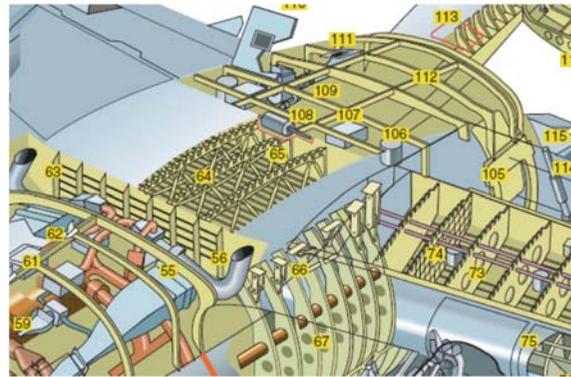


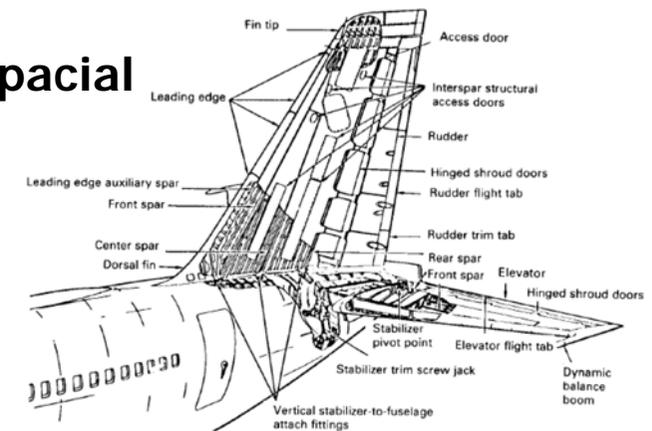
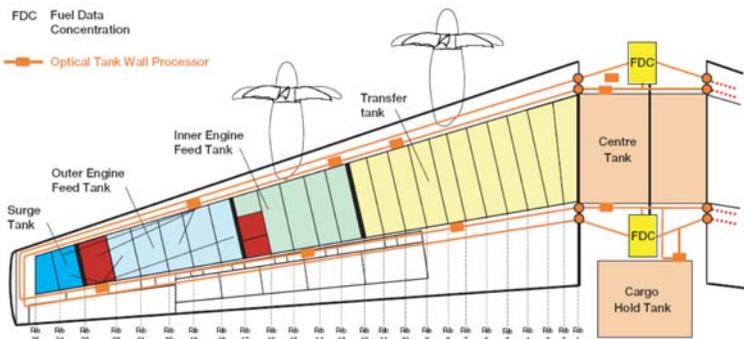
(a) Typical transport wing



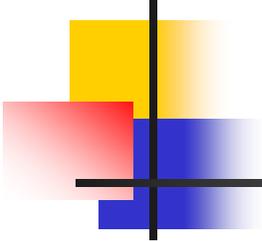
Estructuras Preliminares

Tema 7

Sergio Esteban Roncero
 Departamento de Ingeniería Aeroespacial
 Y Mecánica de Fluidos



(a) Convair 880
 (Courtesy of General Dynamics Corp. - Convair.)

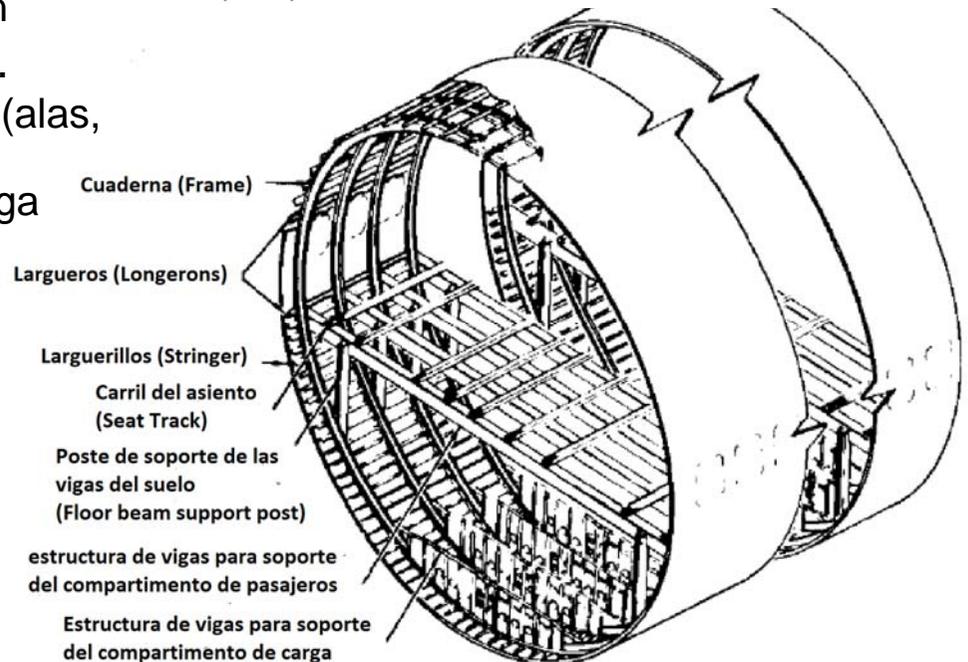
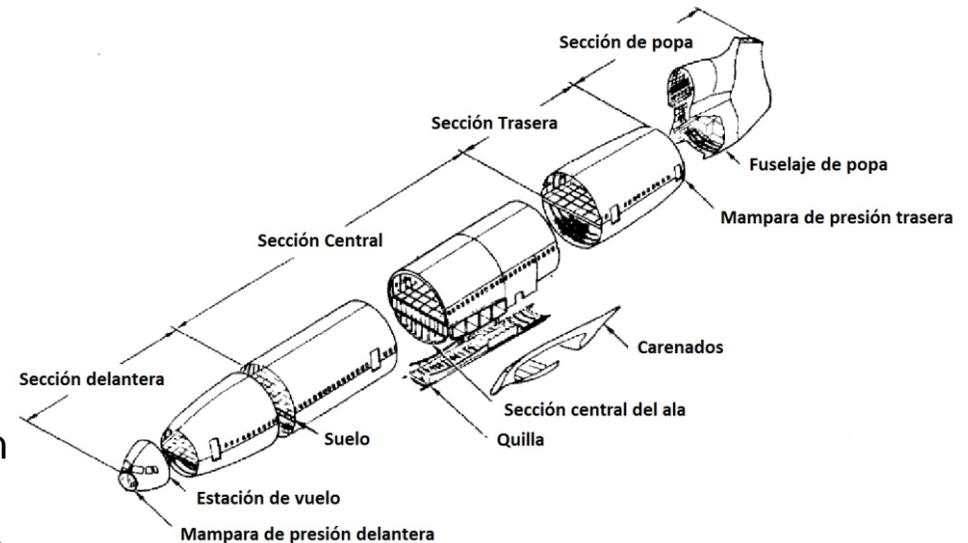


Introducción

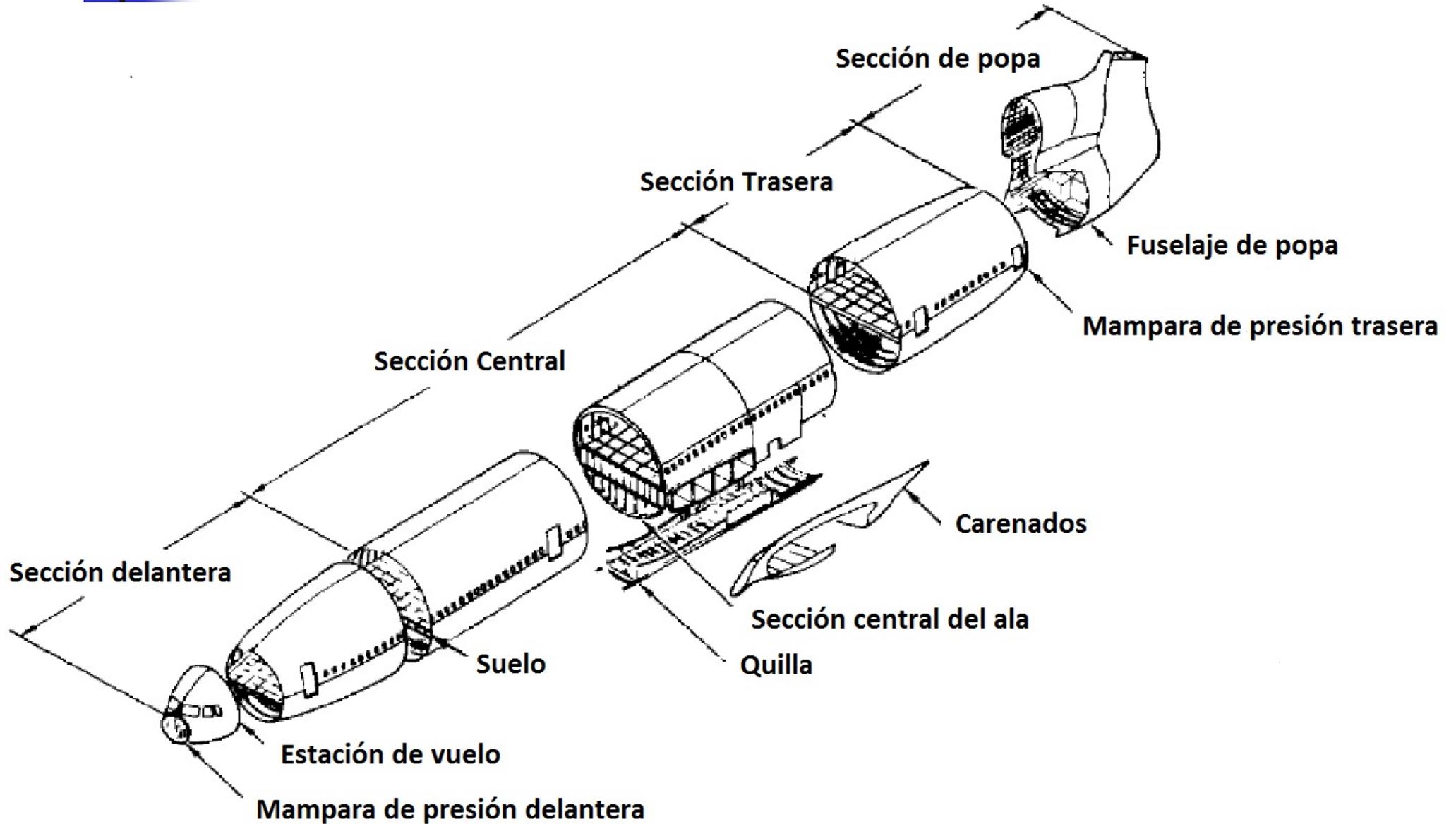
- Estructura (Diseño):
 - Fuselaje
 - Ala
 - Estabilizadores
- Estimación de Pesos:
 - Método simplificado
 - Métodos detallados

Fuselaje: Estructura - I

- Estructura típica (**semimonocasco**):
 - Cuadernas - **frames**.
 - Soportan cargas de tracción (presurización)
 - Revestimiento - **skin**.
 - Fuerzas torsionales.
 - Mantener la presión de cabina.
 - Largueros del fuselaje – **longerons**.
 - Distribuir cargas axiales inducidas por flexión
 - Larguerillos del fuselaje - **stringers**
 - Distribuir cargas axiales inducidas por flexión
 - Mampara de presión – **pressure bulkhead**.
 - Ubicados en puntos de fuerza concentrados (alas, cola, tren de aterrizaje)
 - Estructura bastante grande – distribuir la carga aplicada en los revestimientos del fuselaje.
 - Zonas reforzadas.
 - Tren de aterrizaje
 - Unión con las superficies sustentadoras.
 - Vigas y paneles
 - División entre cabina y bodega



Fuselaje: Estructura - II



Fuselaje: Estructura - III

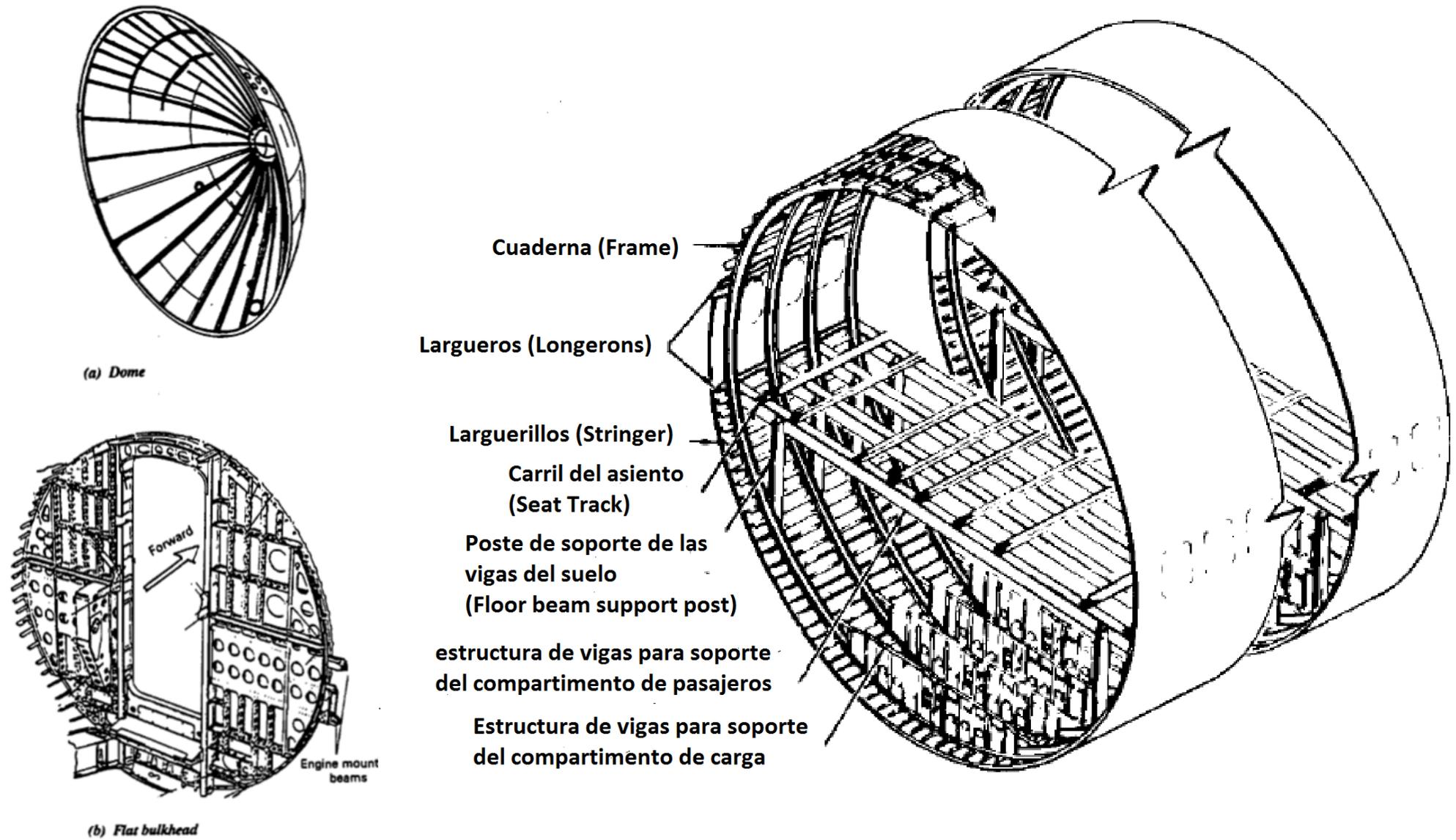
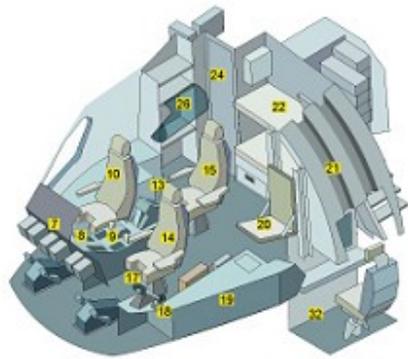
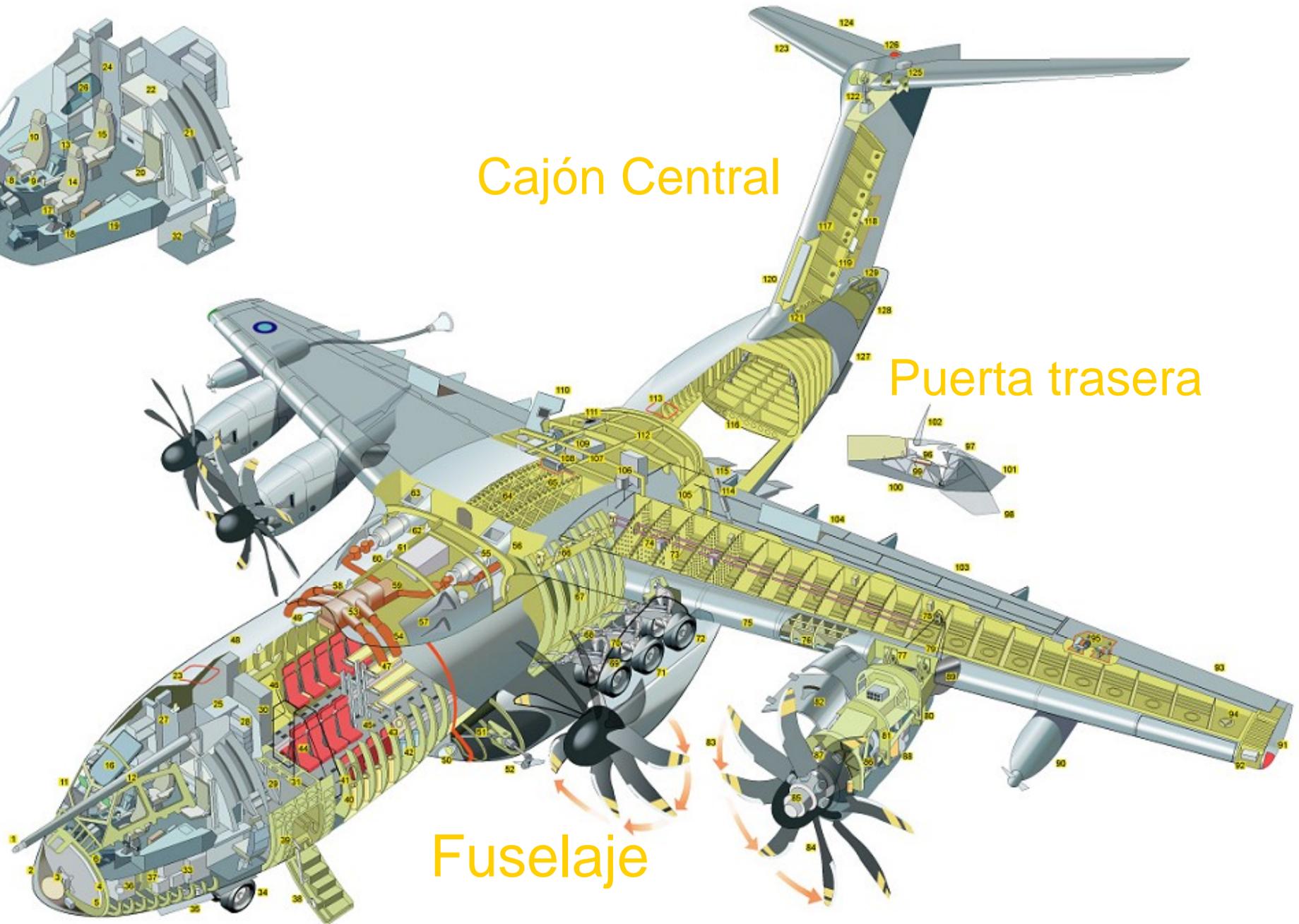


Fig. 11.3.28 Typical pressure bulkheads.



Cajón Central

Puerta trasera



Fuselaje

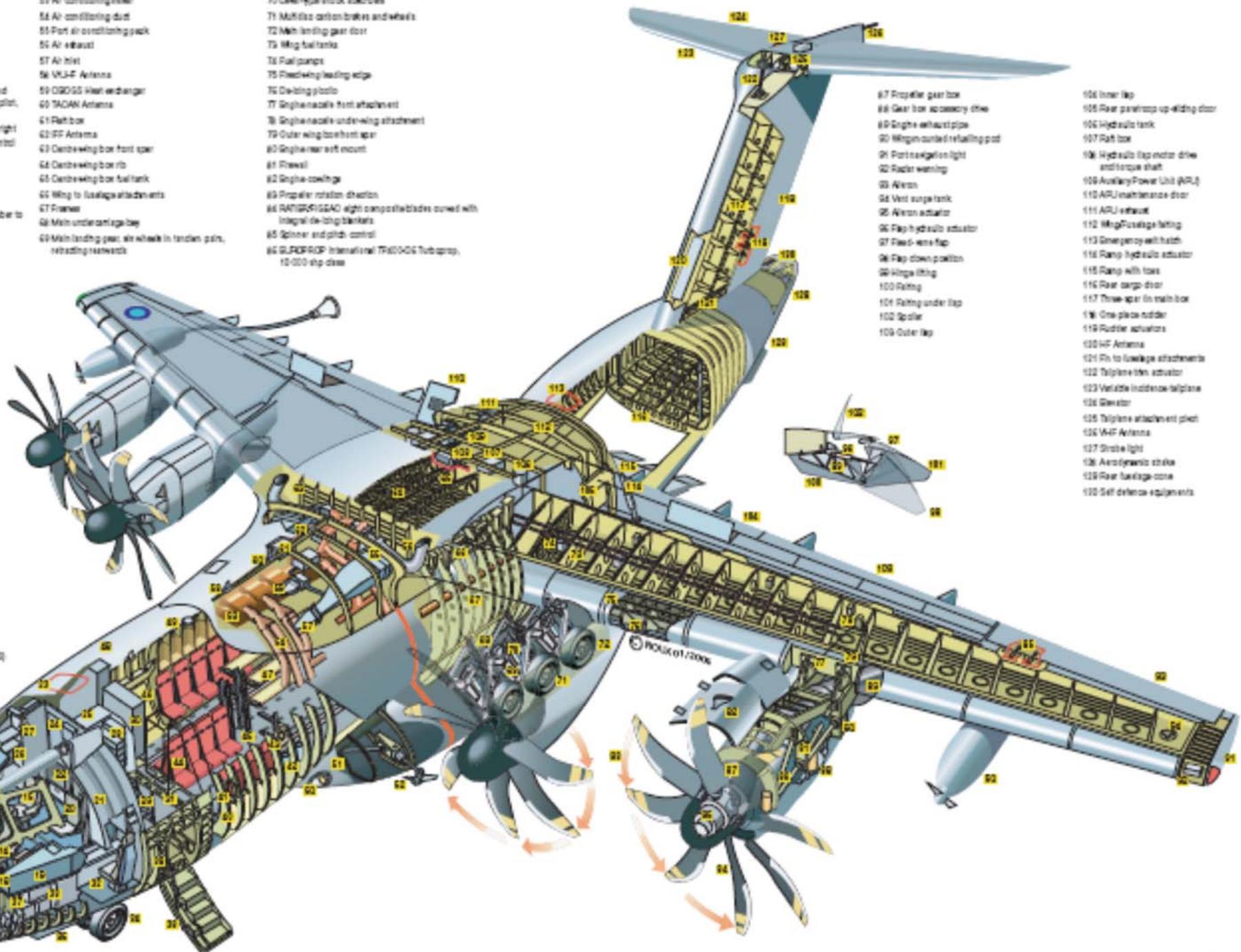
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AIRBUS MILITARY A400M

- 1 Removable in-flight refueling probe
- 2 Upward hinged rations
- 3 Weather radar
- 4 Front pressure bulkhead
- 5 Glideslope antenna
- 6 Rudder pedals
- 7 Front instrument panel, Primary Flight Display and Navigation/Attitude Display for each pilot and copilot, Engine Warning and Systems display in center
- 8 Multipurpose Control and Display Units left and right
- 9 Center pedestal, throttle control levers, director control sticks
- 10 Copilot's seat
- 11 Midcabin
- 12 Head-Up Display
- 13 Forward facing workstation for third crew member to seek tactical missions
- 14 Pilot's seat
- 15 Third crew member's seat
- 16 Overhead panel
- 17 Stairlock controller
- 18 Ground steering control
- 19 Lateral console
- 20 Fourth occupant folding seat
- 21 Cockpit stowage
- 22 Flight crew rest area, two bunks
- 23 Upper fuselage emergency exit hatch
- 24 Cockpit entrance door
- 25 Galley
- 26 Storage space
- 27 IFF Antenna
- 28 Electronics racks
- 29 Right station stairs
- 30 Avionics bay
- 31 Machine support beams
- 32 Loadmaster station
- 33 Underfloor electronics bay
- 34 Forward retracting nose landing gear
- 35 Nose landing gear main doors
- 36 Forward intake warning sensor
- 37 Nose Landing Gear box
- 38 Crew removal access with integral stairs
- 39 Ramp, door surrounding structure
- 40 Oxygen bottles
- 41 Forward window
- 42 On Ground Oxygen Generating System (OGGS)
- 43 Leading edge door warning light
- 44 Troop seat opened position
- 45 Cargo handling roller and tie-down rings
- 46 Standard forward emergency exit door
- 47 Medical evacuation bunk accommodation
- 48 TACAN Antenna
- 49 SATCOM Antenna
- 50 Landing light
- 51 Port apogee
- 52 Drop-out ram air turbine

- 53 Air conditioning mixer
- 54 Air conditioning duct
- 55 Port air conditioning pack
- 56 Air exhaust
- 57 Air hint
- 58 VLF Antenna
- 59 OGGS Heat exchanger
- 60 TACAN Antenna
- 61 Ref box
- 62 IFF Antenna
- 63 Centre-wing box front spar
- 64 Centre-wing box rib
- 65 Centre-wing box fuel tank
- 66 Wing to fuselage attachment
- 67 Frames
- 68 Main undercarriage bay
- 69 Main landing gear, air wheel in tandem pair, retracting rearwards
- 70 Low-type shock absorber
- 71 Multi-disc carbon brakes and wheels
- 72 Main landing gear door
- 73 Wing fuel tanks
- 74 Fuel pumps
- 75 Fixed wing leading edge
- 76 De-icing photo
- 77 Engine nacelle front attachment
- 78 Engine nacelle under-wing attachment
- 79 Outer wing box front spar
- 80 Engine rear seat mount
- 81 Firewall
- 82 Engine cowling
- 83 Propeller rotation direction
- 84 RATIDEGRIDAD eight composite blades curved with integral de-icing blankets
- 85 Spinner and pitch control
- 86 GULFSTREAM International TR4000 Turboprop, 10,000 shp class

