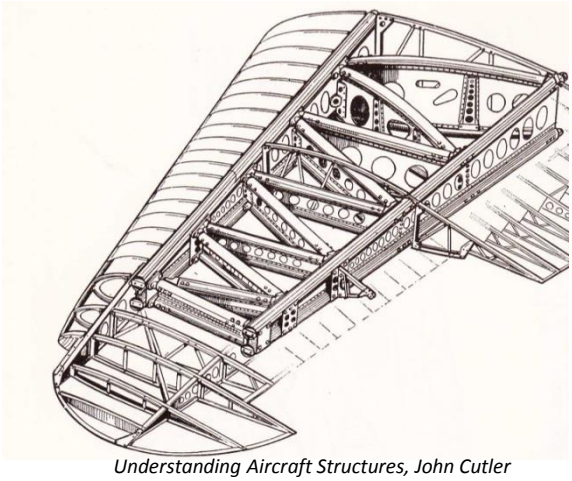
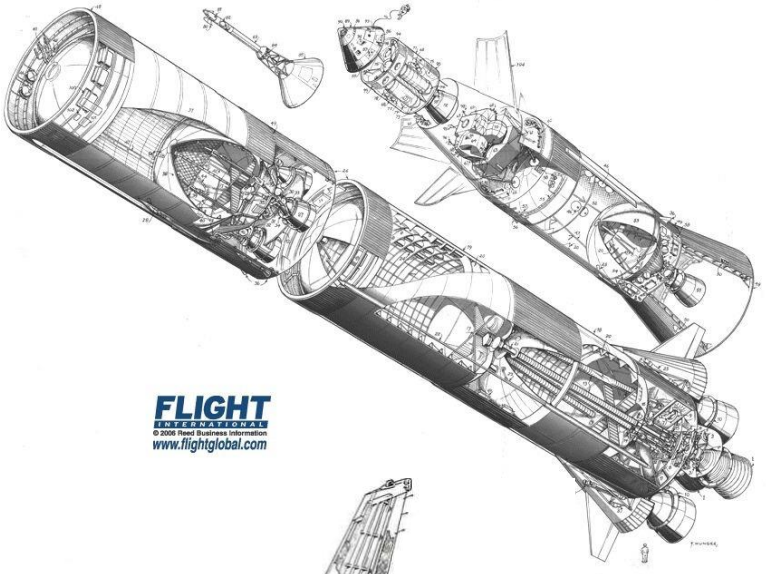
Aerospace Structures
AEM 341
Spring 2018



Understanding Aircraft Structures, John Cutler



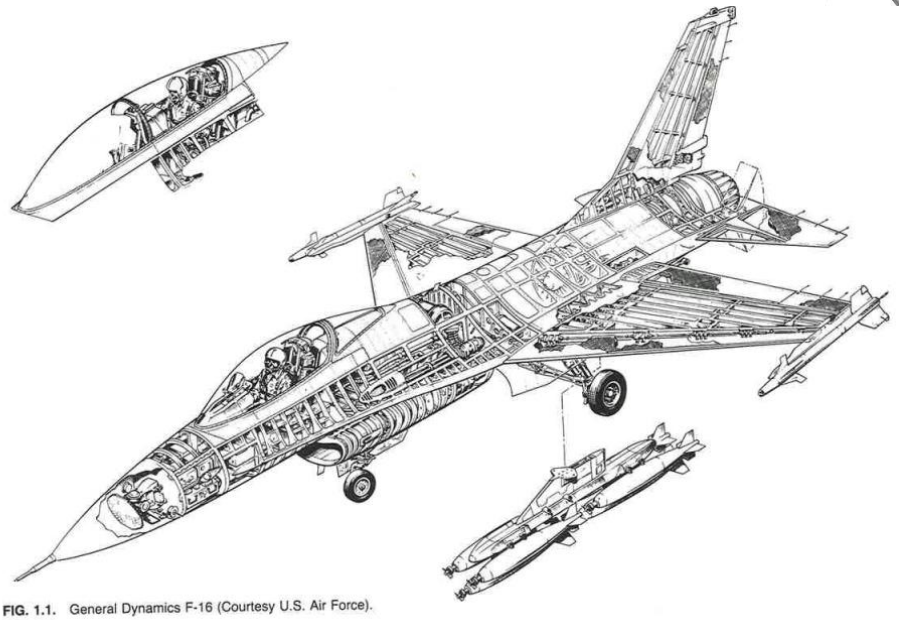


FIG. 1.1. General Dynamics F-16 (Courtesy U.S. Air Force).

