC
13 gpm
Ram Air Turbine (RAT)
25 gpm
Electric Driven Pump (EDP)
+/- 270V DC
Electric Motor Pump (EMP)
27 gpm
OB Aileron – IB Flaperon
Spoilers IB & OB
Elevator
Rudder
Thrust Reverser
Trailing Edge Flaps
Leading Edge Flaps
Nose Landing Gear & Steering
Main Landing Gear
L Wing: OB & IB R Wing: IB
L Wing: 3 R Wing: 12
Left
PCU
Left
L Wing: OB R Wing: OB & IB
L Wing: 1, 7 R Wing: 8, 14
Left & Right
PCU
Motor
Motor
Normal
Reserve
Left & Right
L Wing: IB R Wing: OB
L Wing: 2, 6 R Wing: 9, 13
Right
PCU
Right
5000 psi systems with common pumps
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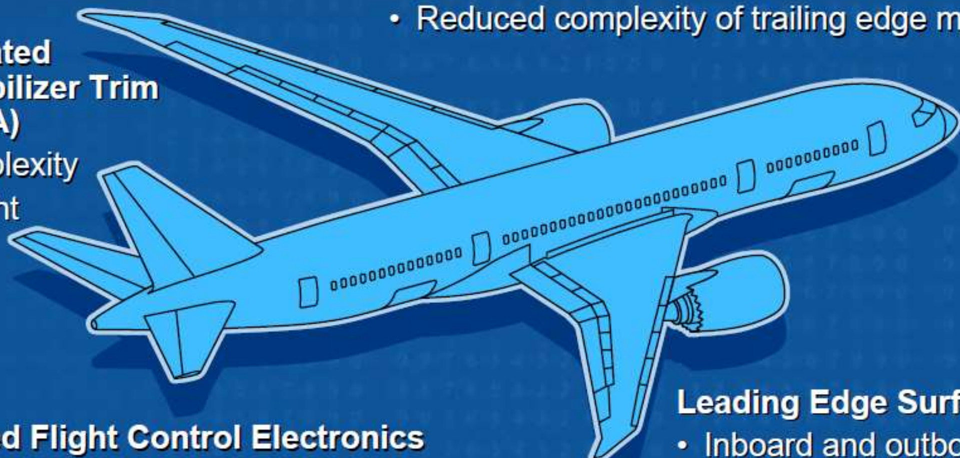
787 Fly-by-Wire Flight Controls

All Surfaces Fly-By-Wire
- Eliminates cables
- Reduced weight
- Improved functionality

Trailing Edge Surfaces
- Inboard and outboard single slotted flaps
- Single outboard ailerons
- Single flaperons
- Seven spoiler pairs with droop function
- Trailing Edge Variable Camber (TEVC)
- Reduced complexity of trailing edge mechanism

Electric Integrated Horizontal Stabilizer Trim Actuator (HSTA)
- Reduced complexity
- Reduced weight



Integrated Flight Control Electronics
- Reduced weight and space

Leading Edge Surfaces
- Inboard and outboard 3-position slats
- Sealing Krueger Flap at pylon