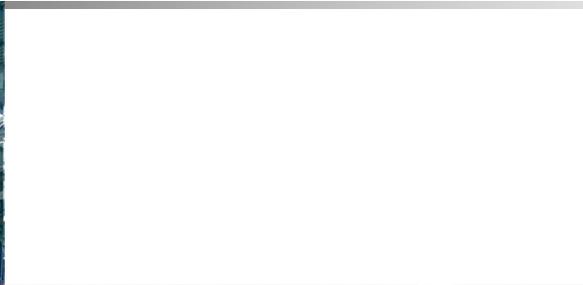
- 87 Propeller gear box
- 88 Gear box accessory drive
- 89 Engine exhaust pipe
- 90 Wing-mounted refueling pod
- 91 Port navigation light
- 92 Radio warning
- 93 Aileron
- 94 Vent surge tank
- 95 Aileron actuator
- 96 Flap hydraulic actuator
- 97 Flap-own flap
- 98 Flap down position
- 99 Wings fitting
- 100 Railing
- 101 Railing under flap
- 102 Spoiler
- 103 Outer flap
- 104 Inner flap
- 105 Rear paratroop up-riding door
- 106 Hydraulic tank
- 107 Fuel box
- 108 Hydraulic flap motor drive and torque shaft
- 109 Auxiliary Power Unit (APU)
- 110 APU maintenance door
- 111 APU exhaust
- 112 Wing/Fuselage fitting
- 113 Emergency exit hatch
- 114 Ramp hydraulic actuator
- 115 Ramp with tows
- 116 Rear cargo door
- 117 Three spar in main box
- 118 One piece rudder
- 119 Rudder actuators
- 120 IFF Antenna
- 121 Pin to fuselage attachment
- 122 Tailplane rib actuator
- 123 Vertical incidence tailplane
- 124 Elevator
- 125 Tailplane attachment point
- 126 VHF Antenna
- 127 Drive light
- 128 Aerodynamic strake
- 129 Rear fuselage cone
- 130 Self defence equipment



Fuselaje: Estructura - IV



**Sect. Central
Delantera Fuselaje**



Sect 17 Fuselaje trasero



Fuselaje

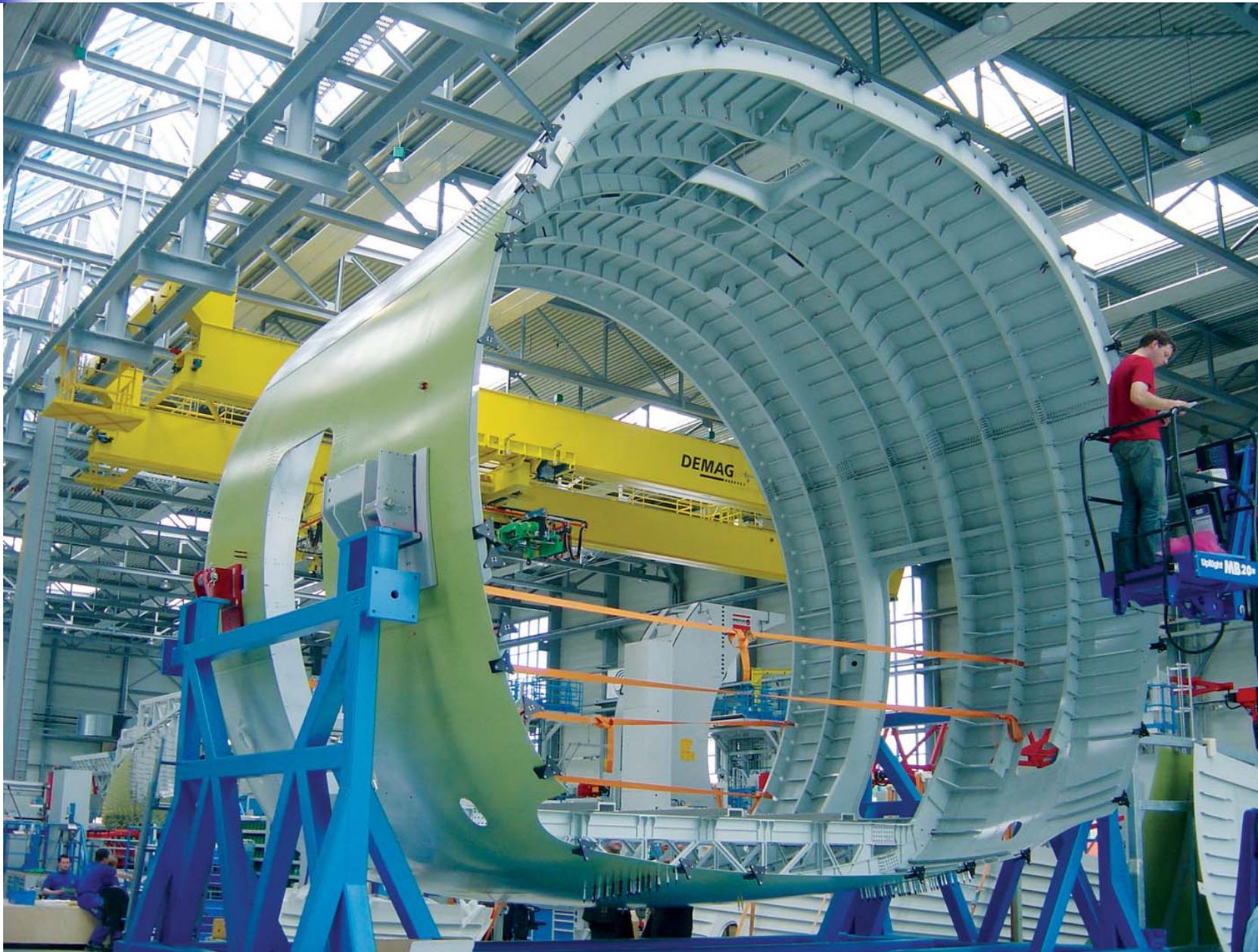


Mampara de presión

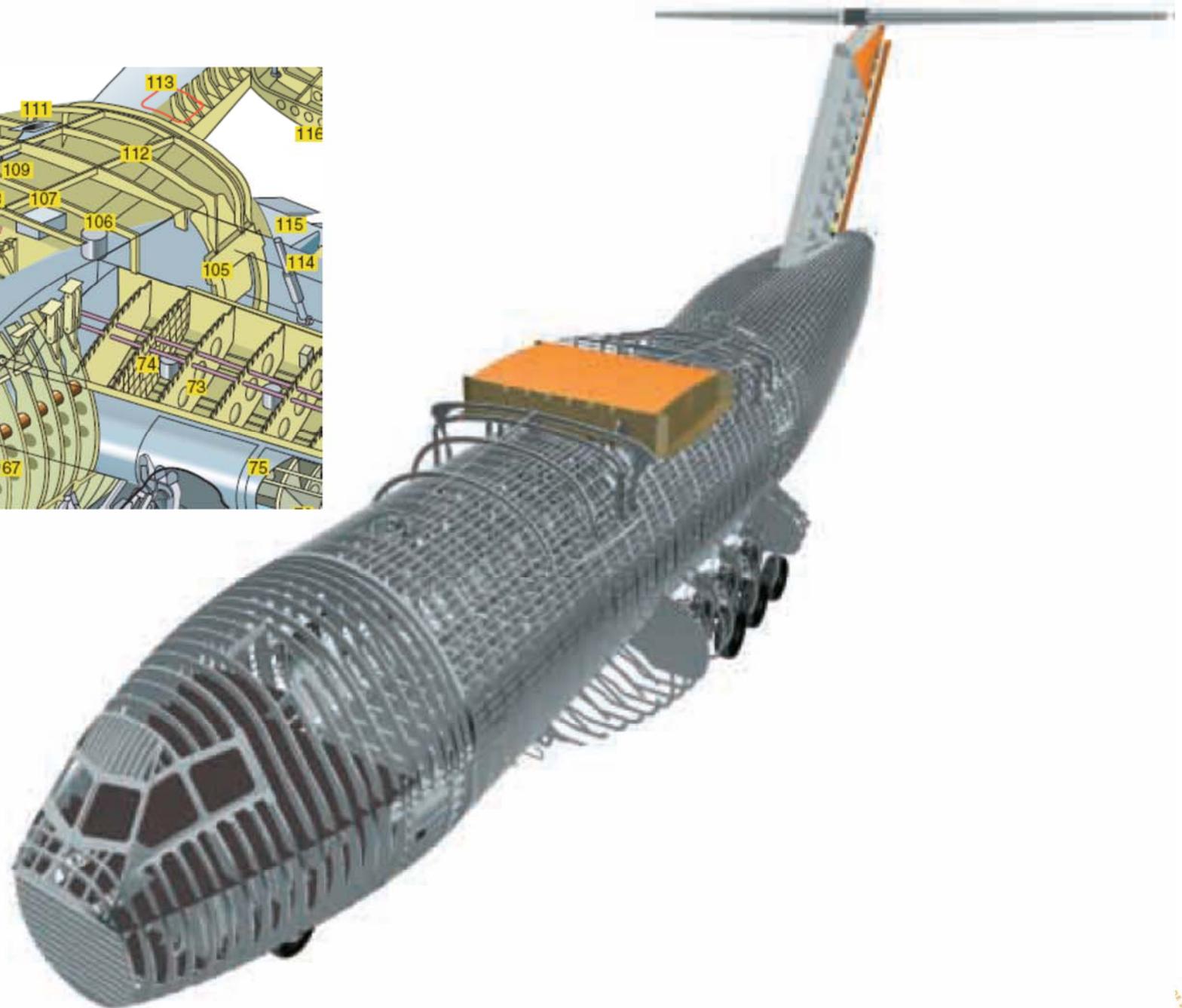
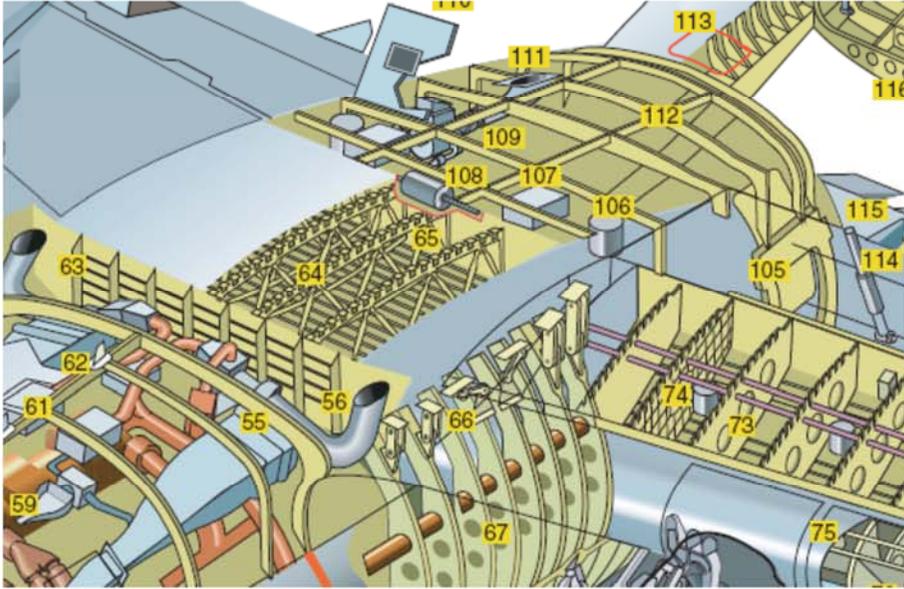


Sect Cono de cola

Fuselaje: Estructura - IV



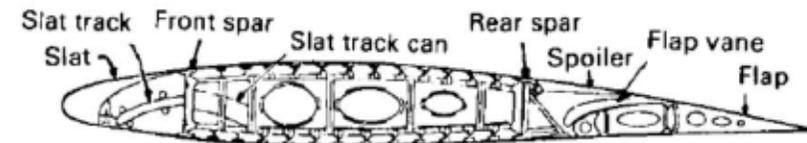
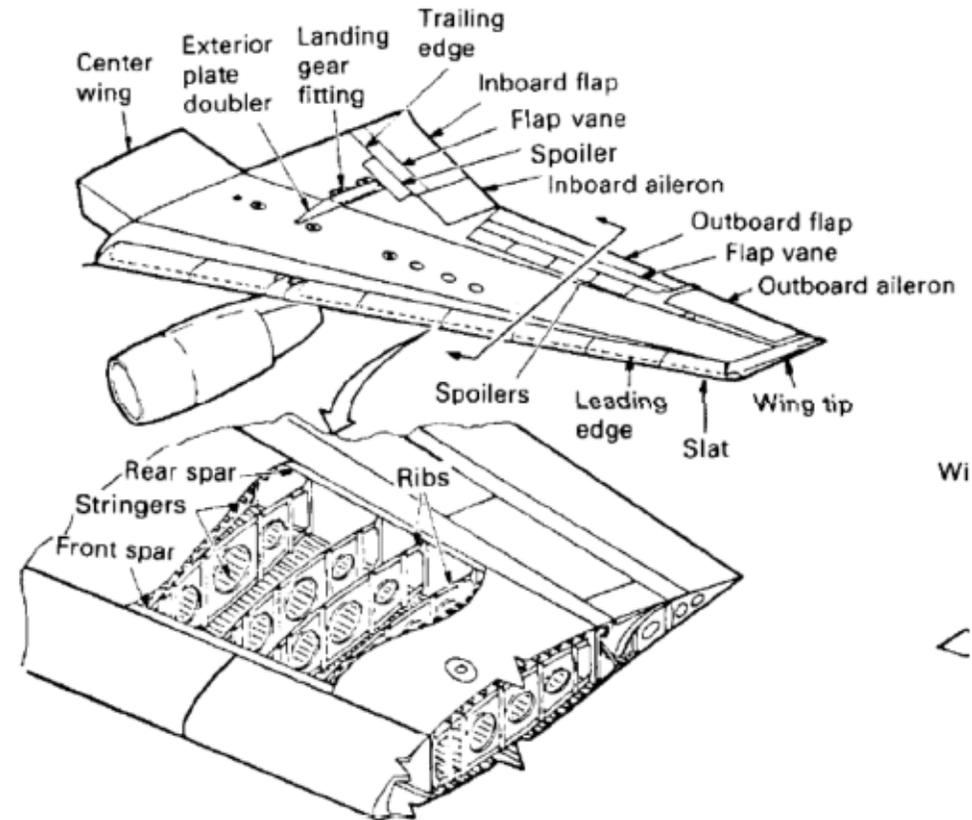
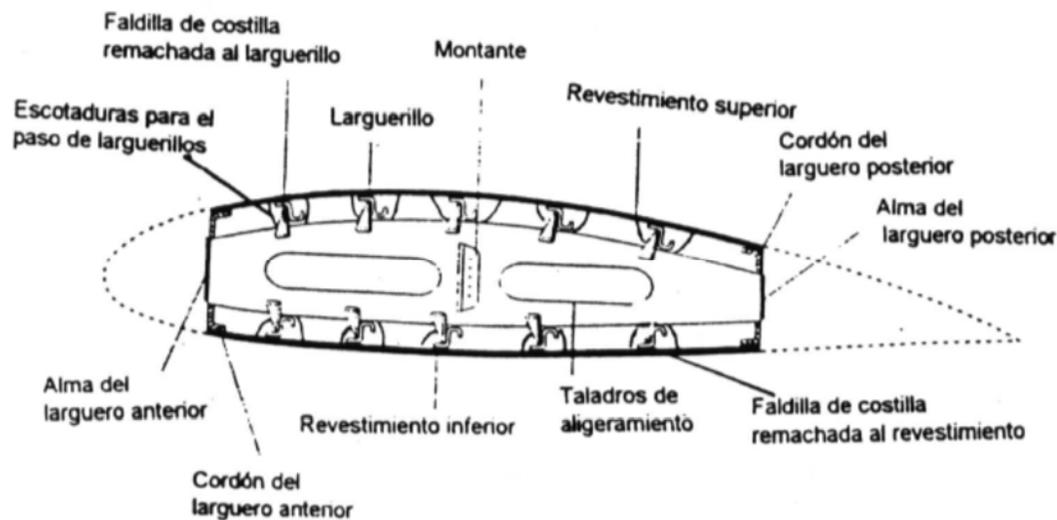
A400M – Estructura del fuselaje



Estructura: Ala - I

■ Elementos constitutivos:

- Largueros - *spar*.
- Costillas - *ribs*.
- Larguerillos - *Longitudinal stringer*.
- Revestimiento - *skin*.
- Cajón de torsión – *torsional box – D-box*.
- Borde de entrada – *leading edge*
- Borde de salida – *trailing edge*
- Extremo del ala - *wingtip*
- Puertas de acceso.
- Uniones entre elementos.
- Zonas reforzadas:
 - Tren de aterrizaje.
 - Motores.
- Unión ala-fuselaje.
- Alojamiento del tren.



(a) Typical transport wing

Estructura: Ala - II

■ Costillas:

- Generalmente contruidos en **una pieza sólida** a la que se le practican **orificios de acceso**. También se pueden construir mediante **triangulación de perfiles**.
- Objetivo de los orificios
 - Pasar **cableado: hidráulico, eléctrico**.
 - **Reducción de peso**

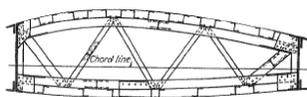


Fig. A21.4

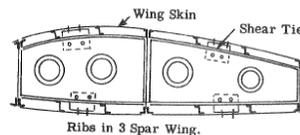


Fig. A21.5

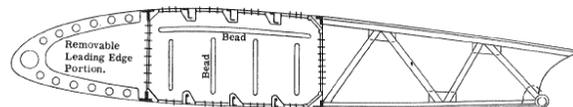


Fig. A21.6

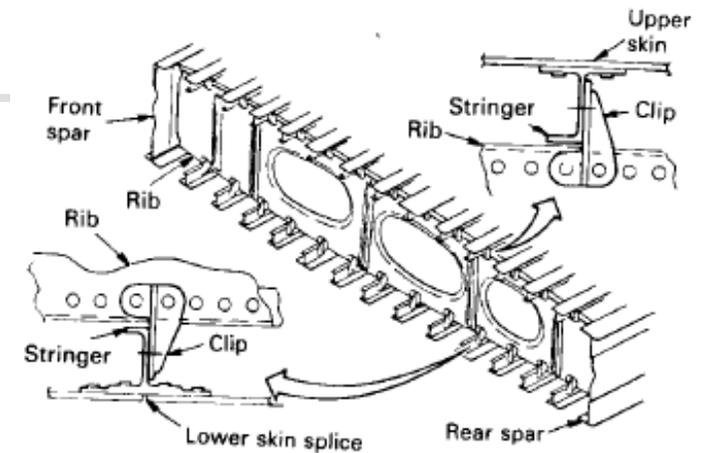


Fig. 8.5.2 Typical rib construction.

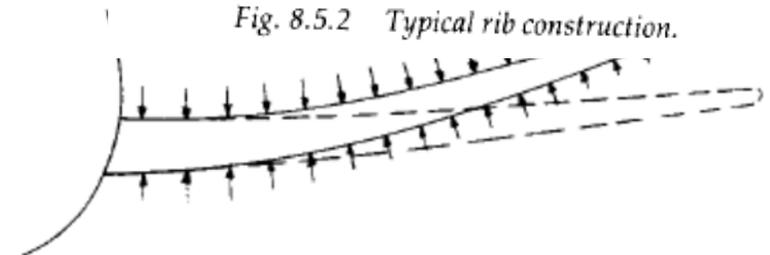


Fig. 8.5.4 Wing crushing loads due to flexure bending.

■ Misión estructural

- Transferir las **cargas aerodinámicas** externas a los largueros.
- Soportar las **cargas de aplastamiento**, manteniendo la geometría del perfil.
- **Redistribuir** las **cargas concentradas** (góndola motor y tren de aterrizaje) a los largueros y a los paneles de recubrimiento.
- **Soporte** para los **larguerillos**
- **Redistribución de cizalladura** en los lugares de cargas concentradas.



Estructura: Ala - III

- Largueros:
 - **Elementos longitudinales** que recorren el ala de la **raíz** a la **punta**.
 - Se suelen usar dos **largueros paralelos**, formando el llamado cajón del ala (*wingbox*)
 - Se encargan principalmente de **soportar** los **esfuerzos de flexión**, debidos a las **cargas aerodinámicas**.
 - Pueden soportar **cargas concentradas** debidas al **tren de aterrizaje** y los **motores**.
 - Elementos:
 - Alma, alas, montantes

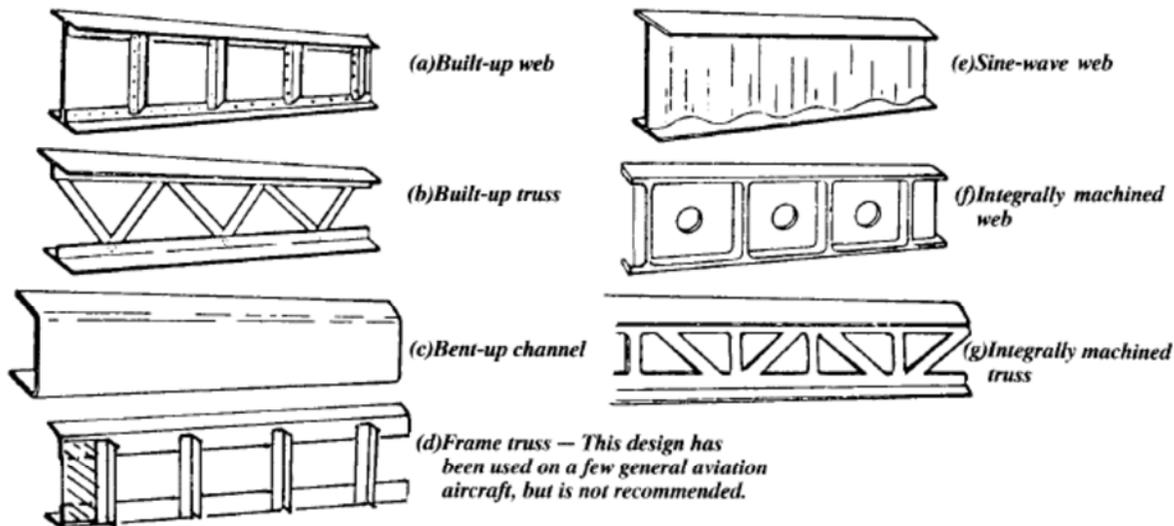
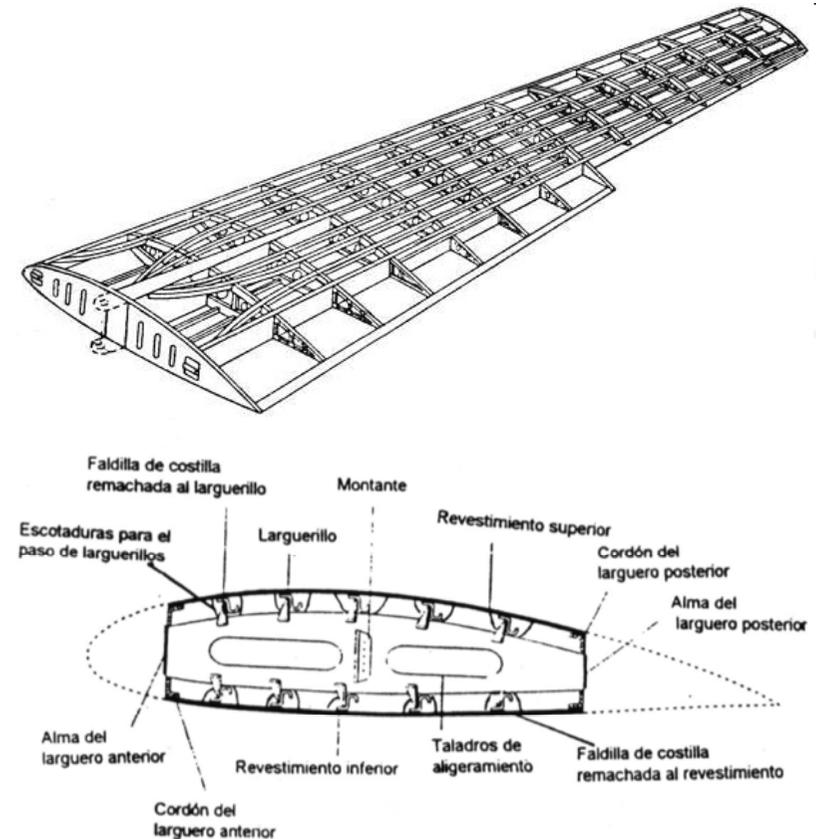
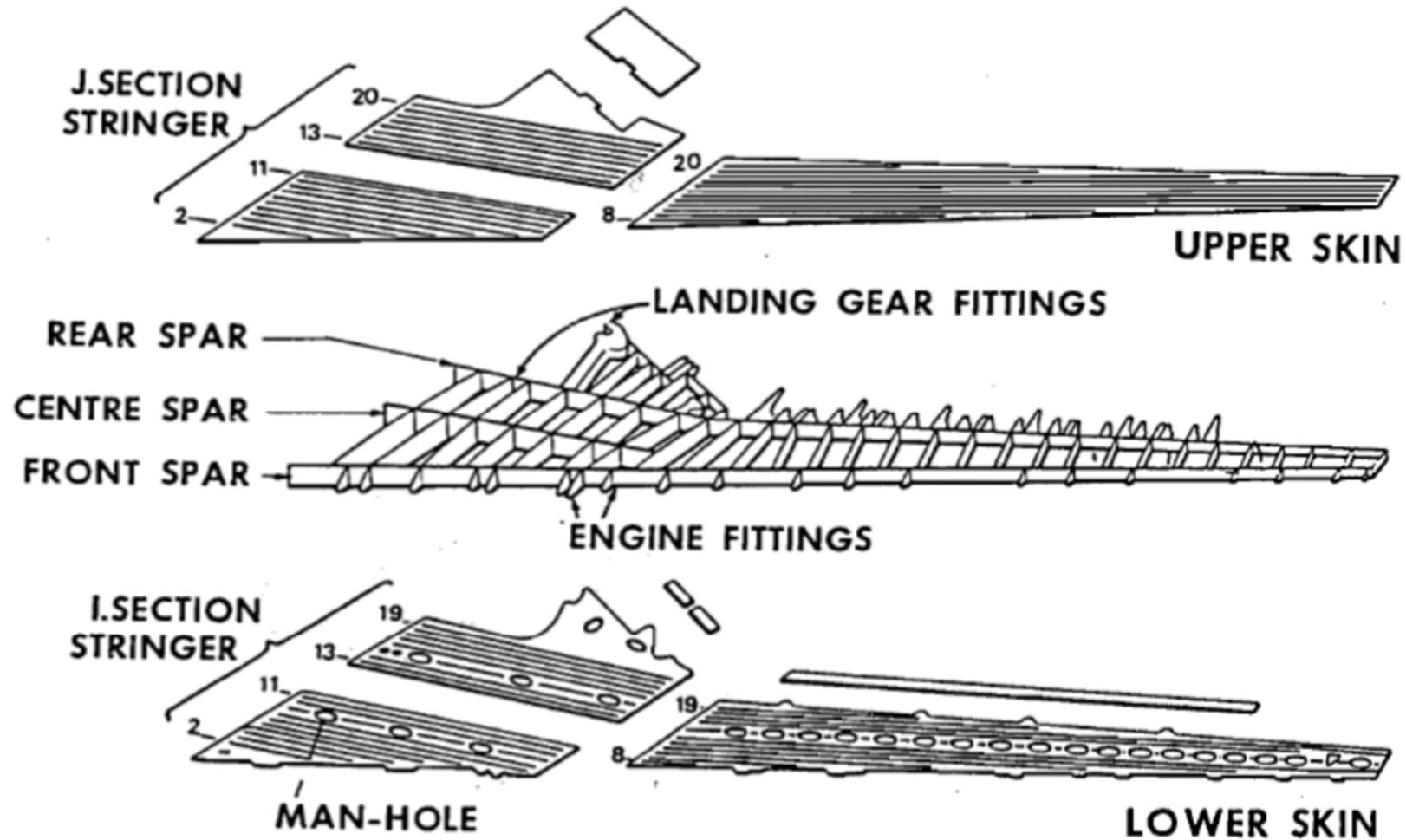


Fig. 8.4.3 Typical spar configurations.