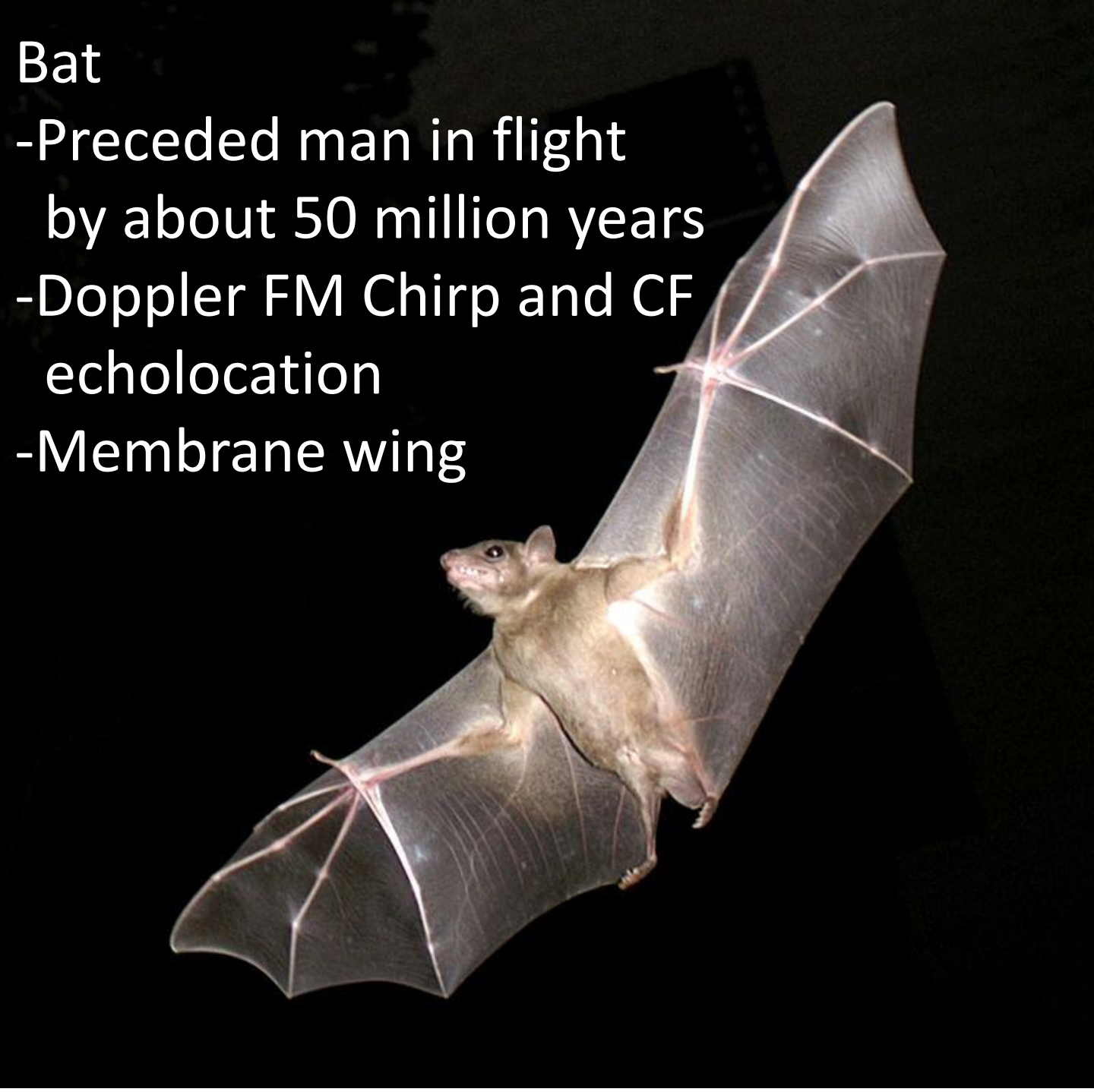
Warren Photographic

Bat

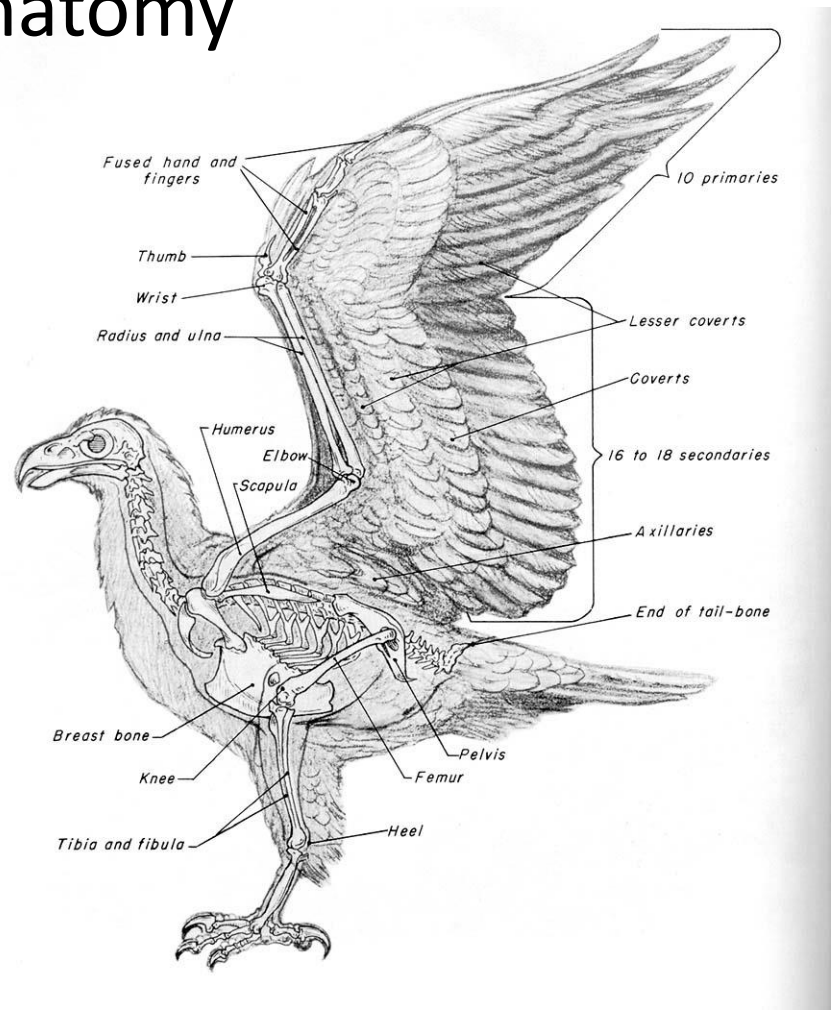