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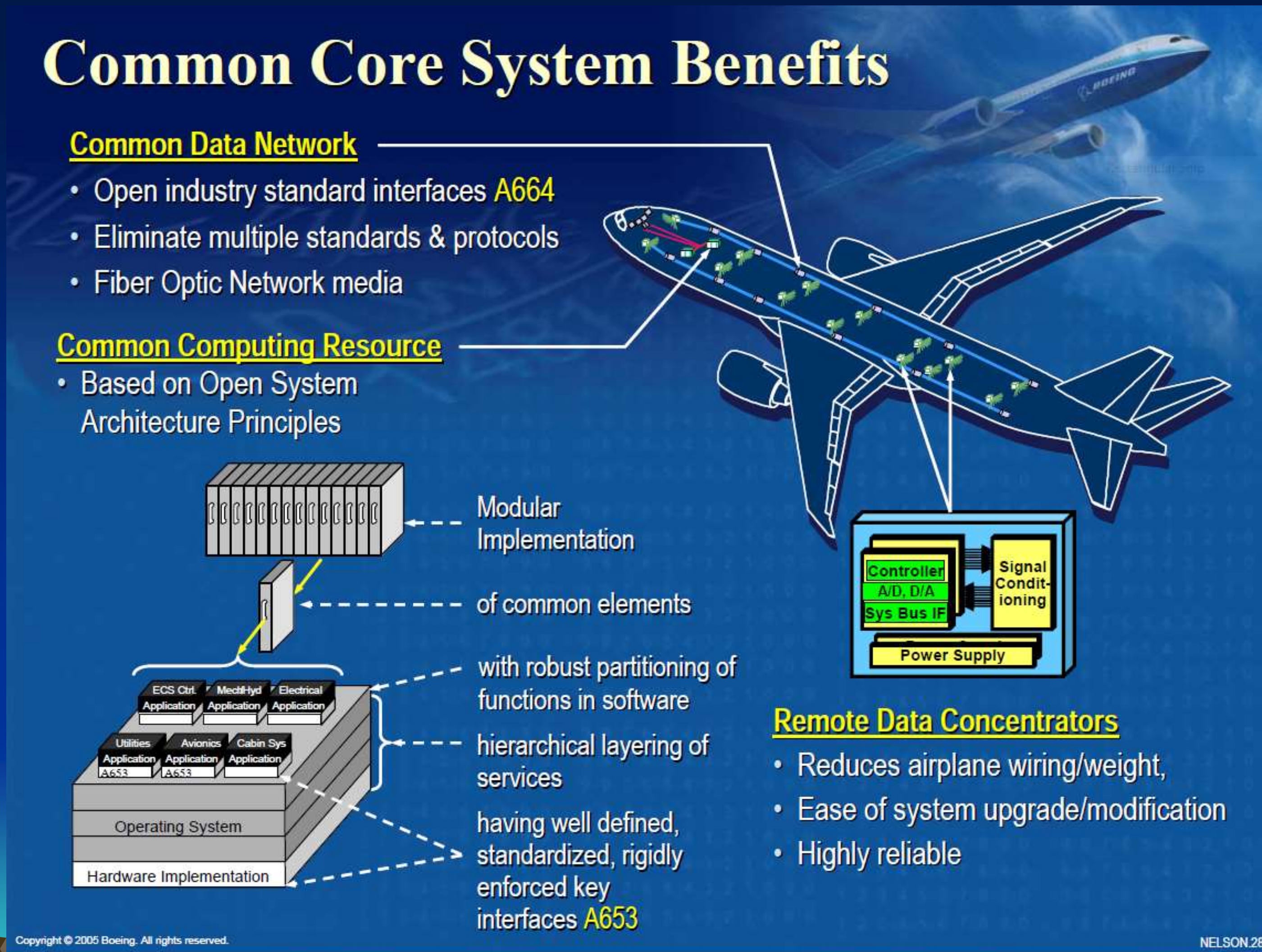
Common Core System Benefits
Common Data Network
• Open industry standard interfaces A664
• Eliminate multiple standards & protocols
• Fiber Optic Network media
Common Computing Resource
• Based on Open System Architecture Principles
Modular Implementation
of common elements
with robust partitioning of functions in software
hierarchical layering of services
having well defined, standardized, rigidly enforced key interfaces A653
ECS Ctrl. Application
Mech/Hyd Application
Electrical Application
Utilities Application A653
Avionics Application A653
Cabin Sys Application
Operating System
Hardware Implementation
Controller
A/D, D/A
Sys Bus IF
Signal Condit-ioning
Power Supply
Remote Data Concentrators
• Reduces airplane wiring/weight,
• Ease of system upgrade/modification
• Highly reliable
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Summary: Aircraft Subsystems

- Pneumatic (usually bleed, but electrical compressor on 787)
  - Pressurization
  - Environmental Control System (ECS)
- Electrical
- Hydraulic
  - Flaps
  - Landing gear
- Flight Controls (electro-hydraulic)
- Avionics

More Electric!!