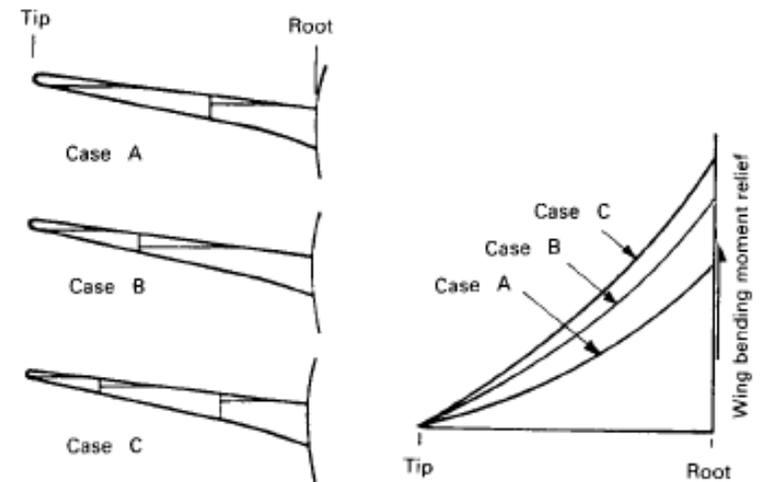
Estructura: Ala - III

- Revestimientos:
 - Cuenta con larguerillos para evitar el **pandeo**.
 - Compuertas de servicio: *hand-hole, man-hole*



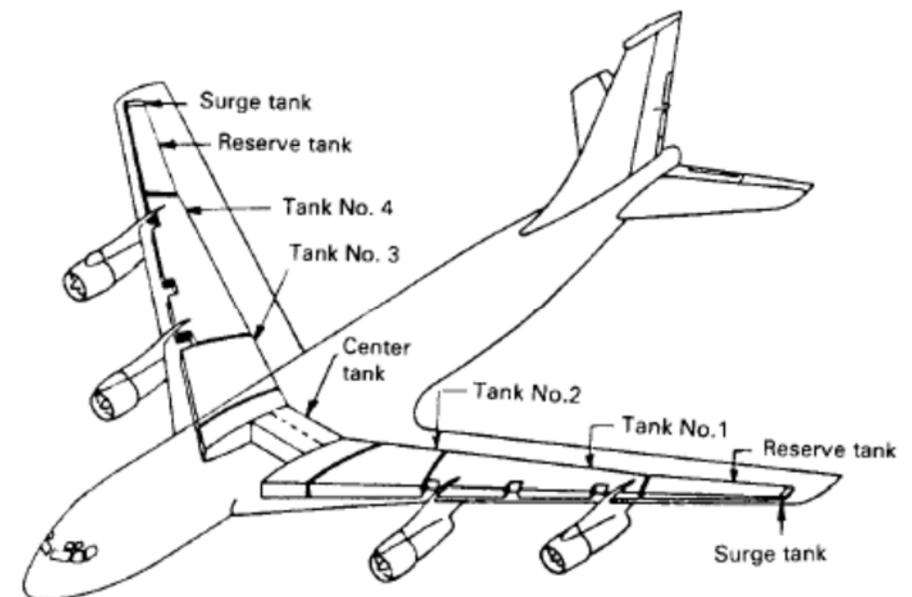
Estructura: Ala - IV

- Tanques de combustible
 - Se **aprovecha** el cajón central del ala para ubicar el **combustible**.
 - Se consigue **aliviar esfuerzos** de flexión.
 - Se **libera espacio** en la cabina.
 - Se utilizan **tanques integrados**, sellando la estructura con compuestos resistentes al combustible.
 - Todas las paredes tienen que ser **accesibles**: detección y reparación de **fugas**.
 - Evitar cambios bruscos de forma y secciones afiladas donde se encuentren los sellados
 - **Administración** de tanques de combustible:
 - **Alivio del par** de flexión.
 - Sistemas complejos de administración no son bienvenidos por los pilotos.



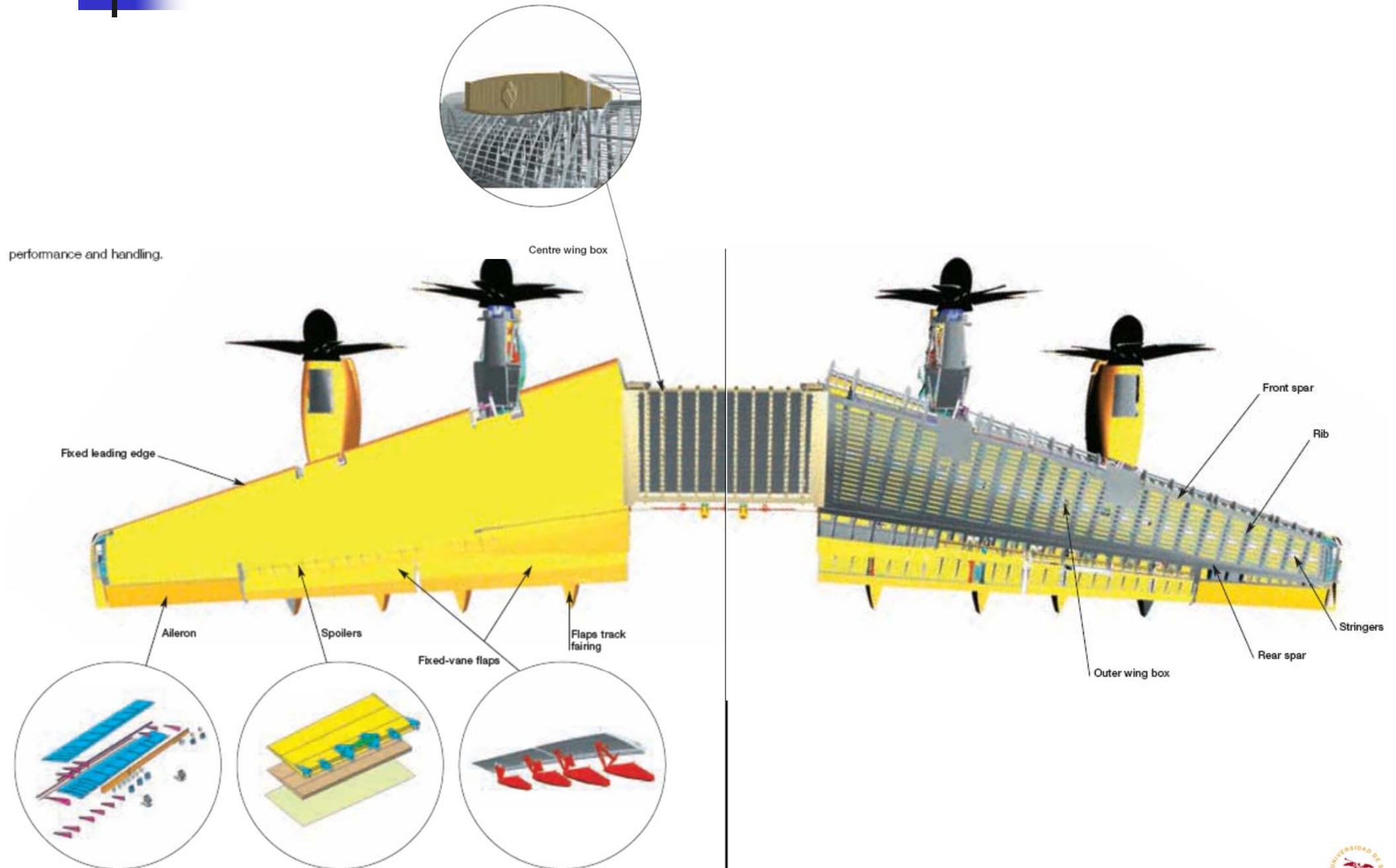
(b) Fuel tank geometry vs. wing relief

Fig. 8.8.4 Transport fuel tank geometry vs. wing load relief.

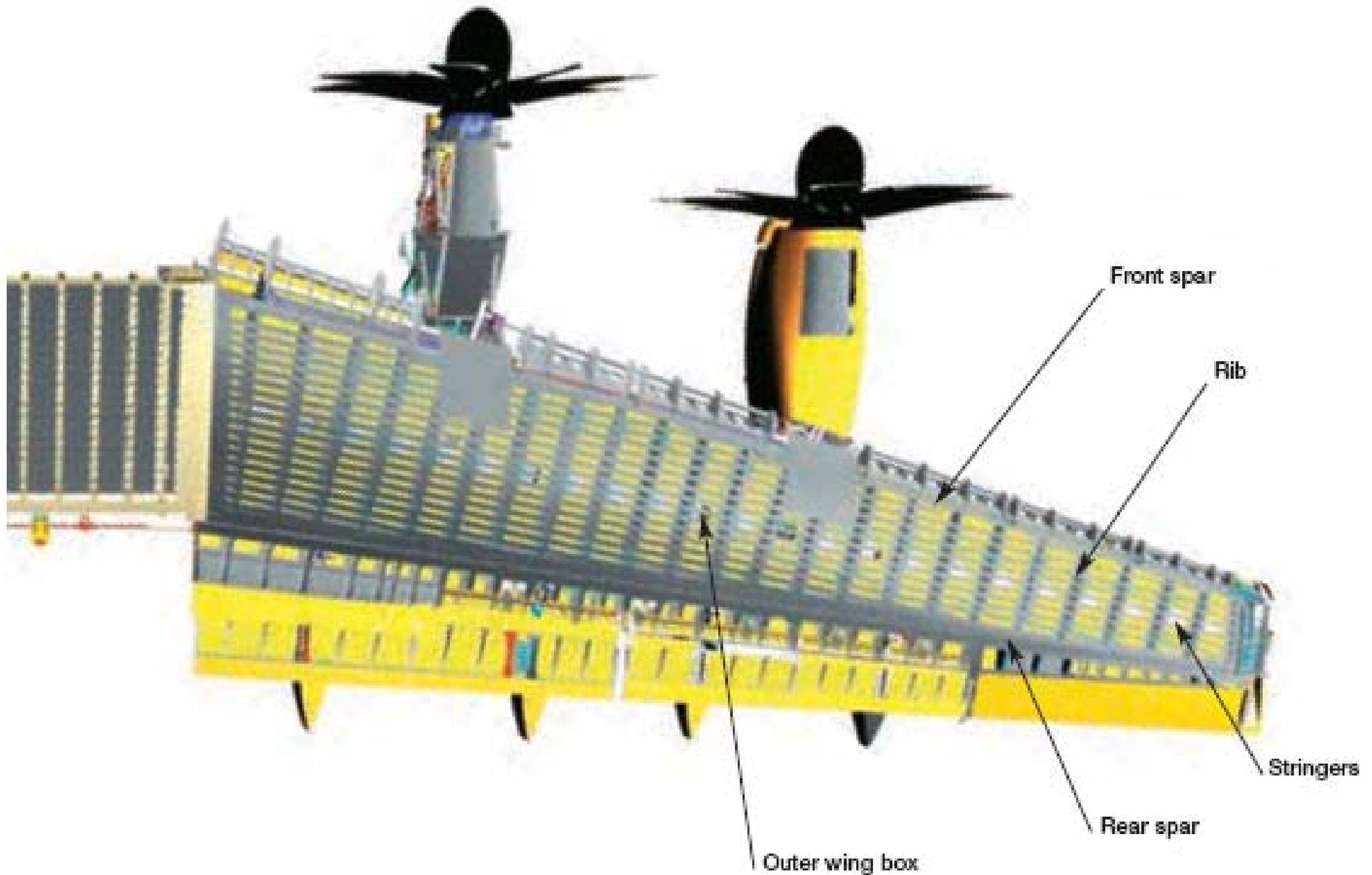


(a) Fuel tank installation

A400M – Estructura del ala - I

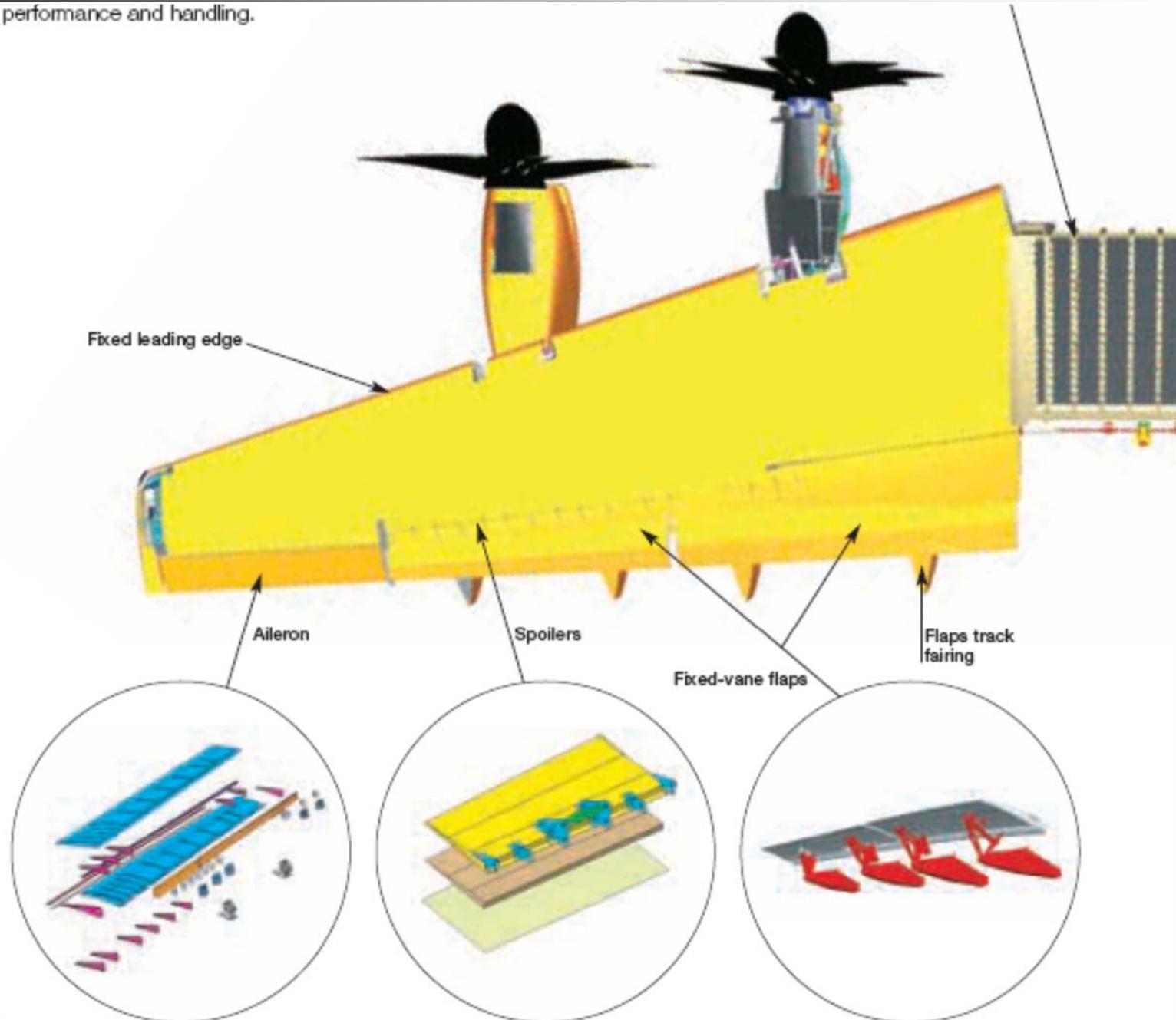


A400M – Estructura del ala - I

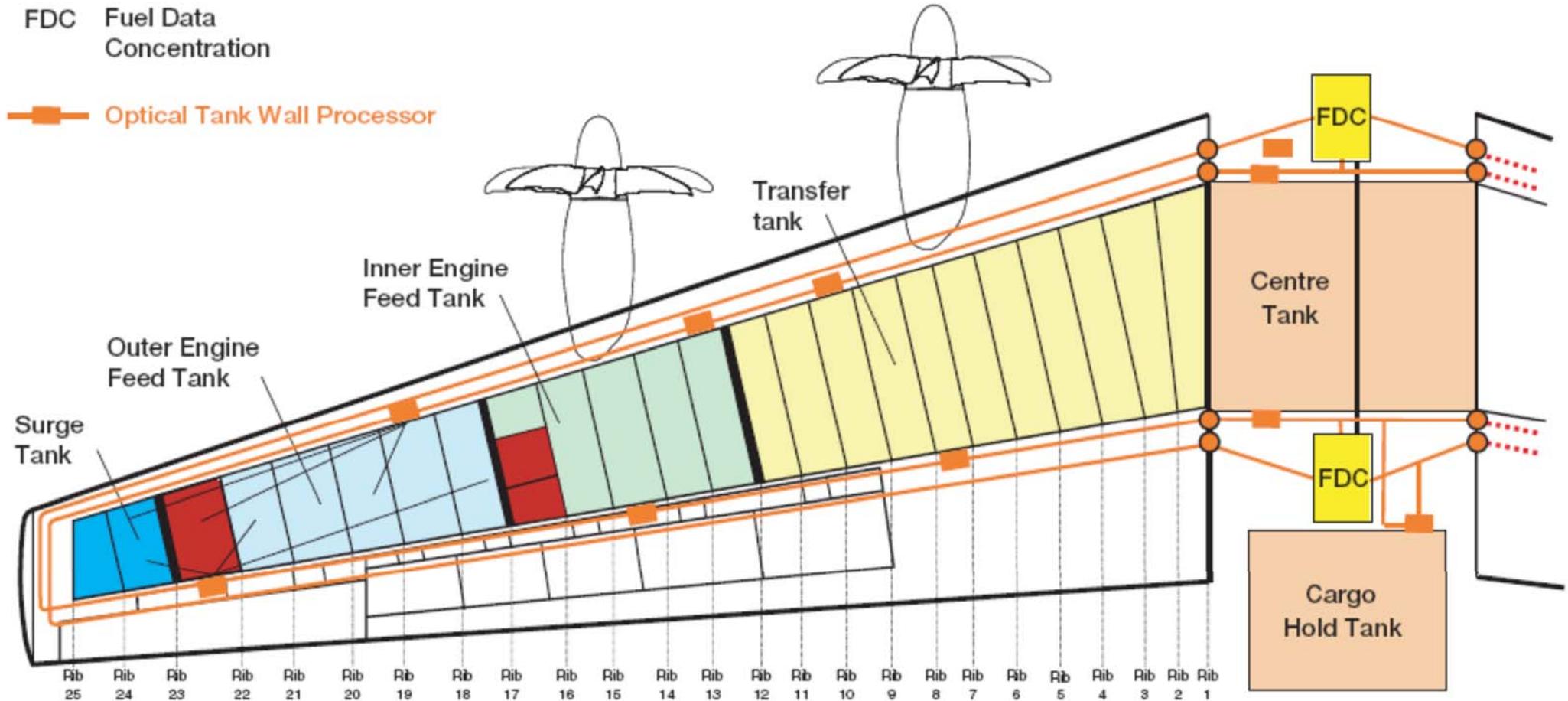


A400M – Ala y superficies

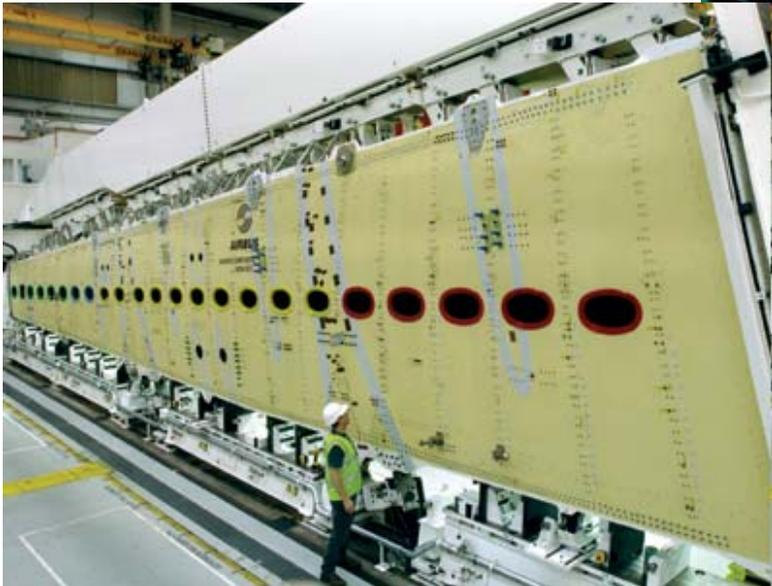
performance and handling.



A400M - Almacenaje de Combustible

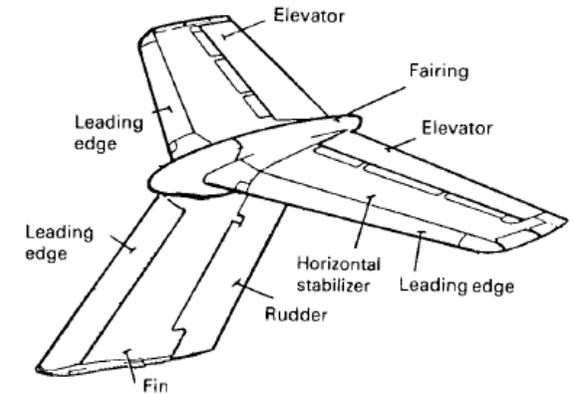


Estructura: Ala - V

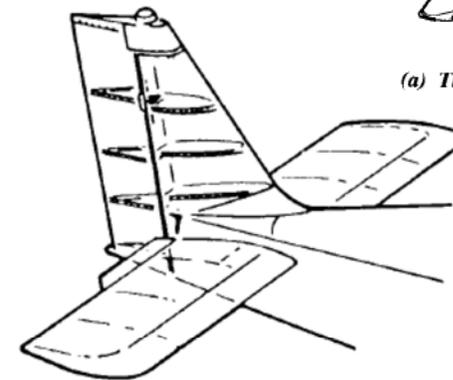


Arquitectura de la cola - Cargas soportadas

- Generales:
 - Fatiga debida a la zona sónica.
 - Carga de las bisagras debidas a flexión excesiva.
 - Inversión en el control de la superficie (*control surface reversal*)
 - Fallos de estructura.
 - Efectividad de la superficie de control.
 - Aplastamiento de las costillas.
 - Soporte de las superficies de control.
 - Soporte de los actuadores.
 - Redistribución de las cargas concentradas.
- Borde de entrada:
 - Golpe de granizo.
- Estabilizador horizontal:
 - Elevador instantáneo
 - Golpes de viento en T-tail.
 - Maniobras positivas y negativas.
 - Distribución asimétrica de la sustentación.
- Estabilizador vertical:
 - Timón de cola instantáneo.
 - Sobre-guiñada dinámica
 - Fallo de motor
 - Golpe de viento lateral
- Popa del fuselaje (parte trasera)
 - Redistribución de las cargas derivas horizontal y vertical



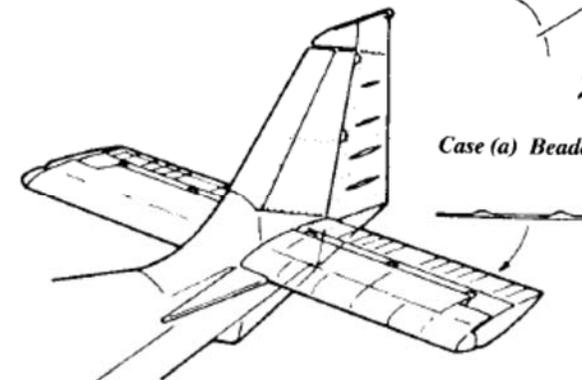
(a) Transport tail



Case (c) Spar and ribs design

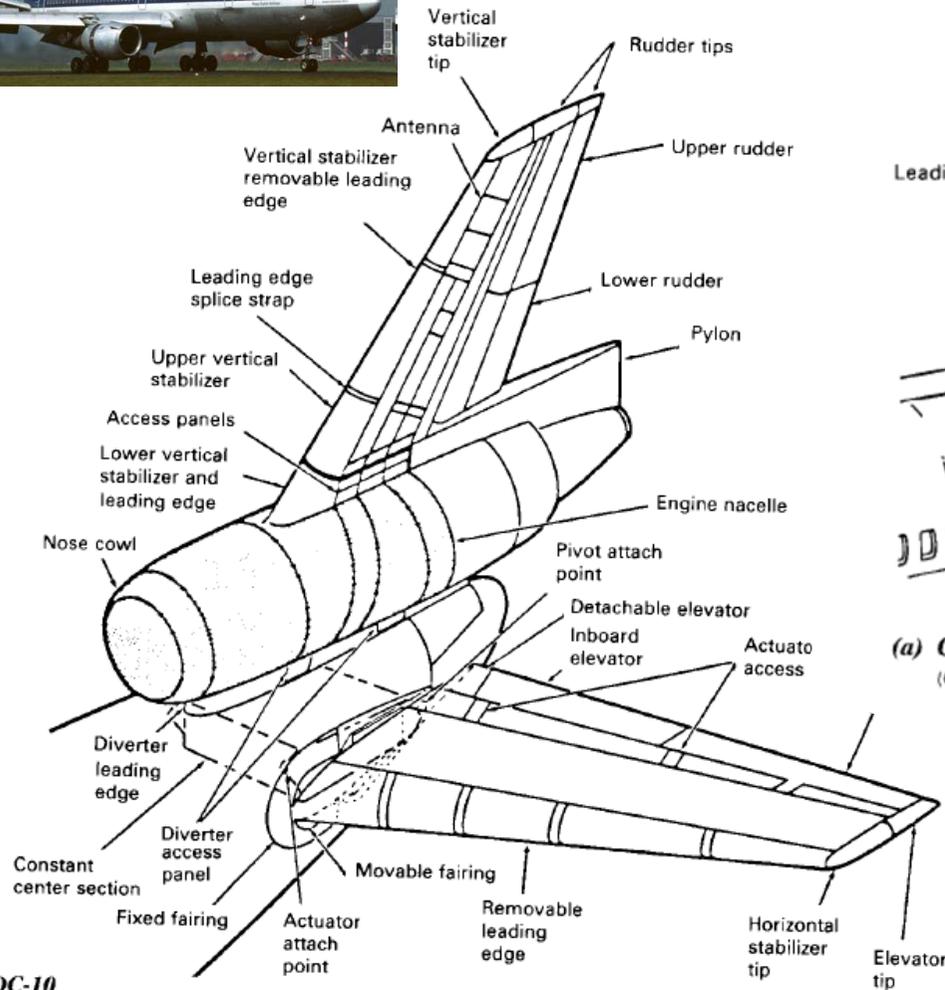


Case (a) Beaded skin or skin dimpling

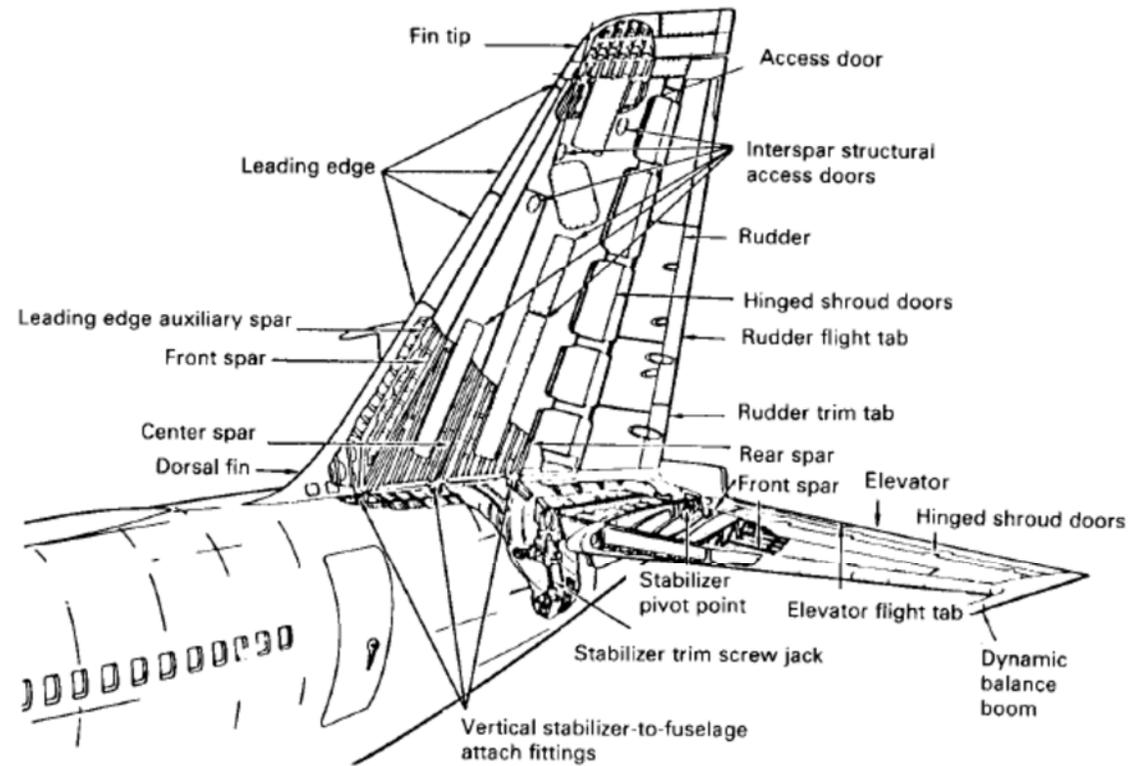


Case (b) Elevators and rudder-beaded skin or skin dimpling; main boxes – spar and ribs

Estructura: Estabilizadores - I



(b) DC-10
(Courtesy of Douglas Aircraft Co.)

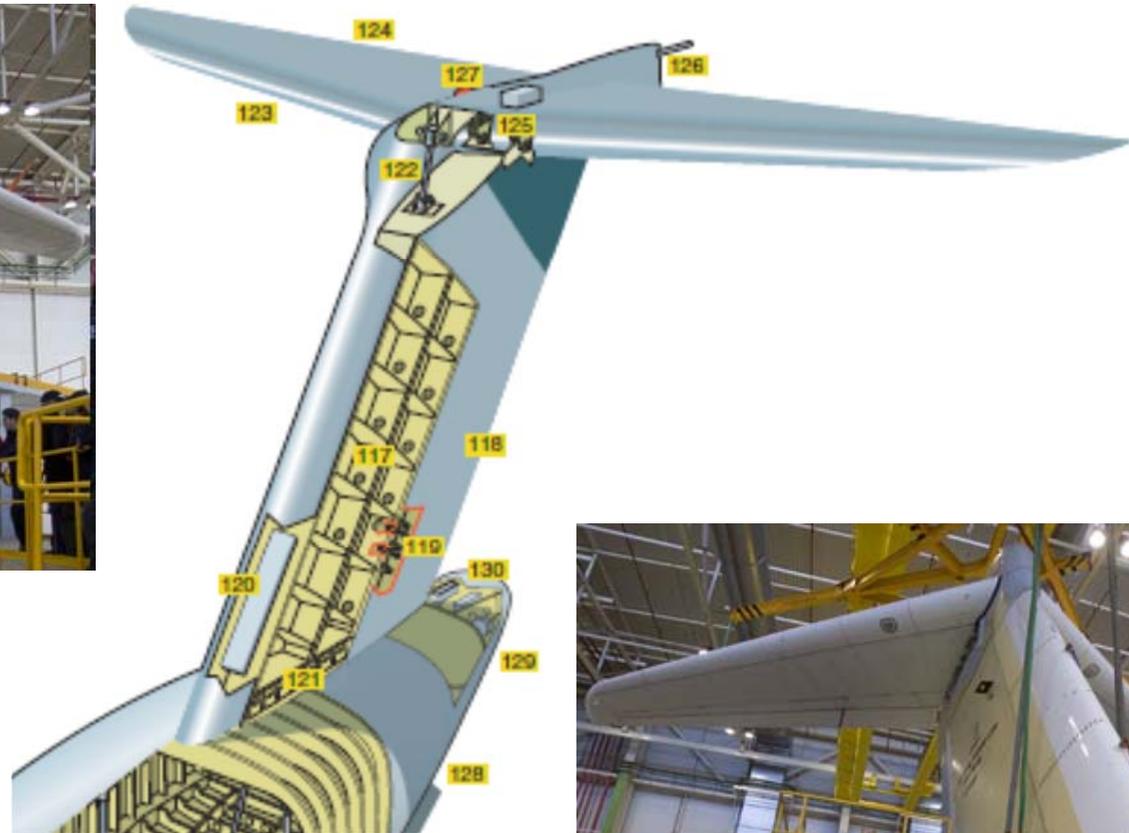


(a) Convair 880
(Courtesy of General Dynamics Corp. - Convair.)



Fig. 10.1.2 Structural arrangement of transport tails.

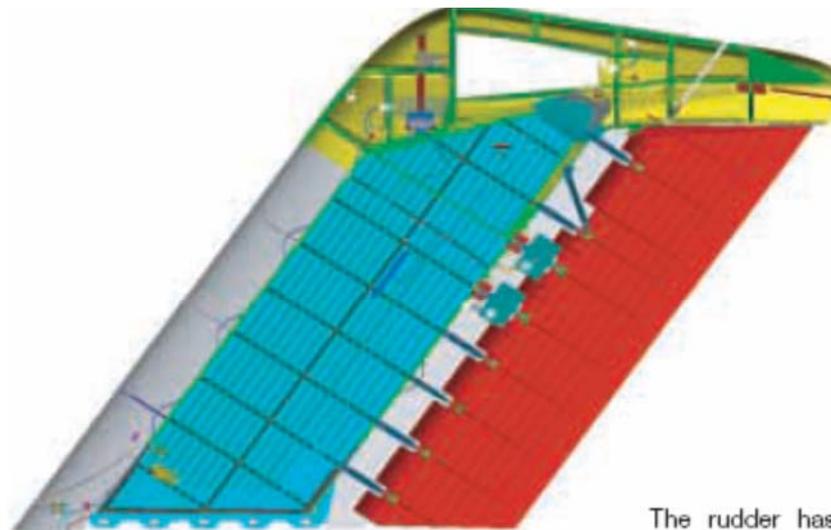
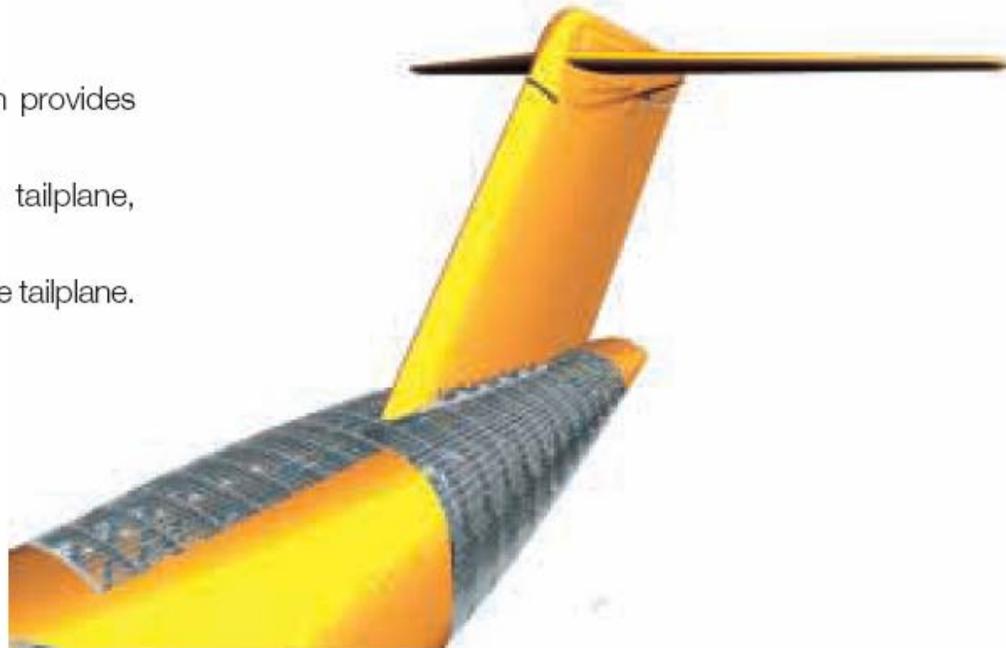
Estructura: Estabilizadores - II



A400M - Cola

The A400M has a T-tail configuration, which provides the following benefits:

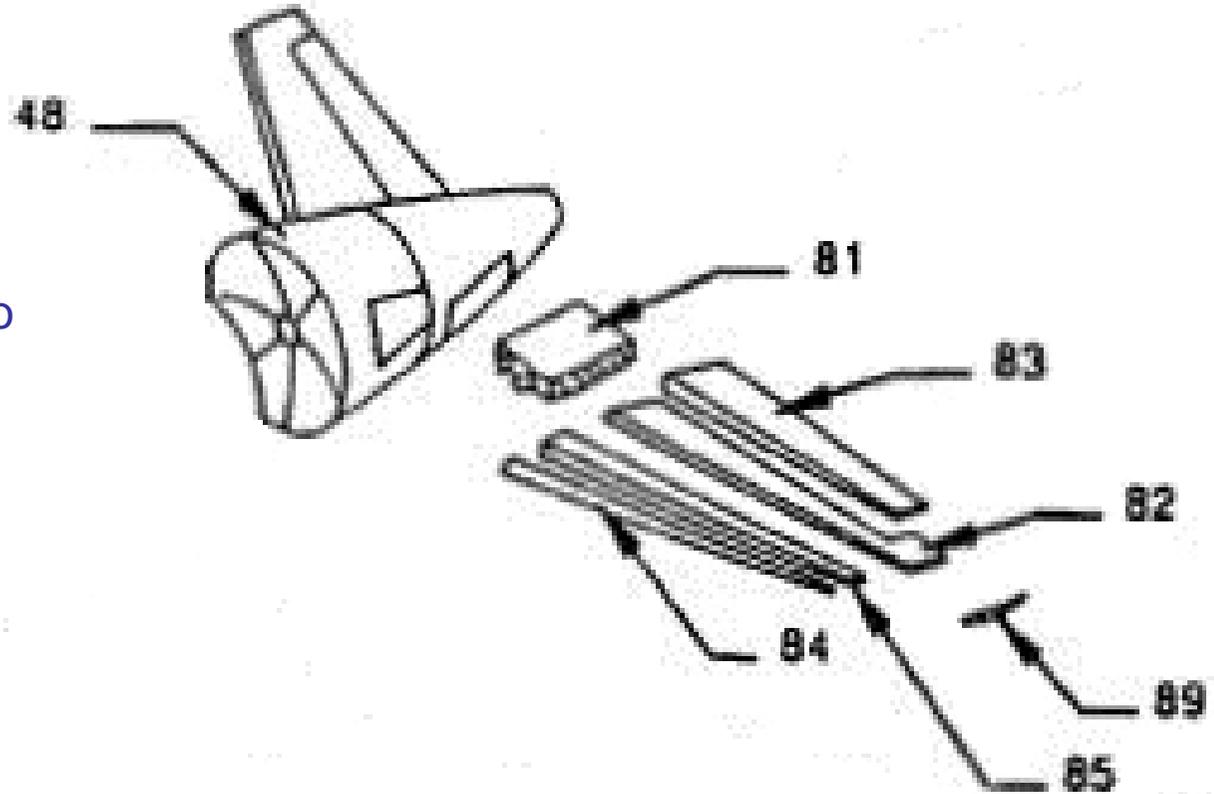
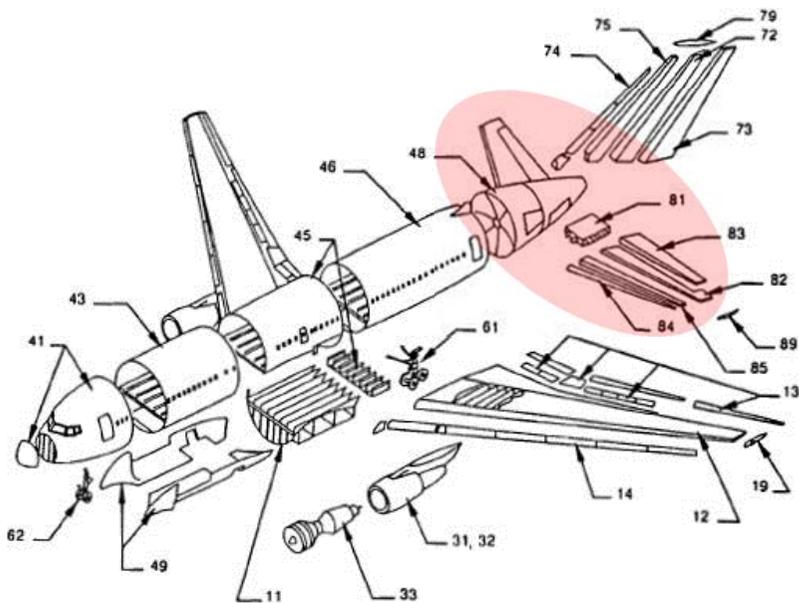
- Improved aerodynamic efficiency of the tailplane, since it is outside of the wing's wake;
- Reduced risk of foreign object damage to the tailplane.



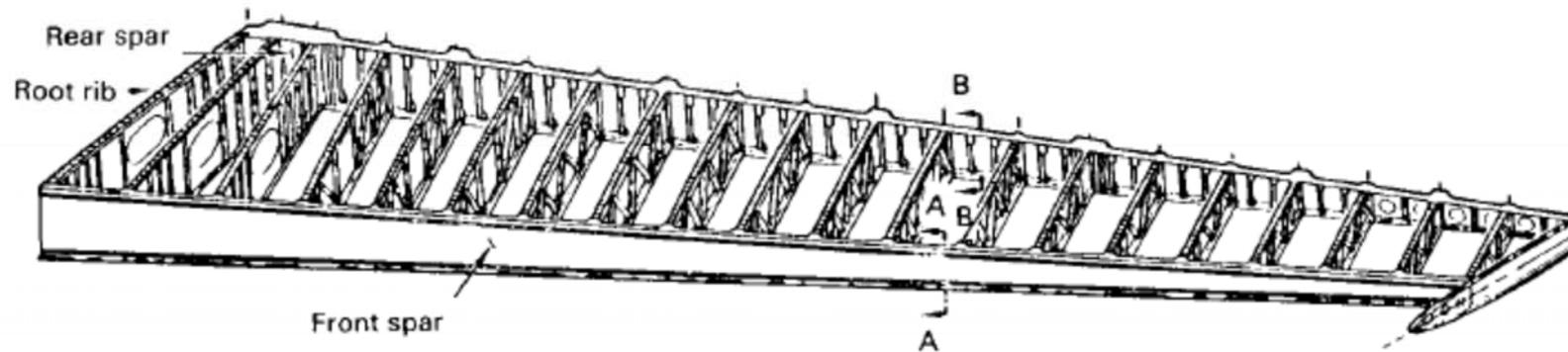
The rudder has a carbon-fibre reinforced plastic structure with aluminium being used in the rudder brackets. It is actuated by two electro-hydraulic servos.

Estabilizador Horizontal - I

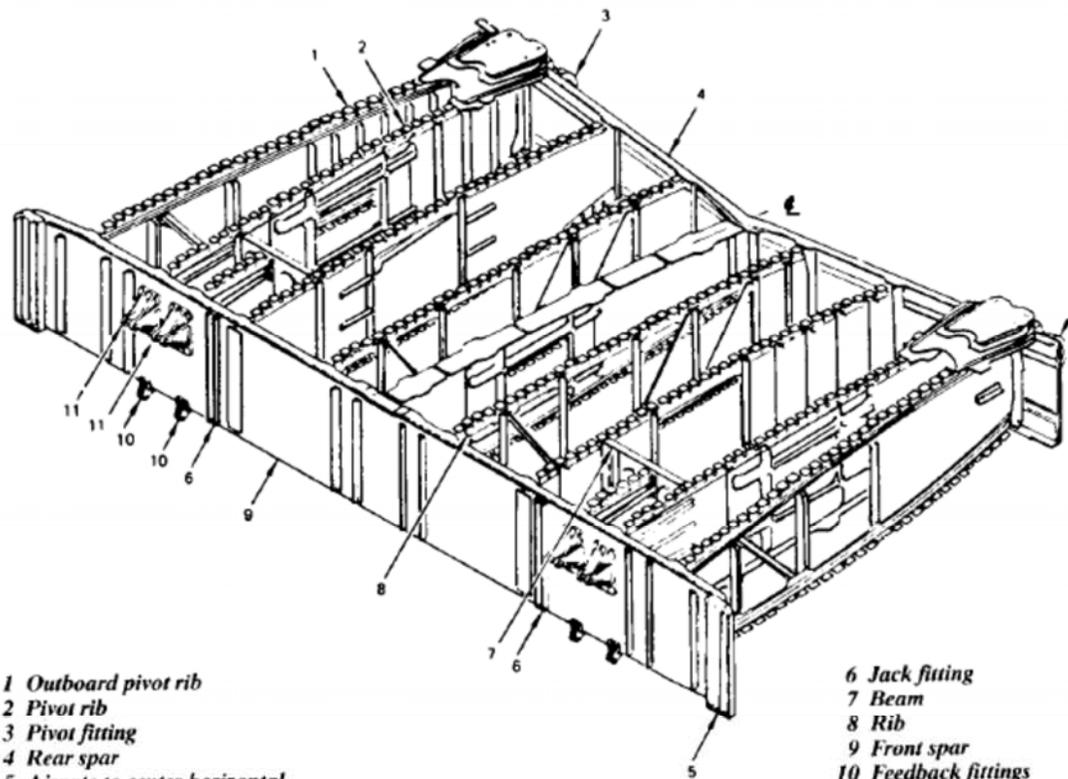
- 48 - Sección del cono de cola
- 81 - Sección central
- 82 - Cajón de torsión trasero
- 83 - Borde de salida
- 84 - Borde de ataque
- 85 - Cajón de torsión delantero
- 89 - Sección de punta



Estabilizador Horizontal - II



(b) *Outboard section*



- 1 Outboard pivot rib
- 2 Pivot rib
- 3 Pivot fitting
- 4 Rear spar
- 5 Airgate to center horizontal stabilizer fitting

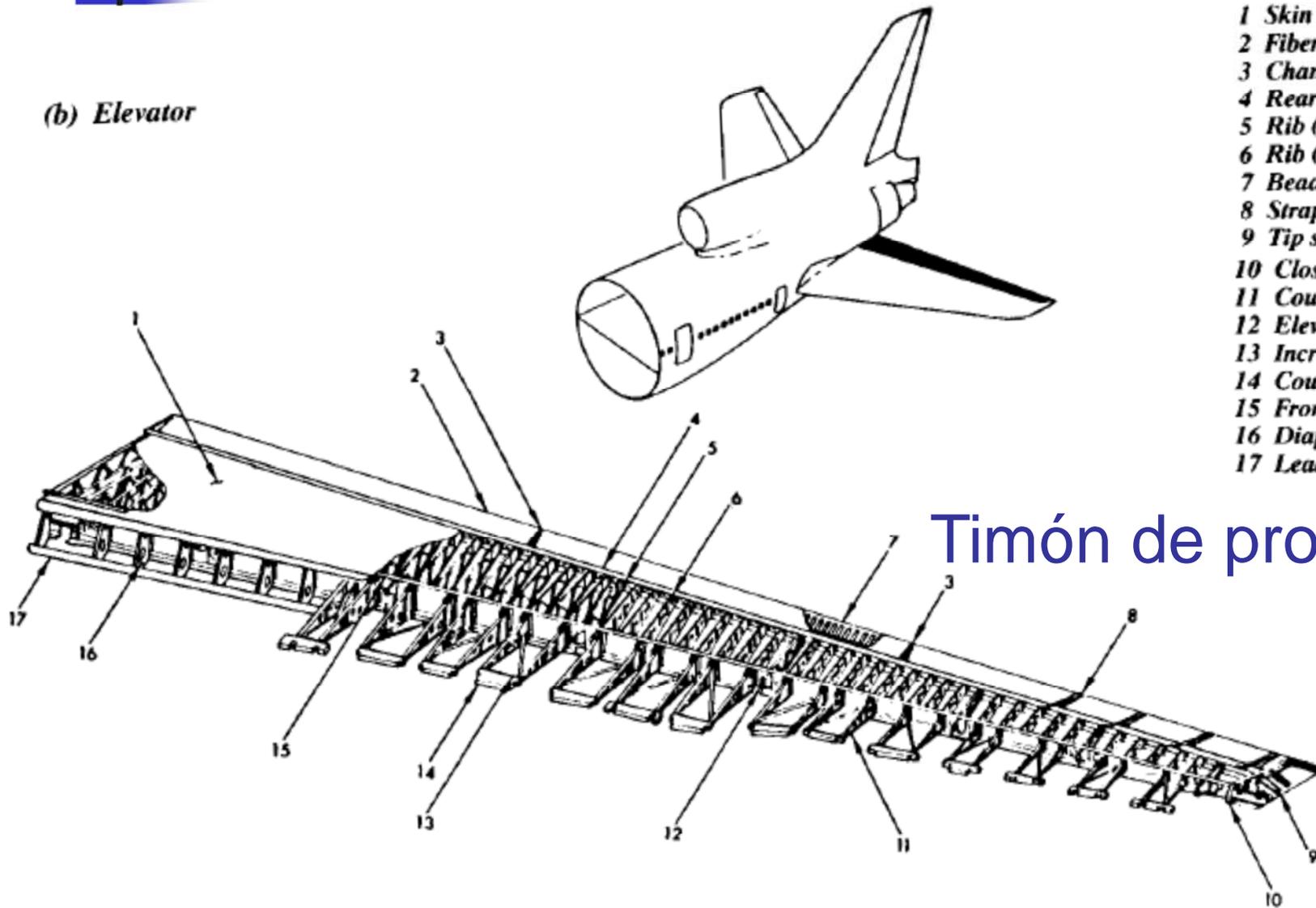
- 6 Jack fitting
- 7 Beam
- 8 Rib
- 9 Front spar
- 10 Feedback fittings
- 11 Actuator fittings



(a) *Center-section*

Estabilizador Horizontal - III

(b) Elevator

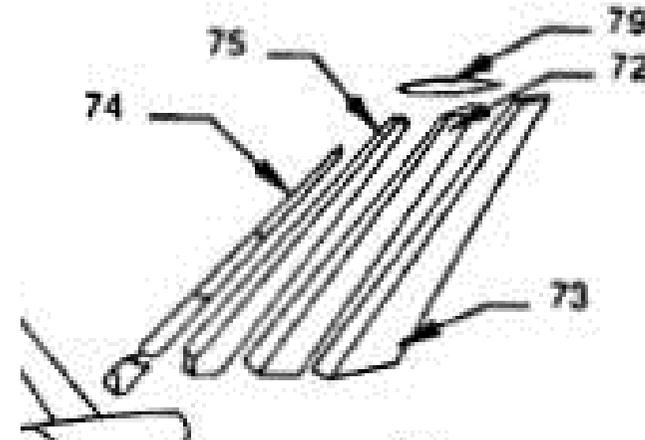
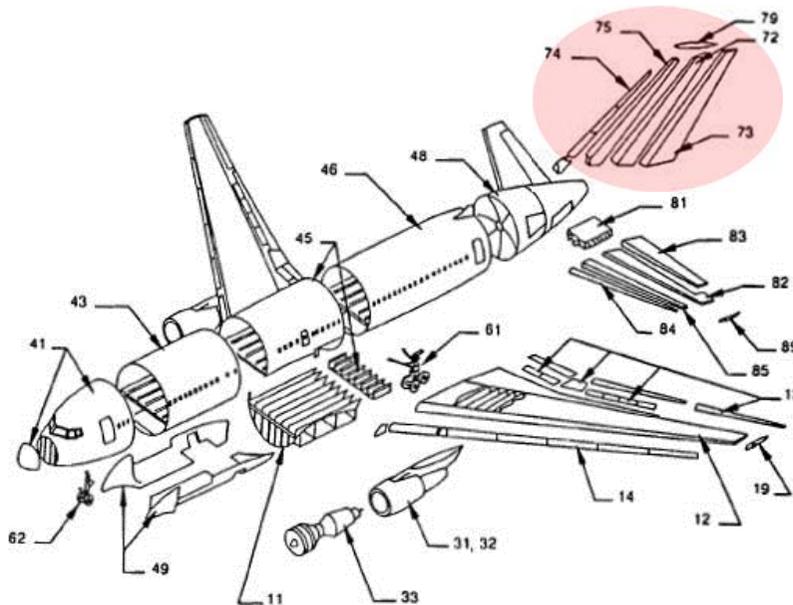


- 1 Skin
- 2 Fiberglass trailing edge
- 3 Channel
- 4 Rear spar
- 5 Rib (typical inboard)
- 6 Rib (typical outboard)
- 7 Beaded doubler inner skin
- 8 Strap and retainer
- 9 Tip structure
- 10 Closure rib
- 11 Counterbalance weight support arm
- 12 Elevator hinge fitting
- 13 Incremental weight
- 14 Counterbalance weight
- 15 Front spar
- 16 Diaphragm
- 17 Leading edge shroud

Timón de profundidad

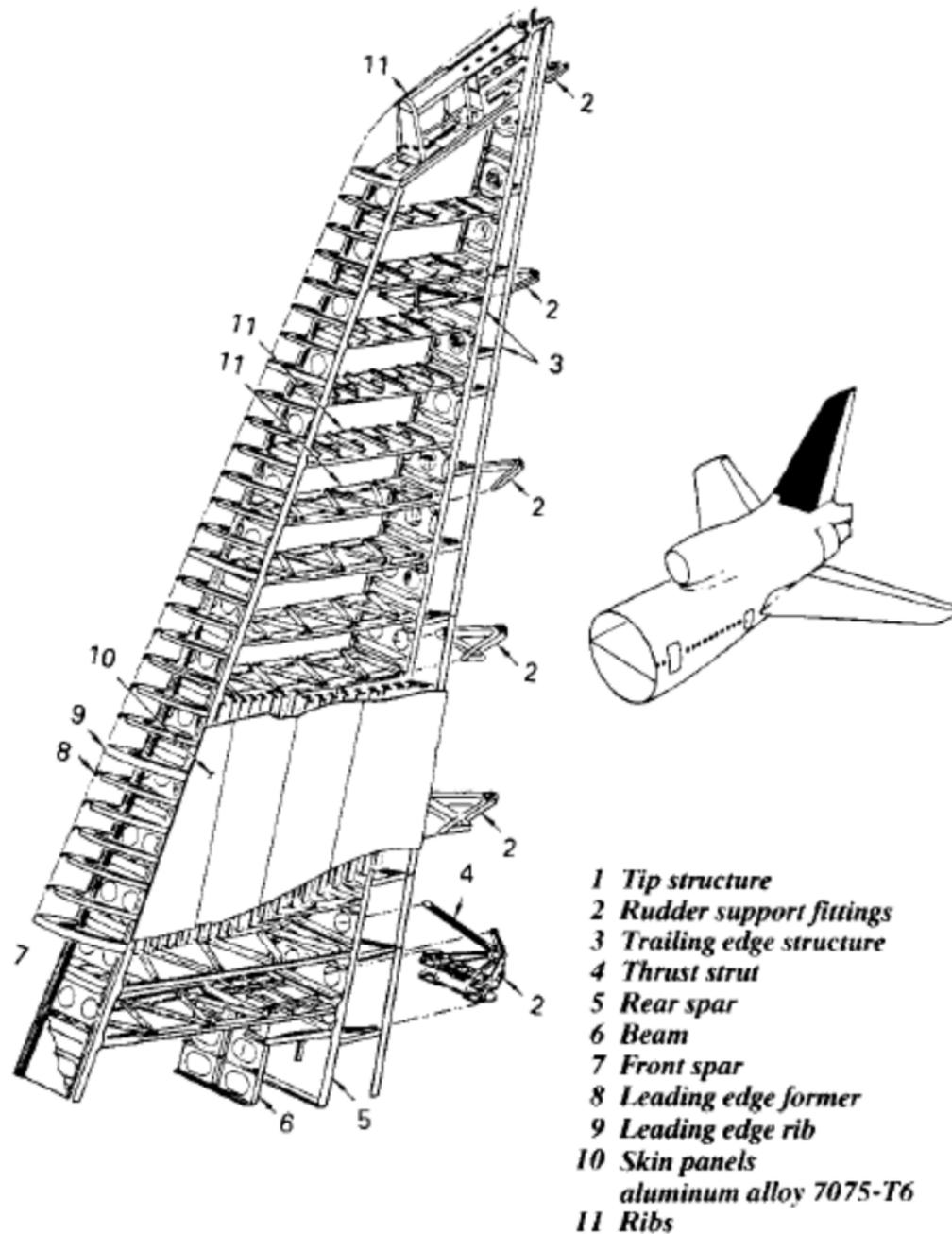
Estabilizador Vertical - I

- 72 - Cajón de torsión trasero
- 73 - Borde de salida
- 74 - Borde de ataque
- 75 - Cajón de torsión delantero
- 79 - Sección de punta



Estabilizador Vertical - II

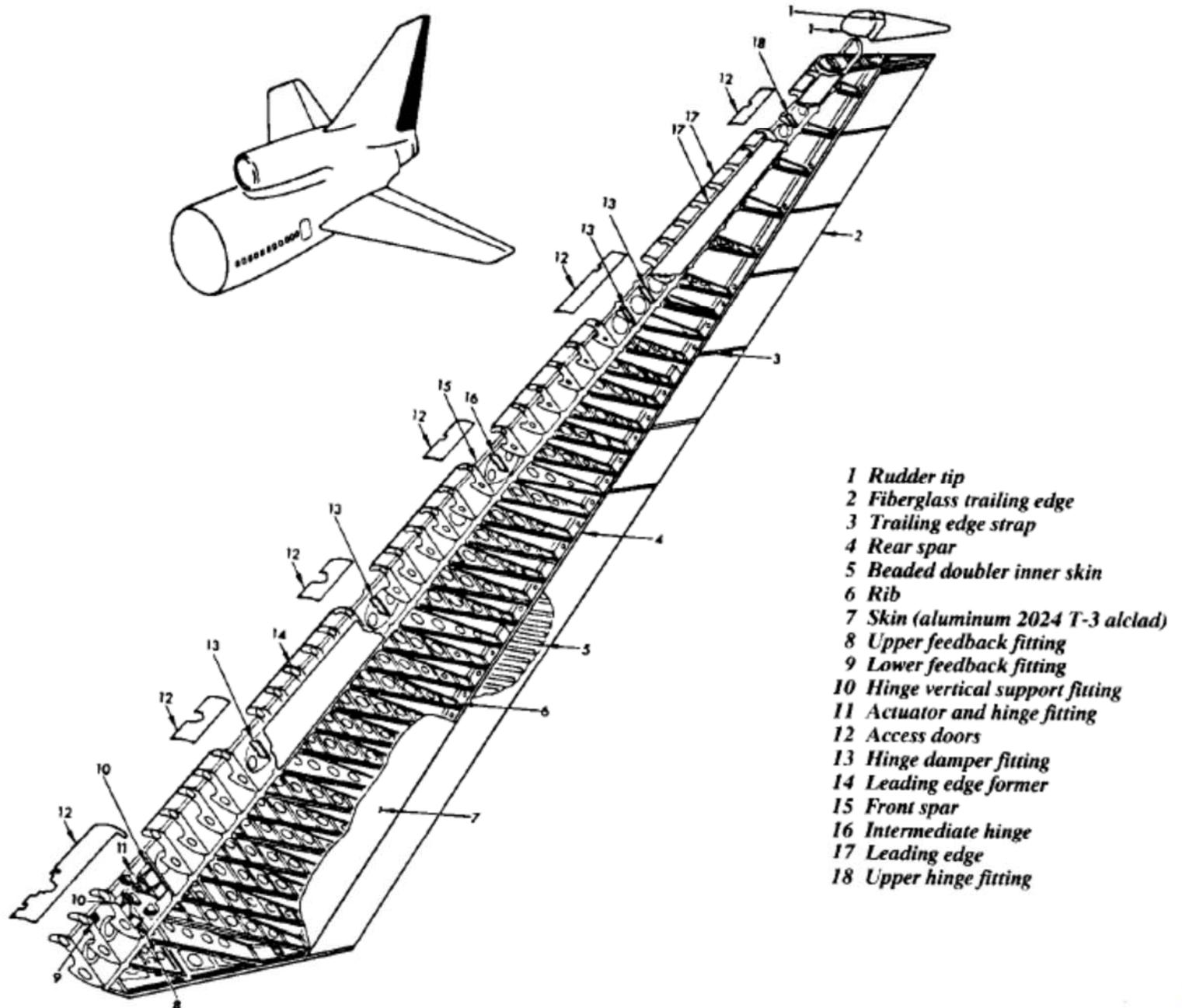
Deriva



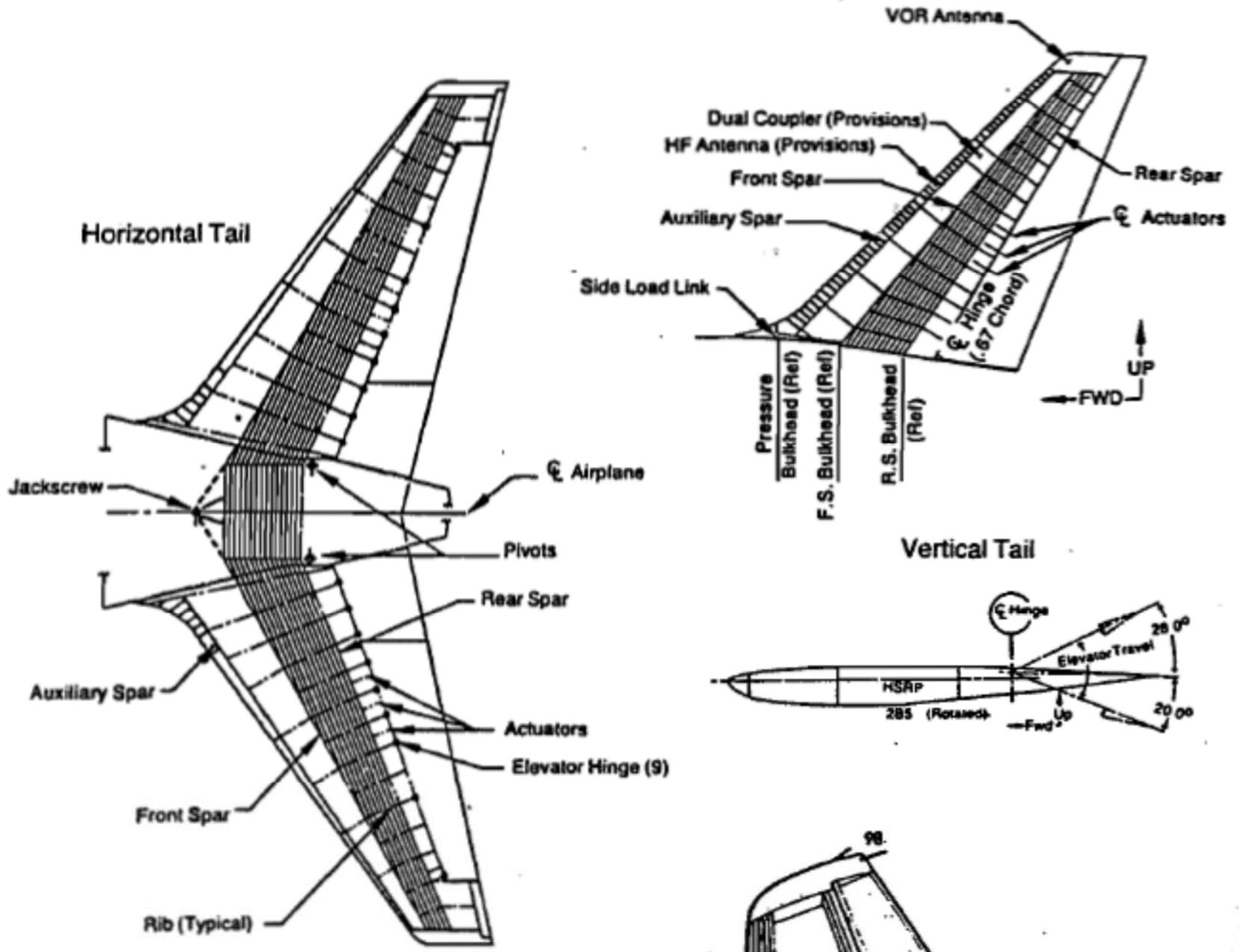
Estabilizador Vertical - III

(a) Rudder

Timón de cola



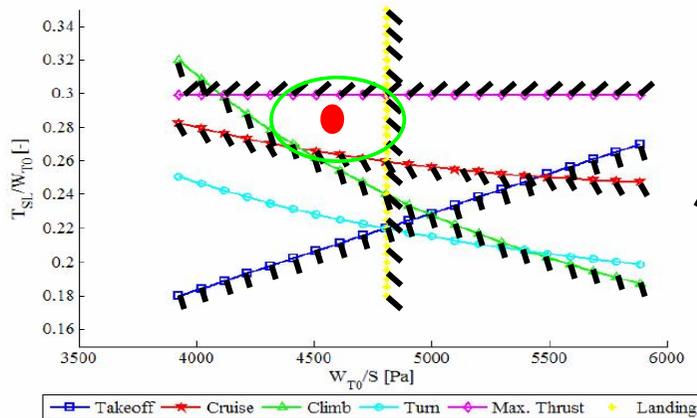
Arquitectura de la cola - Ejemplos



Estimación de Pesos - I

- Determinación de forma estadística.
- Previo a tener valores más representativos obtenidos mediante modelado en CAD.
 - 1ª Fase: determinar el peso de las estructuras simplificadas
 - Uso de multiplicadores lineales
 - fuselaje, ala, estabilizadores horizontal, motor, tren de aterrizaje, % de misceláneos
 - 2ª Fase: ajustar los pesos de dichas estructuras simplificadas
 - Método literatura
 - 3ª Fase: incluir pesos de sistemas aplicables:
 - Flight Control System, Hydraulic and Pneumatic System, Instrumentation, Avionics and Electronics, Electrical System, Air-conditioning, Pressurization, Anti- and De-icing System, Oxygen System, Auxiliary Power Unit, Furnishings, Baggage and Cargo Handling Equipment, Operational Items
 - 4ª fase: determinar incremento de pesos asociados a refuerzos estructurales
 - Identificación de zonas de carga
 - 5ª Fase: reducción de peso estructural ateniendo a selección de materiales

Estimación de Pesos - III



W/S & T/W

x W_0

S & T

W_w & W_e

$$W_{w_{Torenb}} = 0.00125 W_{TO} n_{ult}^{0.55} \left(\frac{b_w}{\cos \Lambda_{c/2_w}} \right)^{0.75} \left\{ 1 + \left(\frac{6.3 \cos \Lambda_{c/2_w}}{b_w} \right)^{0.5} \right\} \left(\frac{b_w S_w}{t_{r_w} W_{TO} \cos \Lambda_{c/2_w}} \right)^{0.30}$$

Estimación de Pesos - II

- Pautas 1ª Fase
- El procedimiento ha de seguir las siguientes pautas
 - A) Empleo de multiplicadores lineales para determinar el peso en vacío (W_e) de las estructuras principales: ala (W_{wing}), horizontal (W_{hor}), vertical (W_{vert}), canard (W_{can}), fuselaje (W_{fus}), tren de aterrizaje (W_{lg}), motores (W_{eng}), y miscelaneos (W_{misc})

$$W_{empty} = W_{wing} + W_{hor} + W_{vert} + W_{can} + W_{fus} + W_{fuel} + W_{eng} + W_{misc} + W_{lg}$$

- B) Tener en cuenta que W_{lg} y W_{misc} dependen de W_0 si se emplean multiplicadores lineales
- C) Estimación del peso total del avión atendiendo a la siguiente ecuación

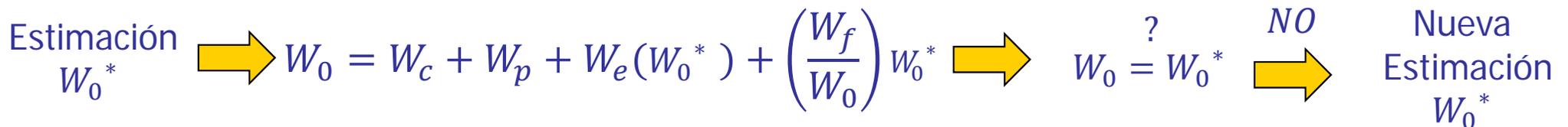
Reescribiendo la ecuación \Rightarrow
$$W_0 = W_c + W_p + W_e(W_0) + \left(\frac{W_f}{W_0}\right) W_0$$

- D) Se calcula el peso inicial asumiendo un W_0 que permita calcular el peso en vacío y el peso de combustible definido por el departamento de actuaciones/propulsión mediante un proceso iterativo:

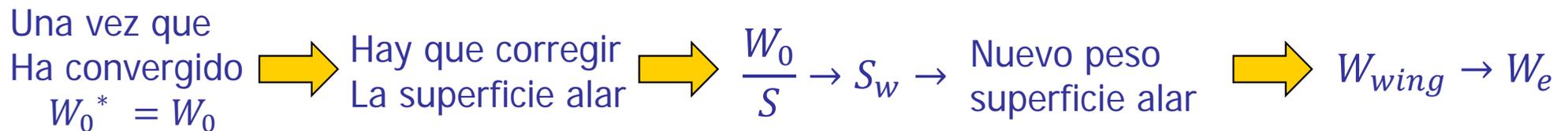
Estimación de Pesos - III

■ Pautas 1ª Fase

- D) Se calcula el peso inicial asumiendo un W_0 que permita calcular el peso en vacío y el peso de combustible definido por el departamento de actuaciones/propulsión mediante un proceso iterativo:
 - 1 - Estimar un W_0^*
 - 2 - Resolver la ecuación de la estimación de W_0 empleando W_0^*
 - 3 - Comparar el valor resultante de $W_0 = W_0^*$
 - 4 - Si no son iguales, hay que hacer una nueva estimación del W_0^* hasta que $W_0 = W_0^*$

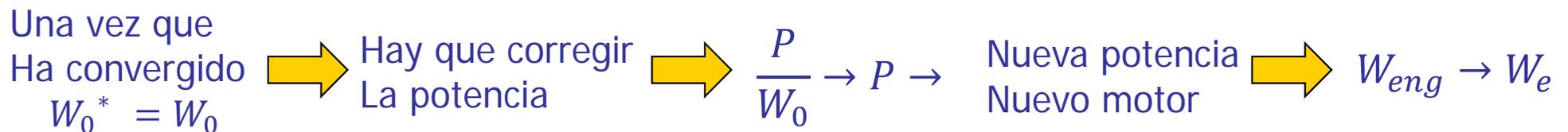


- 5 - Una vez que se ha determinado el W_0 , hay que recalcular la nueva superficie alar asociada a la carga alar fija (W_0/S)
- 6 - Esto determina una nueva S_w lo que genera un nuevo W_{wing}
- 7 - Volver al paso A) y repetir el proceso hasta que S_w no varíe



Estimación de Pesos - IV

- Pautas de la 2ª Fase,
- El procedimiento ha de seguir las siguientes pautas
 - A) Se realiza el mismo procedimiento que en la 1ª Fase, pero utilizando las ecuaciones más avanzadas para determinar el peso en vacío de la estructura en vacío (fuselaje, ala, estabilizadores horizontal, motor, tren de aterrizaje, % de misceláneos)
 - B) Cabe la posibilidad de agregar los siguientes pasos
 - 8 - Con el nuevo cálculo de W_0 determinar nuevo requisito de P, lo que a su vez determina nuevo peso del motor/es



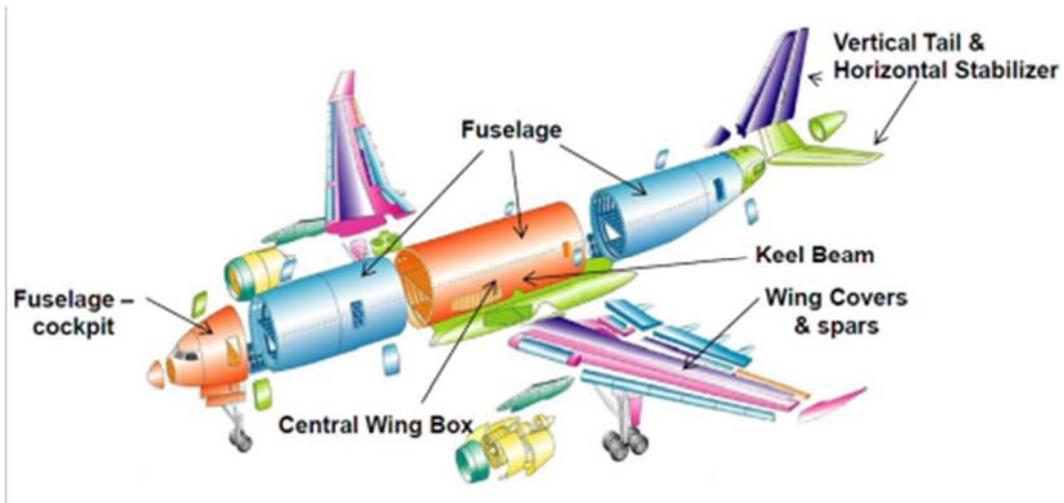
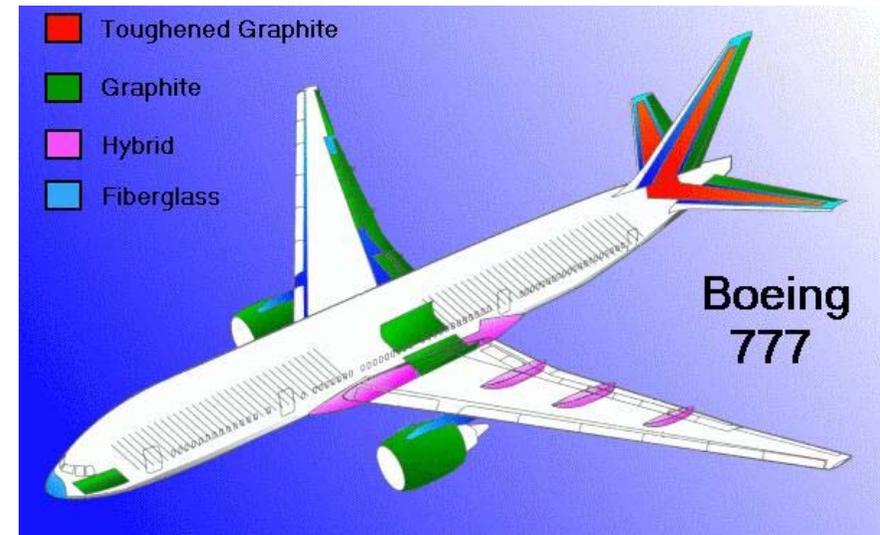
- C) Cabe la posibilidad que para el cálculo del combustible no se emplee la fracción de peso si el departamento de actuaciones/propulsión ha determinado el consumo real de combustible
- D) Dependiendo de las decisiones a tomar por cada grupo de diseño cuando se modifica el peso inicial (W_0) se recalculará la superficie alar y la potencia

Estimación de Pesos - V

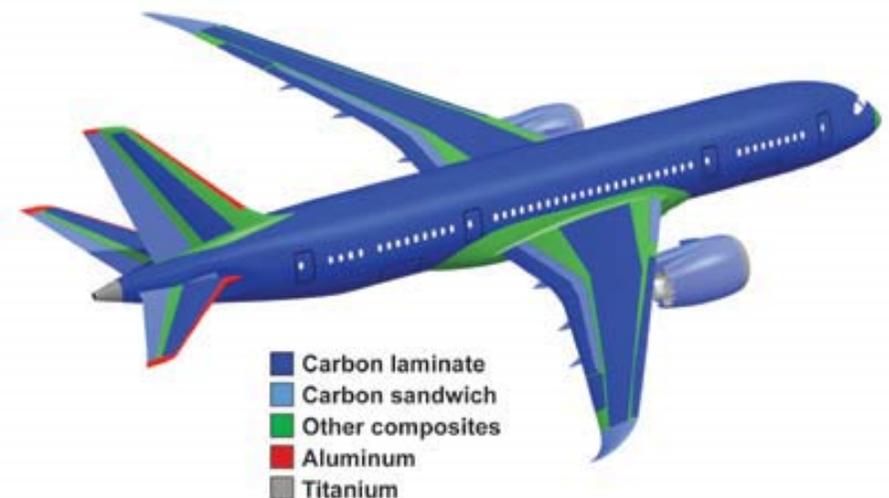
- Pautas de la 3ª Fase,
 - El procedimiento ha de seguir las siguientes pautas
 - A) Se realiza el mismo procedimiento que en la 2ª Fase, pero ajustando el peso en vacío incluyendo los sistemas aplicables.
 - B) Cabe la posibilidad que para el cálculo del combustible no se emplee la fracción de peso si el departamento de actuaciones/propulsión ha determinado el consumo real de combustible
 - C) Dependiendo de las decisiones a tomar por cada grupo de diseño cuando se modifica el peso inicial (W_0) se recalculará la superficie alar y la potencia
- Pautas de la 4ª Fase,
 - El procedimiento ha de seguir las siguientes pautas
 - A) Se realiza el mismo procedimiento que en la 3ª Fase, pero ajustando el peso en vacío incluyendo la estimación de incremento de peso asociado a los refuerzos estructurales.
- Pautas de la 5ª Fase,
 - El procedimiento ha de seguir las siguientes pautas
 - A) Se realiza el mismo procedimiento que en la 4ª Fase, pero ajustando el peso en vacío incluyendo la reducción de pesos por empleo de materiales compuestos.
- Estas pautas pueden ser modificada con vista a optimizar el proceso de diseño de tal manera que se agilicen los cálculos

Tendencias Composites

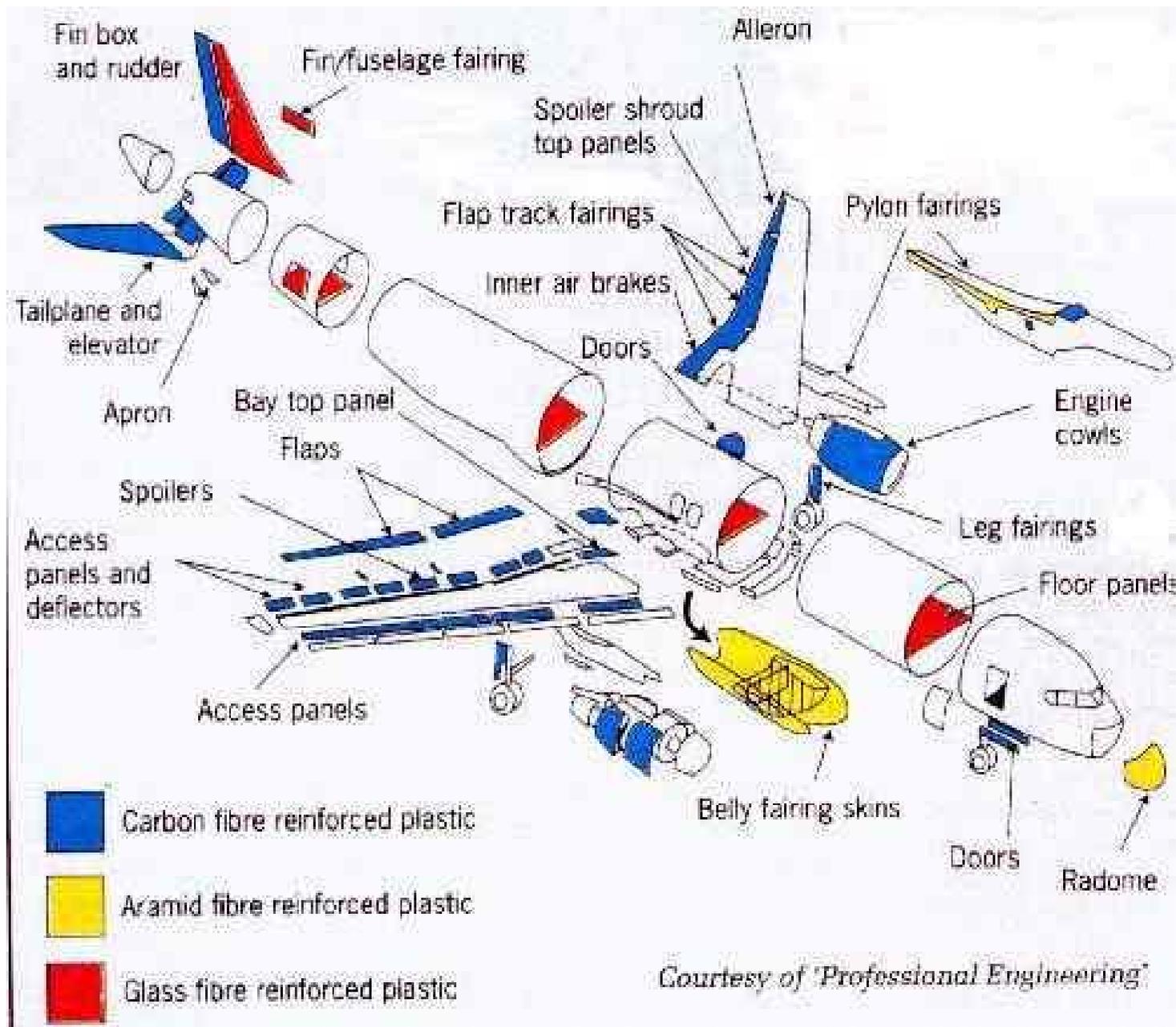
- El porcentaje de composites ha aumentado en los últimos años
- Ejemplos
 - B777
 - B787
 - A380
 - A350
 - Lockheed Martin X55



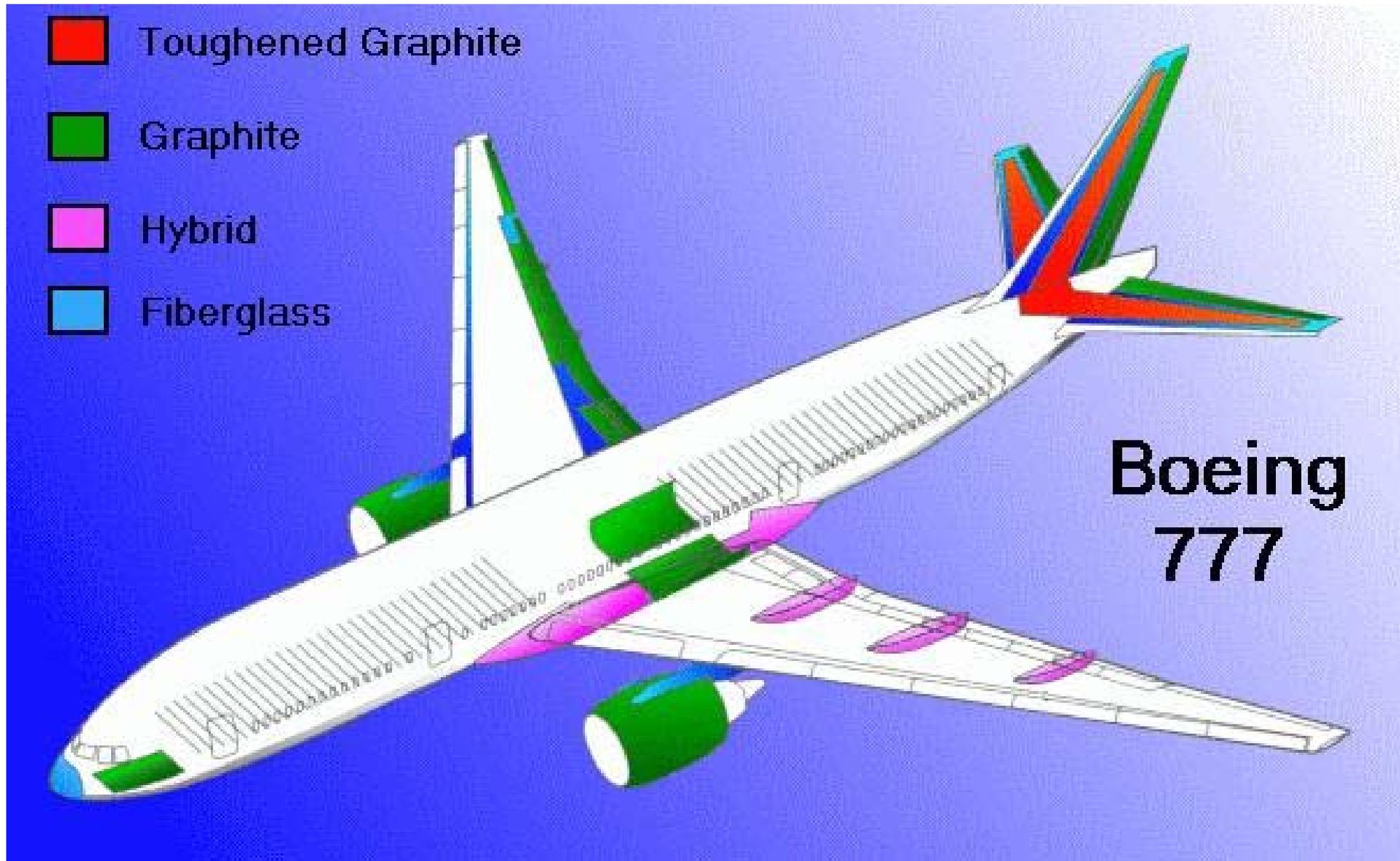
Composites Serve as Primary Structural Material



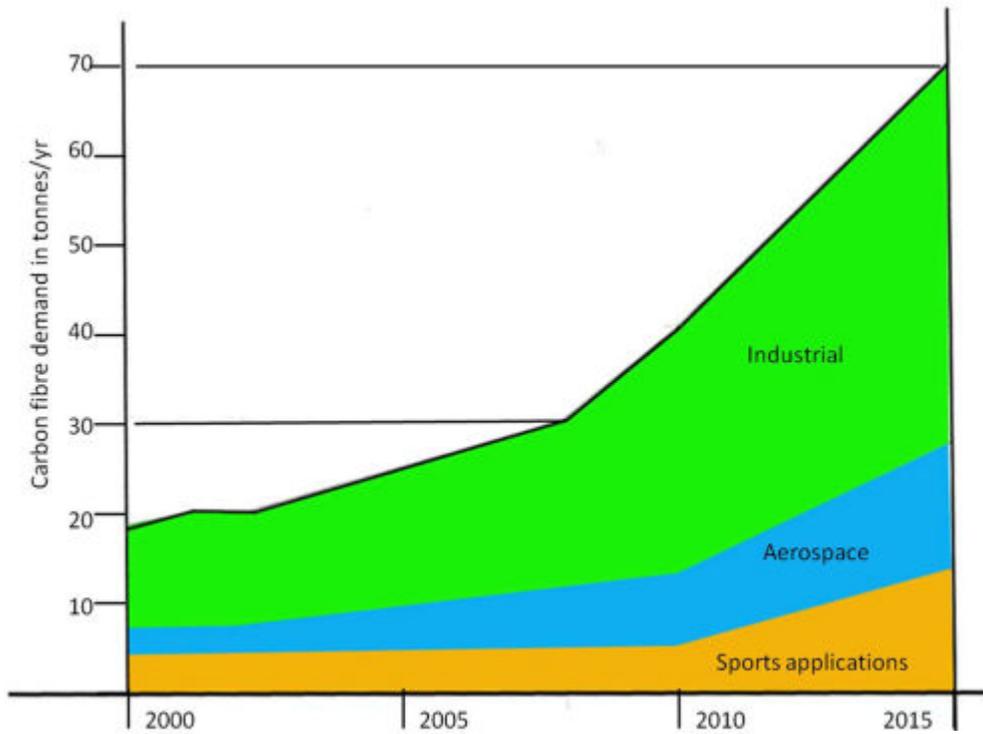
Configuración Antigua Composites - I



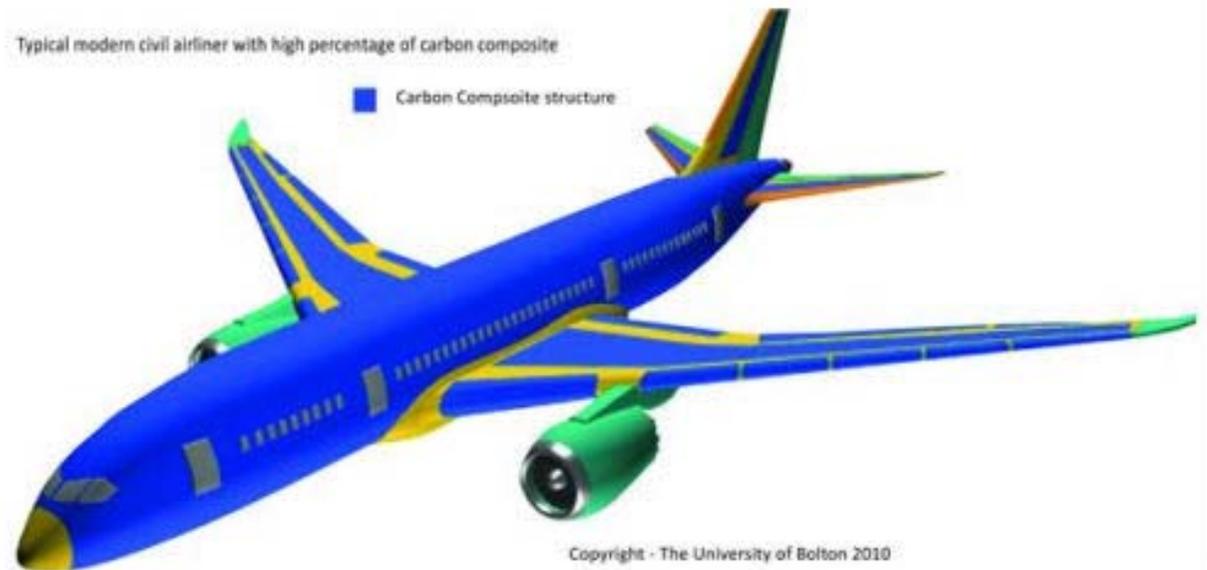
Configuración Antigua Composites - II



Configuración Moderna Composites - I

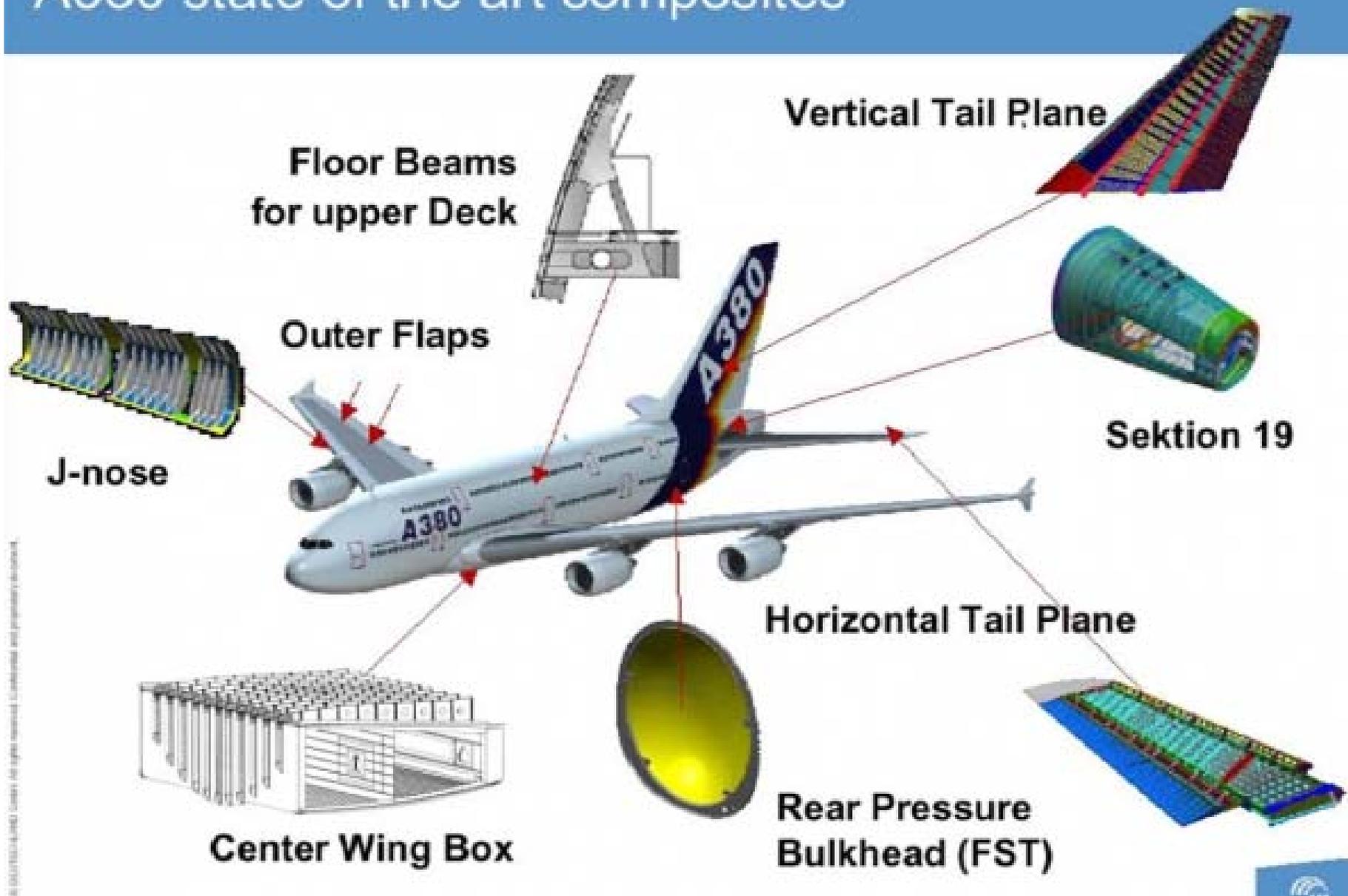


Typical modern civil airliner with high percentage of carbon composite

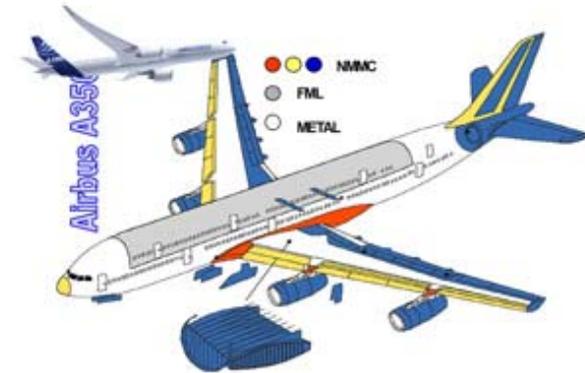


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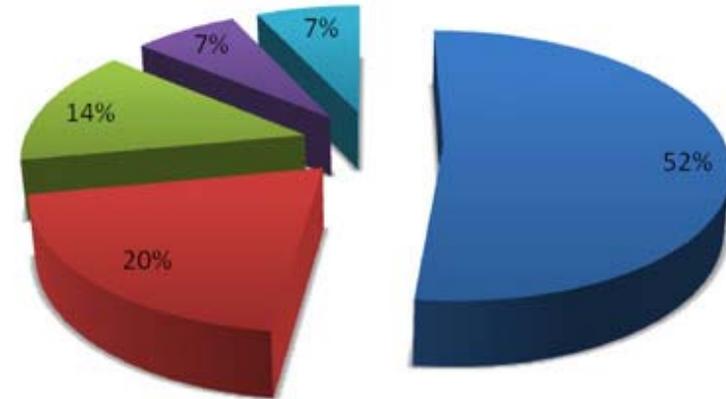
A380 state of the art composites



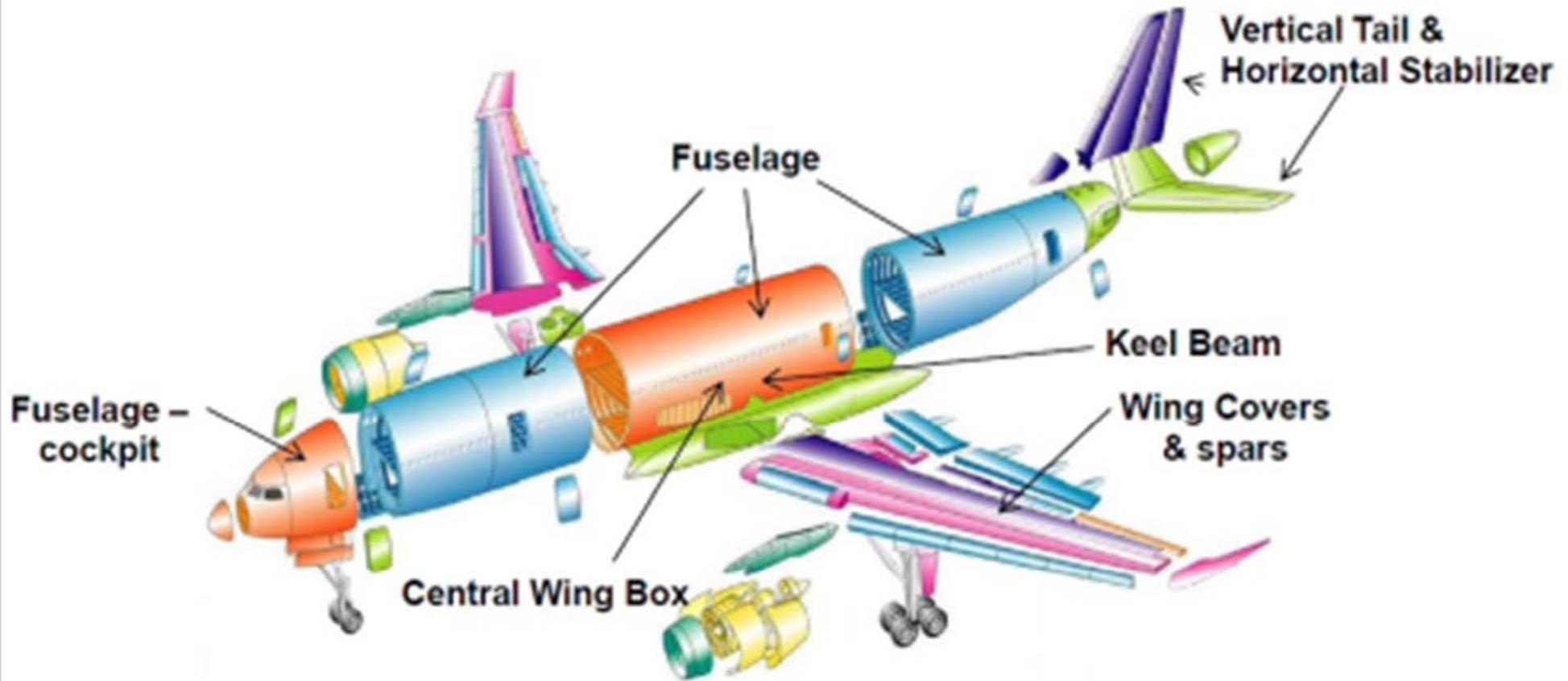
A350 XWB



■ Material Compuesto ■ Aluminio ■ Titanio ■ Acero ■ Otros

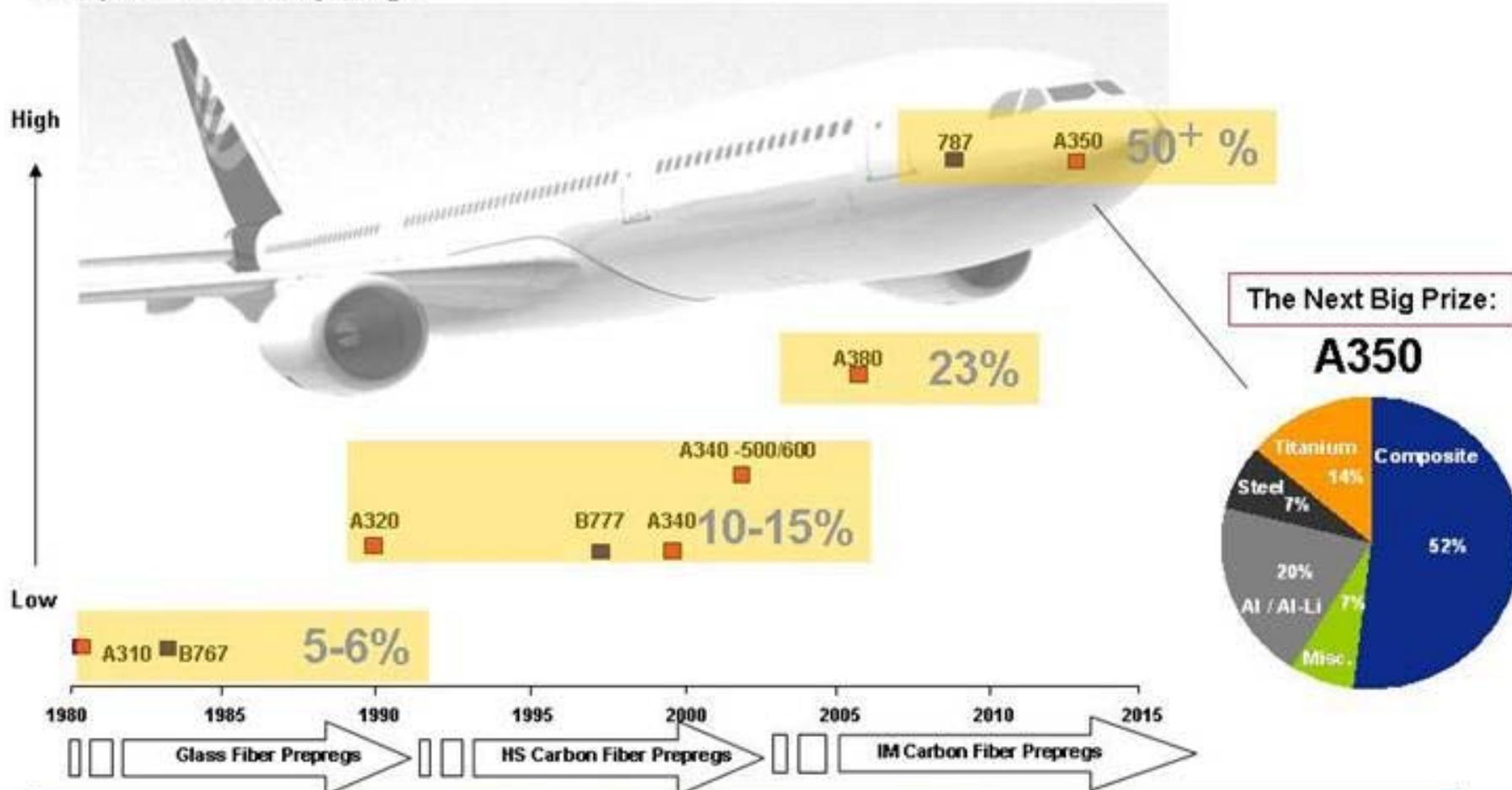


A350 XWB



Commercial Aerospace – Composites Penetration

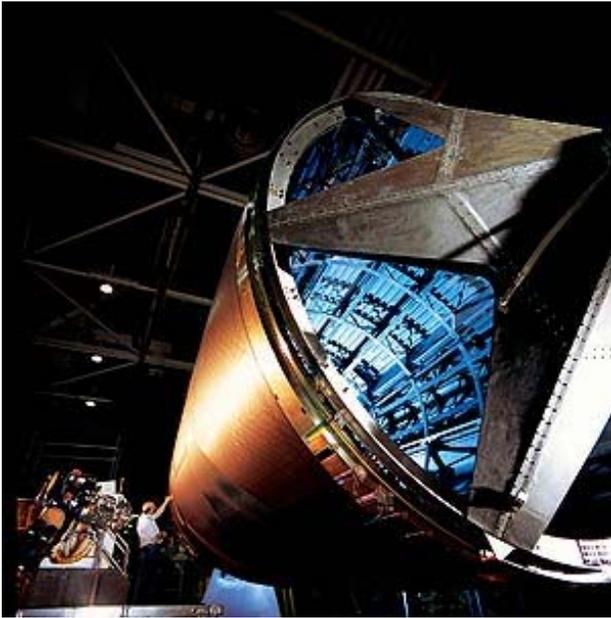
Composite Content by Weight



Step Change Underway with Intermediate Modulus ("IM") Carbon Fiber Prepreg as the new standard... Hexcel's Specialty



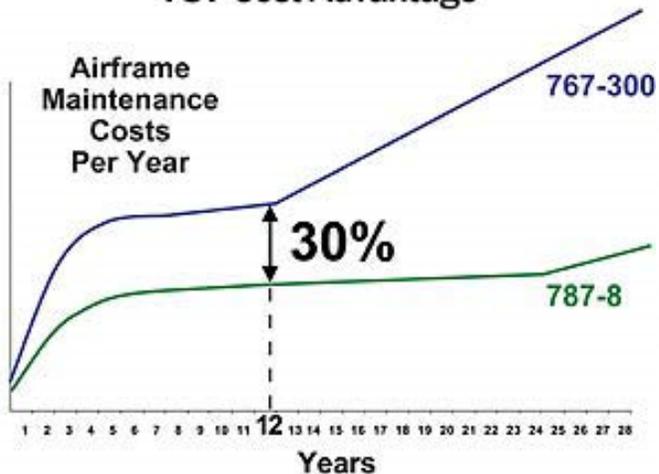
Boeing 787



Composites Serve as Primary Structural Material

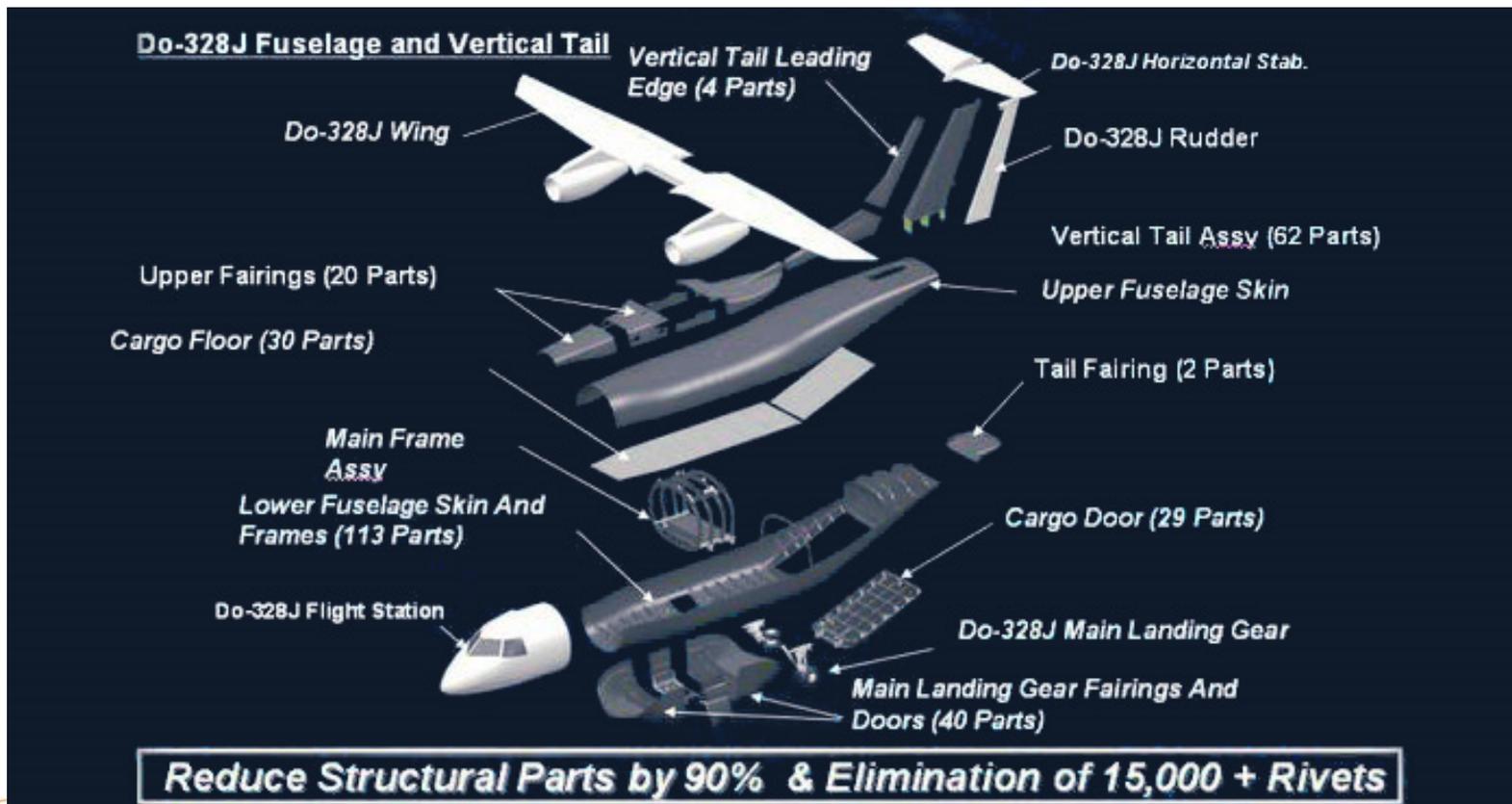


787 Cost Advantage



Advanced Composite Cargo Aircraft (ACCA)

- The Lockheed Martin X-55 Advanced Composite Cargo Aircraft (ACCA)
 - <http://thelexicans.wordpress.com/2012/10/24/the-lockheed-martin-x-55-advanced-composite-cargo-aircraft/>
- Videos
 - <http://youtu.be/MRAtk7ILDpE>
 - <http://youtu.be/T0Fqxt87Qik>



Estimación Pesos

- Se presentan varios métodos para la estimación de pesos estructurales y de sistemas
 - **Cada uno** de los **métodos** es **independiente** y **suficiente por si sólo**
 - Esto significa que las estimaciones de pesos son válidas siempre que estén **dentro** del **orden** de **magnitud** de **aviones similares**: **Necesaria Comparación (si datos disponibles)**
- **NO TODOS** los métodos producen **valores** que se encuentran dentro de rangos **razonables**:
 - Los diseñadores deben de ser capaces de **identificar** si los **valores** son **adecuados** mediante **métodos comparativos** (descritos abajo)
 - No se pueden utilizar ecuaciones de métodos distintos: En caso de querer utilizar ecuaciones de métodos distintos, es necesario hacer la **media** entre **todas** las **estructuras**
 - Por ejemplo, no se puede utilizar la ecuación de estimación del ala de Método I y la del Fuselaje del Método II, sino la media de todas las ecuaciones para ambos métodos
 - Se puede hacer la **media** con **tantos métodos** como se **dese**.
- Se recomienda **comparar** la **estimación** e los **distintos sistemas** y **pesos** con datos de **aviones similares**:
 - Datos de Volumen V de Airplane Design de Roskam
 - Se proporcionan estimaciones de pesos estructurales y sistemas como porcentaje del peso total
 - Comparar si está dentro del rango para aviones de características similares
 - Datos comparativos que aparecen en el Método II (Tema 12)
 - Se proporcionan estimaciones de pesos estructurales y sistemas como porcentaje del peso total
 - Comparar si está dentro del rango para aviones de características similares

Estimación de Pesos - VI

- Diferentes métodos para estimar el peso de diferentes componentes:
 - Airplane Design – Part V : Component Weight Estimation
 - USAF Method
 - GM Method
 - Cessna Method
 - Torenbeek Method
 - Método estadístico
 - Raymer Method
 - DAR Corporation - Roskam
 - Grupos de pesos para diversas aeronaves
 - Airplane Design – Part V : Component Weight Estimation
 - Sirve para determinar mediante comparativas entre los diversos aviones el peso aproximado de algunas de las partes.
 - Técnicas de normalizados para extrapolar posibles líneas de tendencia

Estimación de Pesos - VII

Table 15.1 Group weight format

| | Weight, lb | Loc., ft | Moment, ft-lb | | Weight, lb | Loc., ft | Moment, ft-lb |
|---------------------|--------------|----------|----------------|-----------------------------|---------------|-------------|----------------|
| Structures | 4,526 | | 106,879 | Equipment | 4,067 | | 80,646 |
| Wing | 1,459.4 | 23.3 | 34,004 | Flight controls | 655.7 | 21.7 | 14,229 |
| Horizontal tail | 280.4 | 39.2 | 10,992 | APU | | 0 | 0 |
| Vertical tail | | 0 | 0 | Instruments | 122.8 | 10.0 | 1,228 |
| Ventral tail | | 0 | 0 | Hydraulics | 171.7 | 21.7 | 3,726 |
| Fuselage | 1,574 | 21.7 | 34,156 | Pneumatics | | 21.7 | 0 |
| Main landing gear | 631.5 | 23.8 | 15,030 | Electrical | 713.2 | 21.7 | 15,476 |
| Nose landing gear | 171.1 | 13.0 | 2,224 | Avionics | 989.8 | 10.0 | 9,898 |
| Other landing gear | | 0 | 0 | Armament | | 0 | 0 |
| Engine mounts | 39.1 | 33.0 | 1,290 | Furnishings | 217.6 | 6.2 | 1,3497 |
| Firewall | 58.8 | 33.0 | 1,940 | Air conditioning | 190.7 | 15.0 | 2,860.5 |
| Engine section | 21 | 33.0 | 693 | Anti-icing | | | 0 |
| Air induction | 291.1 | 22.5 | 6,550 | Photographic | | | 0 |
| | | | 0 | Load and handling | 5.3 | 15.0 | 79.5 |
| | | | 0 | Misc. equipment and We | 1,000 | 31.8 | 31,800 |
| | | | 0 | Empty weight allowance | 547 | 23.6 | 12,9237 |
| Propulsion | 2,354 | | 70,931 | Total weight empty | 11,495 | 23.6 | 27,1379 |
| Engine(s)—installed | 1,517 | 33.0 | 50,061 | Useful load | 4,985 | | |
| Accessory drive | | | 0 | Crew | 220 | 15.0 | 3,300 |
| Exhaust system | | | 0 | Fuel—usable | 3,836 | 22.3 | 85,551 |
| Engine cooling | 172 | 33.0 | 5,676 | Fuel—trapped | 39 | 22.3 | 864 |
| Oil cooling | 37.8 | 33.0 | 1,247 | Oil | 50 | 33.0 | 1,650 |
| Engine controls | 20 | 33.0 | 660 | Passengers | | | 0 |
| Starter | 39.5 | 15.7 | 620 | Cargo/payload | 840 | 21.7 | 18,228 |
| Fuel system/tanks | 568 | 22.3 | 12,666 | Guns | | | 0 |
| | | | 0 | Ammunition | 0 | 21.7 | 0 |
| | | | 0 | Misc. useful load | | | 0 |
| | | | 0 | Takeoff gross weight | 16,480 | 22.0 | 362,744 |

Estimación de Pesos - VIII

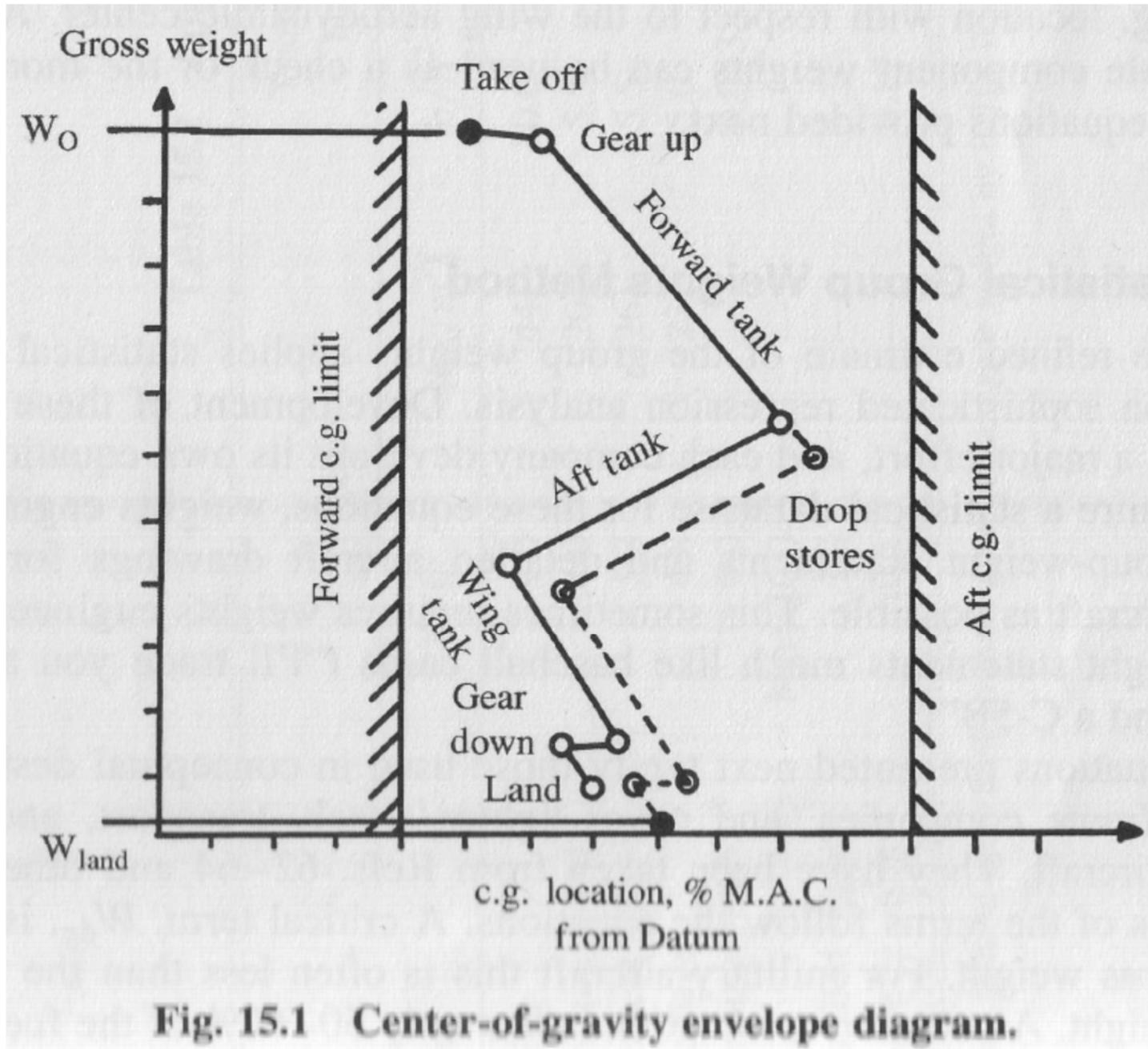


Fig. 15.1 Center-of-gravity envelope diagram.

Estimación de Pesos - IX

Table 15.2 Approximate empty weight buildup

| Item | Fighters | | Transports and bombers | | General aviation (metal) | | Multiplier | Approximate location |
|---------------------------|--------------------|----------------------|------------------------|----------------------|--------------------------|----------------------|-------------------------------|----------------------|
| | lb/ft ² | {kg/m ² } | lb/ft ² | {kg/m ² } | lb/ft ² | {kg/m ² } | | |
| Wing | 9.0 | {44} | 10.0 | {49} | 2.5 | {12} | $S_{\text{exposed planform}}$ | 40% MAC |
| Horizontal tail | 4.0 | {20} | 5.5 | {27} | 2.0 | {10} | $S_{\text{exposed planform}}$ | 40% MAC |
| Vertical tail | 5.3 | {26} | 5.5 | {27} | 2.0 | {10} | $S_{\text{exposed planform}}$ | 40% MAC |
| Fuselage | 4.8 | {23} | 5.0 | {24} | 1.4 | {7} | $S_{\text{wetted area}}$ | 40–50% length |
| Landing gear ^a | 0.033 | — | 0.043 | — | 0.057 | — | TOGW | — |
| | Navy: 0.045 | — | | | | | | |
| Installed engine | 1.3 | — | 1.3 | — | 1.4 | — | Engine weight | — |
| “All-else empty” | 0.17 | — | 0.17 | — | 0.10 | — | TOGW | 40–50% length |

^a15% to nose gear; 85% to main gear; reduce gear weight by 0.014 W_0 if fixed gear.



Estimación de Pesos - X

Table 15.3 Miscellaneous weights (approximate)

| Component | Weight | |
|--|-------------------------------|-------------------------------|
| | lb | kg ^a |
| Missiles | | |
| Harpoon (AGM-84 A) | 1200 | 544 |
| Phoenix (AIM-54 A) | 1000 | 454 |
| Sparrow (AIM-7) | 500 | 227 |
| Sidewinder (AIM-9) | 200 | 91 |
| Pylon and launcher | 0.12 W_{missile} | |
| M61 Gun | | |
| Gun | 250 | 113 |
| 940 rds ammunition | 550 | 250 |
| Commercial aircraft passenger (includes carry-on) | 190 | 86 |
| Seats | | |
| Flight deck | 60 | 27 |
| Passenger | 32 | 15 |
| Troop | 11 | 5 |
| Instruments | | |
| Altimeter, airspeed, accelerometer, rate of climb, clock, compass, turn & bank, Mach, tachometer, manifold pressure, etc. | 1-2 each | 0.5-1 |
| Gyro horizon, directional gyro | 4-6 each | 2-3 |
| Heads-up display | 40 | 18 |
| Lavatories | | |
| Long-range aircraft | 1.11 $N_{\text{pass}}^{1.33}$ | 0.5 $N_{\text{pass}}^{1.33}$ |
| Short-range aircraft | 0.31 $N_{\text{pass}}^{1.33}$ | 0.14 $N_{\text{pass}}^{1.33}$ |
| Business/executive aircraft | 3.90 $N_{\text{pass}}^{1.33}$ | 1.76 $N_{\text{pass}}^{1.33}$ |
| Arresting gear | | |
| Air Force-type | 0.002 W_{dg} | |
| Navy-type | 0.008 W_{dg} | |
| Catapult gear | | |
| Navy carrier-based | 0.003 W_{dg} | |
| Folding wing | | |
| Navy carrier-based | 0.06 W_{wing} | |

^aMass equivalent of weight.

Estimación de Pesos - XI

Ejemplo 1

- Component Weight Estimation – Airplane Design Par V – J. Roskam

- General Aviation Airplanes:

- Pesos de ala

- Cessna Method

$$W_w = 0.04674 (W_{TO})^{0.397} (S)^{0.360} (n_{ult})^{0.397} (A)^{1.712}$$

$$W_w = 0.002933 (S)^{1.018} (A)^{2.473} (n_{ult})^{0.611}$$

$$W_w = 96.948 [(W_{TO} n_{ult} / 10^5)^{0.65} (A / \cos \Lambda_{1/4})^{0.57} (S/100)^{0.61} x \\ x \{(1+\lambda)/2(t/c)_m\}^{0.36} (1 + V_H/500)^{0.5}]^{0.993} \quad (5.4)$$

- USAF Method

- Torenbeek Method

$$W_w = 0.00125 W_{TO} (b / \cos \Lambda_{1/2})^{0.75} [1 + \{6.3 \cos(\Lambda_{1/2}) / b\}^{1/2}] x \\ x (n_{ult})^{0.55} (bS / t_r W_{TO} \cos \Lambda_{1/2})^{0.30} \quad (5.5)$$

- Pesos de cola

- Cessna Method

$$W_h = \frac{3.184 (W_{TO})^{0.887} (S_h)^{0.101} (A_h)^{0.138}}{57.5 (t_{r_h})^{0.223}}$$

$$W_v = \frac{1.68 (W_{TO})^{0.567} (S_v)^{1.249} (A_v)^{0.482}}{15.6 (t_{r_v})^{0.747} (\cos \Lambda_{1/4_v})^{0.882}}$$

- USAF Method

$$W_h = 127 [(W_{TO} n_{ult} / 10^5)^{0.87} (S_h / 100)^{1.2} x \\ x 0.289 (l_h / 10)^{0.483} (b_h / t_{r_h})^{0.5}]^{0.458}$$

$$W_v = 98.5 [(W_{TO} n_{ult} / 10^5)^{0.87} (S_v / 100)^{1.2} x \\ x 0.289 (b_v / t_{r_v})^{0.5}]^{0.458}$$

- Torenbeek Method

$$W_{emp} = 0.04 (n_{ult} (S_v + S_h)^2)^{0.75}$$

Estimación de Pesos - XII

- General Aviation Airplanes:
 - Raymer Method

$$W_{\text{wing}} = 0.036 S_w^{0.758} W_{\text{fw}}^{0.0035} \left(\frac{A}{\cos^2 \Lambda} \right)^{0.6} q^{0.006} \lambda^{0.04} \left(\frac{100 t/c}{\cos \Lambda} \right)^{-0.3} (N_z W_{\text{dg}})^{0.49}$$

$$W_{\text{horizontal tail}} = 0.016 (N_z W_{\text{dg}})^{0.414} q^{0.168} S_{\text{ht}}^{0.896} \left(\frac{100 t/c}{\cos \Lambda} \right)^{-0.12} \left(\frac{A}{\cos^2 \Lambda_{\text{ht}}} \right)^{0.043} \lambda_h^{-0.02}$$

$$W_{\text{vertical tail}} = 0.073 \left(1 + 0.2 \frac{H_t}{H_v} \right) (N_z W_{\text{dg}})^{0.376} q^{0.122} S_{\text{vt}}^{0.873} \left(\frac{100 t/c}{\cos \Lambda_{\text{vt}}} \right)^{-0.49} \left(\frac{A}{\cos^2 \Lambda_{\text{vt}}} \right)^{0.357} \lambda_{\text{vt}}^{0.039}$$

$$W_{\text{fuselage}} = 0.052 S_f^{1.086} (N_z W_{\text{dg}})^{0.127} L_f^{0.051} (L/D)^{-0.072} q^{0.241} + W_{\text{press}}$$

$$W_{\text{main landing gear}} = 0.095 (N_l W_l)^{0.768} (L_m/12)^{0.409}$$

$$W_{\text{nose landing gear}} = 0.125 (N_l W_l)^{0.566} (L_n/12)^{0.845}$$

$$W_{\text{installed engine (total)}} = 2.575 W_{\text{en}}^{0.922} N_{\text{en}}$$

$$W_{\text{fuel system}} = 2.49 V_i^{0.726} \left(\frac{1}{1 + V_i/V_l} \right)^{0.363} N_i^{0.242} N_{\text{en}}^{0.157}$$

$$W_{\text{flight controls}} = 0.053 L^{1.536} B_w^{0.371} (N_z W_{\text{dg}} \times 10^{-4})^{0.80}$$

$$W_{\text{hydraulics}} = 0.001 W_{\text{dg}}$$

$$W_{\text{electrical}} = 12.57 (W_{\text{fuel system}} + W_{\text{avionics}})^{0.51}$$

$$W_{\text{avionics}} = 2.117 W_{\text{uav}}^{0.933}$$

$$W_{\text{air conditioning and anti-ice}} = 0.265 W_{\text{dg}}^{0.52} N_p^{0.68} W_{\text{avionics}}^{0.17} M^{0.08}$$

$$W_{\text{furnishings}} = 0.0582 W_{\text{dg}} - 65$$

Estimación de Pesos - XIII

- Cargo Transport Airplanes:
 - Raymer Method

$$W_{\text{wing}} = 0.0051 (W_{\text{dg}} N_z)^{0.557} S_w^{0.649} A^{0.5} (t/c)_{\text{root}}^{-0.4} (1 + \lambda)^{0.1} (\cos \Lambda)^{-1.0} S_{\text{CSW}}^{0.1}$$

$$W_{\text{horizontal tail}} = 0.0379 K_{\text{uht}} (1 + F_w/B_h)^{-0.25} W_{\text{dg}}^{0.639} N_z^{0.10} S_{\text{ht}}^{0.75} L_t^{-1.0} \times K_y^{0.704} (\cos \Lambda_{\text{ht}})^{-1.0} A_h^{0.166} (1 + S_e/S_{\text{ht}})^{0.1}$$

$$W_{\text{vertical tail}} = 0.0026 (1 + H_t/H_v)^{0.225} W_{\text{dg}}^{0.556} N_z^{0.536} L_t^{-0.5} S_{\text{vt}}^{0.5} K_z^{0.875} (\cos \Lambda_{\text{vt}})^{-1} A_v^{0.35} (t/c)_{\text{root}}^{-0.5}$$

$$W_{\text{fuselage}} = 0.3280 K_{\text{door}} K_{\text{Lg}} (W_{\text{dg}} N_z)^{0.5} L^{0.25} S_f^{0.302} (1 + K_{\text{ws}})^{0.84} (L/D)^{0.10}$$

$$W_{\text{main landing gear}} = 0.0106 K_{\text{mp}} W_l^{0.888} N_l^{0.25} L_m^{0.4} N_{\text{mw}}^{0.321} N_{\text{mss}}^{-0.5} V_{\text{stall}}^{0.1}$$

$$W_{\text{nose landing gear}} = 0.032 K_{\text{np}} W_l^{0.646} N_l^{0.2} L_n^{0.5} N_{\text{nw}}^{0.45}$$

$$W_{\text{nacelle group}} = 0.6724 K_{\text{ng}} N_{\text{Lt}}^{0.10} N_w^{0.294} N_z^{0.119} W_{\text{ec}}^{0.611} N_{\text{en}}^{0.984} S_n^{0.224}$$

(includes air induction)

$$W_{\text{starter (pneumatic)}} = 49.19 \left(\frac{N_{\text{en}} W_{\text{en}}}{1000} \right)^{0.541}$$

$$W_{\text{engine controls}} = 5.0 N_{\text{en}} + 0.80 L_{\text{ec}}$$

$$W_{\text{fuel system}} = 2.405 V_t^{0.606} (1 + V_i/V_t)^{-1.0} (1 + V_p/V_t) N_t^{0.5}$$

$$W_{\text{flight controls}} = 145.9 N_f^{0.554} (1 + N_m/N_f)^{-1.0} S_{\text{CS}}^{0.20} (I_y \times 10^{-6})^{0.07}$$

$$W_{\text{avionics}} = 1.73 W_{\text{uav}}^{0.983}$$

$$W_{\text{APU installed}} = 2.2 W_{\text{APU uninstalled}}$$

$$W_{\text{furnishings}} = 0.0577 N_c^{0.1} W_c^{0.393} S_f^{0.75}$$

$$W_{\text{instruments}} = 4.509 K_r K_{\text{tp}} N_c^{0.541} N_{\text{en}} (L_f + B_w)^{0.5}$$

$$W_{\text{air conditioning}} = 62.36 N_p^{0.25} (V_{\text{pr}}/1000)^{0.604} W_{\text{uav}}^{0.10}$$

$$W_{\text{hydraulics}} = 0.2673 N_f (L_f + B_w)^{0.937}$$

$$W_{\text{anti-ice}} = 0.002 W_{\text{dg}} \quad W_{\text{handling gear}} = 3.0 \times 10^{-4} W_{\text{dg}}$$

$$W_{\text{electrical}} = 7.291 R_{\text{kva}}^{0.782} L_a^{0.346} N_{\text{gen}}^{0.10}$$

$$W_{\text{military cargo handling system}} = 2.4 \times (\text{cargo floor area, ft}^2)$$

Estimación de Pesos - XIV

- Se utilizan factores de corrección sobre las ecuaciones anteriores en función de los materiales empleados y del tipo de estructura

Table 15.4 Weights estimation “fudge factors”

| Category | Weight group | Fudge factor (multiplier) |
|------------------------|---------------------------|---------------------------|
| Advanced composites | Wing | 0.85–0.90 |
| | Tails | 0.83–0.88 |
| | Fuselage/nacelle | 0.90–0.95 |
| | Landing gear | 0.95–1.0 |
| | Air induction system | 0.85–0.90 |
| Braced wing | Wing | 0.82 |
| Braced biplane | Wing | 0.6 |
| Wood fuselage | Fuselage | 1.60 |
| Steel tube fuselage | Fuselage | 1.80 |
| Flying boat hull | Fuselage | 1.25 |
| Carrier-based aircraft | Fuselage and landing gear | 1.2–1.3 |

Comparativa de pesos – Aviones similares - I

- Comparativa de pesos por grupos para aviones similares:
 - Airplane Design – Part V
 - Turbo/propeller Driven Military Transports (pp 176-177)

Table A10.2a Group Weight Data for Turbo/Propeller

Driven Military Transports

| | A.W. (HS) Argosy | Douglas C-133A | Lockheed C-130H | Breguet 941* |
|--------------------|---------------------|-------------------|--------------------|-----------------|
| Number of engines: | 4 | 4 | 4 | 4 |
| Weight Item, lbs | | | | |
| Wing Group | 10,800 | 27,403 | 13,950 | 4,096 |
| Empennage Group | 1,300 | 6,011 | 3,480 | 1,387 |
| Fuselage Group | 11,100** | 30,940 | 14,695 | 6,481 |
| Nacelle Group | 1,200 | 3,512 | 2,756 | in wing |
| Land. Gear Group | 3,180 | 10,635 | 5,309 | 2,626 |
| Nose Gear | | | 730 | |
| Main Gear | | | 4,579 | |
| Structure Total | 27,580 | 78,501 | 40,190 | 14,590 |



Comparativa de pesos – Aviones similares II

| | A.W. (HS) Argosy | Douglas C-133A | Lockheed C-130H | Breguet 941* |
|-------------------------------------|---------------------|-------------------|--------------------|-----------------|
| Number of engines: | 4 | 4 | 4 | 4 |
| Weight Item, lbs | | | | |
| Wing Group | 10,800 | 27,403 | 13,950 | 4,096 |
| Empennage Group | 1,300 | 6,011 | 3,480 | 1,387 |
| Fuselage Group | 11,100** | 30,940 | 14,695 | 6,481 |
| Nacelle Group | 1,200 | 3,512 | 2,756 | in wing |
| Land. Gear Group | 3,180 | 10,635 | 5,309 | 2,626 |
| Nose Gear | | | 730 | |
| Main Gear | | | 4,579 | |
| Structure Total | 27,580 | 78,501 | 40,190 | 14,590 |
| Engines | | 10,470 | 13,746 | |
| Air Induct. System | | | | |
| Fuel System | | 1,338 | 3,105 | |
| Propeller Inst. | | 5,403 | in eng. | |
| Propulsion System | | 2,081 | in eng. | |
| Power Plant Total | | 19,292 | 16,851 | |
| Avionics + Instrum. | | 578 | 3,582 | |
| Surface Controls | in struct. | 1,804 | 1,673 | 1,056 |
| Hydraulic System | | 2,678 | 664 | |
| Pneumatic System | | | | |
| Electrical System | | 2,004 | 2,459 | |
| Electronics | | 2,047 | in avionics | |
| APU | | 188 | 651 | |
| Oxygen System | | | 231 | |
| Air Cond. System*** | | 2,973 | 1,684 | |
| Anti-icing System | | | 797 | |
| Furnishings | | 3,632 | 4,472 | |
| Auxiliary Gear | | 117 | 6 | |
| Operating items | | | 532 | |
| Fixed Equipm't Total | | 16,021 | 16,219 | |
| W _{oil} + W _{tfo} | | 1,693 | 1,089 | |
| Max. Fuel Capacity | | 60,000 | 45,240 | |
| Payload (Max.) | | 97,162 | 33,461 | |

| Type | A.W. (HS) Argosy | Douglas C-133A | Lockheed C-130H | Breguet 941 |
|---|---------------------|-------------------|--------------------|----------------|
| Flight Design Gross Weight, GW, lbs | 82,000 | 275,000 | 155,000 | 58,421 |
| Structure/GW | 0.336 | 0.285 | 0.259 | 0.250 |
| Power Plant/GW | | 0.070 | 0.109 | |
| Fixed Equipm't/GW | | 0.058 | 0.105 | |
| Empty Weight/GW | 0.561 | 0.414 | 0.473 | 0.508 |
| Wing Group/GW | 0.132 | 0.100 | 0.090 | 0.070 |
| Empenn. Group/GW | 0.016 | 0.022 | 0.022 | 0.024 |
| Fuselage Group/GW | 0.135 | 0.113 | 0.095 | 0.111 |
| Nacelle Group/GW | 0.015 | 0.013 | 0.018 | in wing |
| Land. Gear Group/GW | 0.039 | 0.039 | 0.034 | 0.045 |
| Take-off Gross Wht, W _{TO} , lbs | 82,000 | 275,000 | 155,000 | 58,421 |
| Empty Weight, W _E , lbs | 46,000 | 113,814 | 73,260 | 29,675 |
| Wing Group/S, psf | 7.4 | 10.3 | 8.0 | 4.5 |
| Emp. Grp/S _{emp} , psf | 2.3 | 4.2 | 4.2 | 2.6 |
| Ultimate Load Factor, g's | 3.75* | 2.50 | 3.75* | 3.75* |
| Surface Areas, ft ² | | | | |
| Wing, S | 1,458 | 2,673 | 1,745 | 902 |
| Horiz. Tail, S _h | 327 | 801 | 536 | 320 |
| Vert. Tail, S _v | 250 | 641 | 300 | 223 |
| Empenn. Area, S _{emp} | 577 | 1,442 | 836 | 543 |

*Assumed

Comparativa de pesos – Aviones similares

Ejemplo – más información carpeta de material extra

Table I.1 Jet Transport Aircraft Weights Summary (Weights in Pounds)

| Aircraft | McDonnell Douglas | | Boeing | | | Airbus |
|-----------------------------------|-------------------|----------|---------|---------|---------|---------|
| | MD-80 | DC-10-30 | 737-200 | 727-100 | 747-100 | A-300 |
| Wing | 15,560 | 58,859 | 10,613 | 17,764 | 86,402 | 44,131 |
| Empennage | 3,320 | 14,676 | 2,718 | 4,133 | 11,850 | 5,941 |
| Fuselage | 16,150 | 47,270 | 12,108 | 17,681 | 71,845 | 35,820 |
| Nacelle | 5,340 | 9,127 | 1,392 | 3,870 | 10,031 | 7,039 |
| Landing gear | 5,340 | 25,761 | 4,354 | 7,211 | 31,427 | 13,611 |
| Nose gear | 550 | 1,832 | — | — | — | — |
| Main gear | 4,790 | 23,929 | — | — | — | — |
| Structure total | 42,490 | 155,693 | 31,185 | 50,659 | 211,555 | 106,542 |
| Engine | 8,820 | 26,163 | 6,217 | 9,325 | 34,120 | 16,825 |
| Nozzle system and $T_{reversor}$ | 1,540 | 6,916 | 1,007 | 1,744 | 6,452 | 4,001 |
| Air induction system ^a | 0 | 0 | 0 | 0 | 0 | 0 |
| Fuel system | 640 | 4,308 | 575 | 1,143 | 2,322 | 1,257 |
| Propulsion install | — | — | 378 | 250 | 802 | 814 |
| Propulsion total | 11,000 | 37,387 | 8,177 | 12,462 | 43,696 | 22,897 |
| Avionics and instruments | 2,130 | 4,274 | 625 | 756 | 1,909 | 377 |
| Surface controls | 2,540 | 6,010 | 2,348 | 2,996 | 6,982 | 5,808 |
| Hydraulic system | 540 | 2,587 | 873 | 1,418 | 4,471 | 3,701 |

^aEngines in pods, weight included in nacelle.

Comparativa de pesos – Aviones similares

| Aircraft | McDonnell Douglas | | Boeing | | | Airbus |
|--|-------------------|----------|---------|---------|---------|---------|
| | MD-80 | DC-10-30 | 737-200 | 727-100 | 747-100 | A-300 |
| Pneumatic system | 1,720 | 5,912 | — | — | — | — |
| Electrical system | — | — | 1,066 | 2,142 | 3,348 | 4,923 |
| Electronics | — | — | 956 | 2,142 | 3,348 | 4,923 |
| Auxiliary power units (APU) | 840 | 1,643 | 836 | 1,591 | 4,429 | 1,726 |
| Oxygen system | 220 | 256 | — | — | — | — |
| Environmental control system (ECS) | 1,580 | 2,723 | 1,416 | 1,976 | 3,969 | 3,642 |
| Anti-icing system | 550 | 471 | — | — | — | — |
| Furnishings | 8,450 | 34,124 | 6,643 | 10,257 | 37,245 | 13,161 |
| Miscellaneous | 3,650 | 16,274 | 124 | 85 | 421 | 732 |
| Equipment total | 25,460 | 76,194 | 14,887 | 21,281 | 63,062 | 35,053 |
| Empty weight (lb) | 78,950 | 269,274 | 60,210 | 88,300 | 353,398 | 168,805 |
| Fuel | 39,362 | 247,034 | 34,718 | 48,353 | 331,675 | 76,512 |
| Oil | — | — | — | — | — | — |
| Payload (lb) | 43,950 | 98,726 | 34,790 | 29,700 | 140,000 | 69,865 |
| TOGW (lb) | 140,000 | 555,000 | 115,500 | 160,000 | 710,000 | 302,000 |
| Wing span (ft) | 107.7 | 165.3 | 94.0 | 108.0 | 195.7 | 147.3 |
| Wing area, S (ft ²) | 1,270 | 3958 | 980 | 1,700 | 5,500 | 2,799 |
| Horizontal tail area, S_H (ft ²) | 314 | 1,338 | 321 | 376 | 1,470 | 748 |
| Vertical tail area, S_V (ft ²) | 168 | 605 | 233 | 356 | 830 | 487 |

Estimación de Pesos (DAR Corp)

- Method for estimating the components of the airplane empty weight (DAR Corporation - Roskam).
- Las ecuaciones para la estimación de los pesos del ala se diferencian en función del tipo de avión al que se hace referencia siendo estos:
 - General Aviation Airplanes
 - Commercial Transport Airplanes
 - Military Patrol, Bomb and Transport Airplanes
 - Fighter and Attack Airplanes



Structure Weight - II

The General Aviation Airplanes category contains the following airplane types:

Homebuilts

Single engine props

Multi-engine props

Agricultural

Regional turboprops below 12,500 pounds

Low speed military trainers

Small, low speed flying boats, amphibious airplanes, and float airplanes



The Military Patrol, Bomb and Transport Airplanes category contains the following types of airplanes:

Military patrol airplanes

Bombers

Military transports

Supersonic military patrol airplanes

Supersonic bombers

Supersonic military transports



The Commercial Transport Airplanes category contains the following types of airplanes:

Business jets

Regional turboprops above 12500 pounds

Jet transports

Large, high speed flying boats, amphibious airplanes, and float airplanes

Commercial supersonic cruise airplanes (use Fighter inlet data)



The fighter and attack airplanes category contains the following airplane types:

High speed military trainers

Fighters

Supersonic fighters and attack airplanes



Weight Estimation - Class II Method

- Class II Method for estimating the components of the airplane empty weight (DAR Corporation - Roskam).

$$W_E = W_{structure} + W_{pp} + W_{fix}$$

where:

$W_{structure}$ is the Class II airplane structure weight.

W_{pp} is the Class II airplane powerplant weight.

W_{fix} is the Class II airplane fixed equipment weight.

$$W_{TO} = \frac{W_E + W_{PL} + W_{crew} + W_{PLexp} - W_{Frefuel}}{M_{ff} (1 + M_{Fres}) - M_{Fres} - M_{tfo}}$$

- Divididos en:
 - Class II Structure Weight
 - Class II Powerplant Weight
 - Class II Fixed Equipment Weight

where:

W_E is the airplane empty weight.

W_{PL} is the payload weight.

W_{crew} is the crew weight.

W_{PLexp} is the total expenditure payload weight.

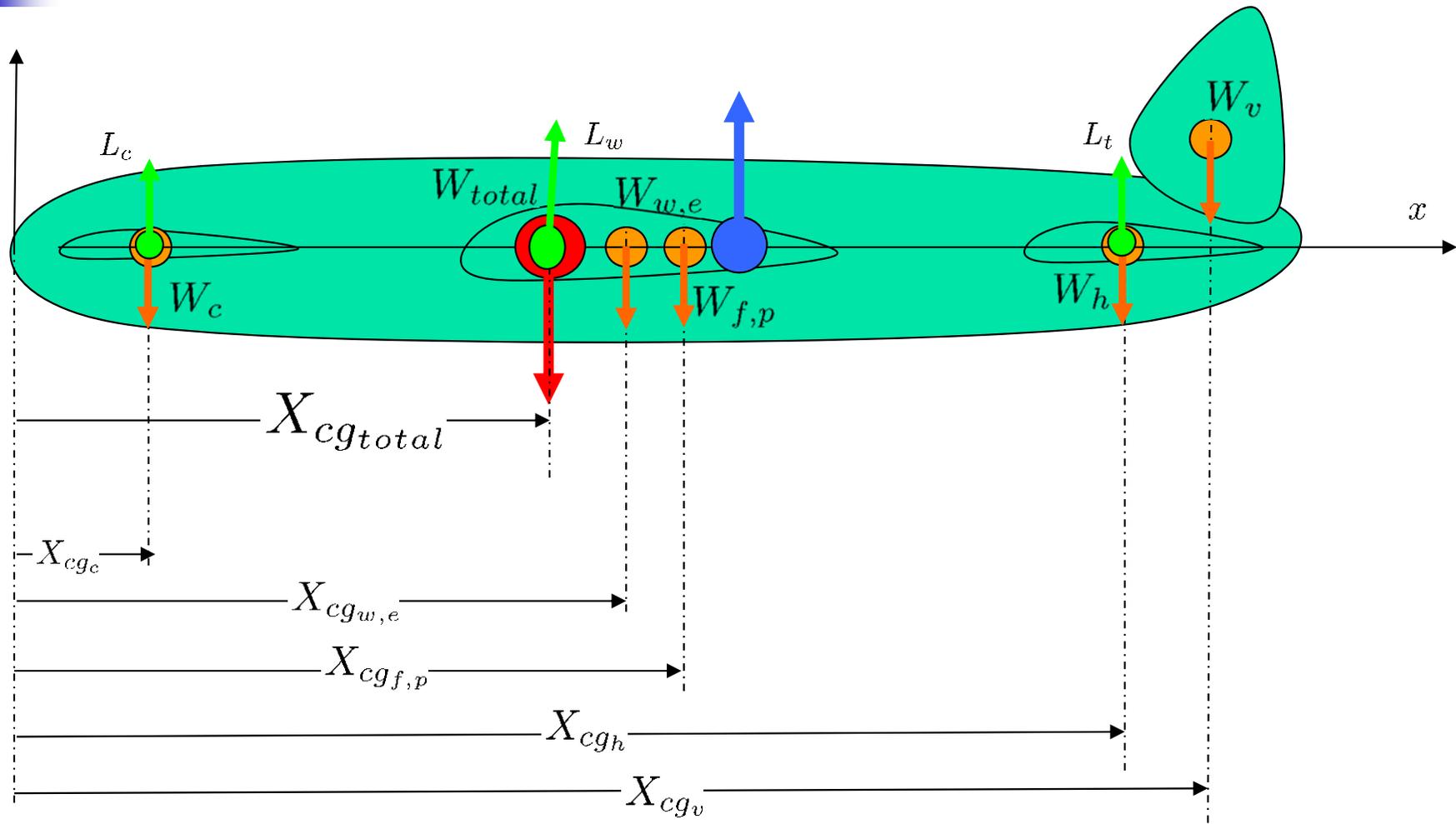
$W_{Frefuel}$ is the total refueled fuel weight.

M_{ff} is the mission fuel fraction.

M_{Fres} is the reserved fuel weight as a fraction of fuel weight used in the mission.

M_{tfo} is the trapped fuel and oil weight as a fraction of airplane take-off weight.

Equilibrado de Fuerzas Aerodinámicas y Gravitatorias



canard Fuselage -payload wing -engines tail

$$X_{cg} = \frac{\sum (W_i \times X_{cgi})}{\sum W_i} = \frac{W_c \times X_{cgc} + W_{f,p} \times X_{cgf,p} + W_{w,e} \times X_{cgw,e} + W_t \times X_{cgt}}{W_c + W_{f,p} + W_{w,e} + W_t}$$

Class II – Structure Weight

- Organizado según:

- Wing
- Horizontal Tail
- Vertical Tail
- V-tail
- Canard
- Fuselage
- Landing gear
- Nacelles
- Tailboom

$$W_{structure} = W_w + W_h + W_v + W_{vee} + W_c + W_f + W_{tboom} + W_n + W_{gear}$$

where:

- W_w is the wing weight.
- W_h is the horizontal tail weight.
- W_v is the vertical tail weight.
- W_{vee} is the V-Tail weight.
- W_c is the canard weight.
- W_f is the fuselage weight.
- W_{tboom} is the tail boom weight.
- W_n is the nacelle weight.
- W_{gear} is the landing gear weight.

- Las ecuaciones para la estimación de los pesos de los diferentes elementos se diferencian en función del tipo de avión al que se hace referencia:

- General Aviation Airplanes
- Commercial Transport Airplanes
- Military Patrol, Bomb and Transport Airplanes
- Fighter and Attack Airplanes

- Para el diseño de aviones de patrulla y transporte militar se utilizan los métodos GD y Torenbeek

- Military Patrol, Bomb and Transport Airplanes**

- Los métodos GD y Torenbeek methods empleados para la estimación de los pesos del Commercial Transport Airplanes son los utilizados para determinar los pesos para los aviones de patrulla militar y de transporte con la salvedad de que el factor de carga último empleado es de 4.5.
- Mientras que el peso de diseño para tanto aviones de transporte comerciales como de aviones ligeros se emplea el peso en despegue,
- Para aviones militares, el peso empleado para el diseño del ala se emplea el peso de diseño para la misión (flight design gross).

General Aviation Airplane

- Unidades Imperiales en todos los parámetros
- Tres métodos:
 - Cessna Method
 - Ecuaciones válidas para aviones pequeños, de actuaciones moderadas y con velocidades por debajo de los 200 knots
 - El peso de los carenados de punta de ala y las superficies de controestá incluido
 - USAF Method
 - Ecuaciones válidas para pequeños aviones utilitarios con actuaciones de hasta 300 knots.
 - Torenbeek Method
 - Ecuaciones válidas para aviones de transporte ligero con pesos al despegue por debajo de 12,500 lbs (55,603 N).

where:

| | |
|-------------|--------------------------------|
| W_w | is the wing weight. |
| W_h | is the horizontal tail weight. |
| W_v | is the vertical tail weight. |
| W_{vee} | is the V-Tail weight. |
| W_c | is the canard weight. |
| W_f | is the fuselage weight. |
| W_{tboom} | is the tail boom weight. |
| W_n | is the nacelle weight. |
| W_{gear} | is the landing gear weight. |

The General Aviation Airplanes category contains the following airplane types:

Homebuilts

Single engine props

Multi-engine props

Agricultural

Regional turboprops below 12,500 pounds

Low speed military trainers

Small, low speed flying boats, amphibious airplanes, and float airplanes

Structure Weight – Wing – I (ejemplo)

- Unidades Imperiales en todos los parámetros
- El peso del ala se determina mediante la media entre los métodos empleados.
- Cessna Method

- Para alas en voladizo (cantilever wing)

$$W_{wCessna} = 0.04674 W_{TO}^{0.397} S_w^{0.360} n_{ult}^{0.397} AR_w^{1.712}$$

- Para alas enriestrada (braced wing)

$$W_{wCessna} = 0.002933 S_w^{1.018} n_{ult}^{0.611} AR_w^{2.473}$$

where:

W_{TO} is the airplane take-off weight.

S_w is the wing area.

n_{ult} is the airplane ultimate load factor.

AR_w is the wing aspect ratio.

- USAF Method

$$W_{wUSAF} = 96.948 \left\{ \left(\frac{W_{TO} n_{ult}}{10^5} \right)^{0.65} \left(\frac{AR_w}{\cos \Lambda_{c/4_w}} \right)^{0.57} \left(\frac{S_w}{100} \right)^{0.61} \left(\frac{1 + \lambda_w}{2 \left(\frac{t}{c} \right)_{r_w}} \right)^{0.36} \left(1 + \frac{V_{Heas}}{500} \right)^{0.5} \right\}^{0.993}$$

where:

W_{TO} is the airplane take-off weight.

n_{ult} is the airplane ultimate load factor.

AR_w is the wing aspect ratio.

$\Lambda_{c/4_w}$ is the wing quarter chord sweep angle.

S_w is the wing area.

λ_w is the wing taper ratio.

$\left(\frac{t}{c} \right)_{r_w}$ is the wing root thickness ratio.

V_{Heas} is the equivalent maximum level speed.

Structure Weight – Wing – II (ejemplo)

- Torenbeek Method:

$$W_{wTorenbeek} = 0.00125W_{TO}n_{ult}^{0.55} \left(\frac{b_w}{\cos \Lambda_{c/2_w}} \right)^{0.75} \left\{ 1 + \left(\frac{6.3 \cos \Lambda_{c/2_w}}{b_w} \right)^{0.5} \right\} \left(\frac{b_w S_w}{t_{r_w} W_{TO} \cos \Lambda_{c/2_w}} \right)^{0.30}$$

The wing span is calculated from:

$$b_w = \sqrt{S_w AR_w}$$

where:

S_w is the wing area.

AR_w is the wing aspect ratio.

The wing root maximum thickness

$$t_{r_w} = \left(\frac{t}{c} \right)_{r_w} \left(\frac{2S_w}{b_w(1 + \lambda_w)} \right)$$

where:

$\left(\frac{t}{c} \right)_{r_w}$ is the wing root thickness ratio.

S_w is the wing area.

b_w is the wing span.

λ_w is the wing taper ratio.

Peso del ala determinado por la media entre los pesos de todos los métodos

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