-Preceded man in flight by about 50 million years

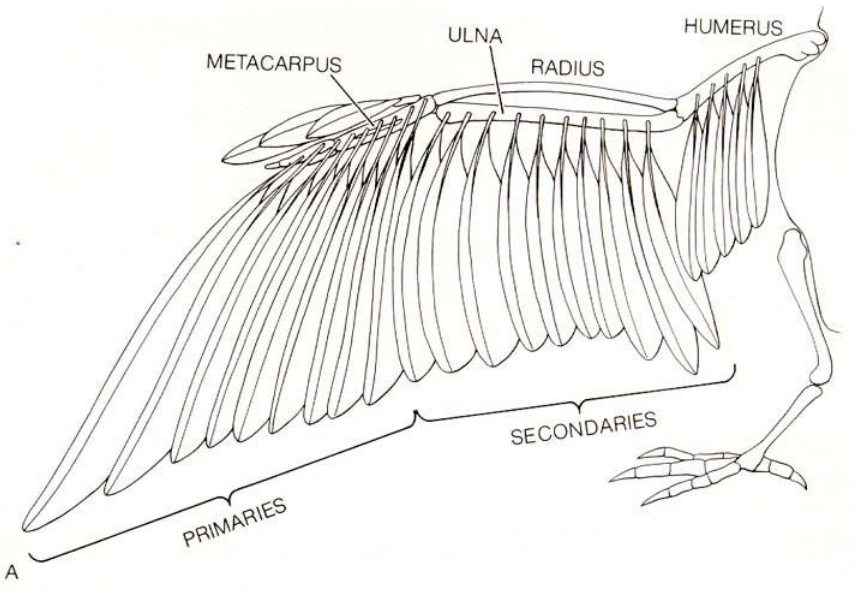
-Doppler FM Chirp and CF echolocation

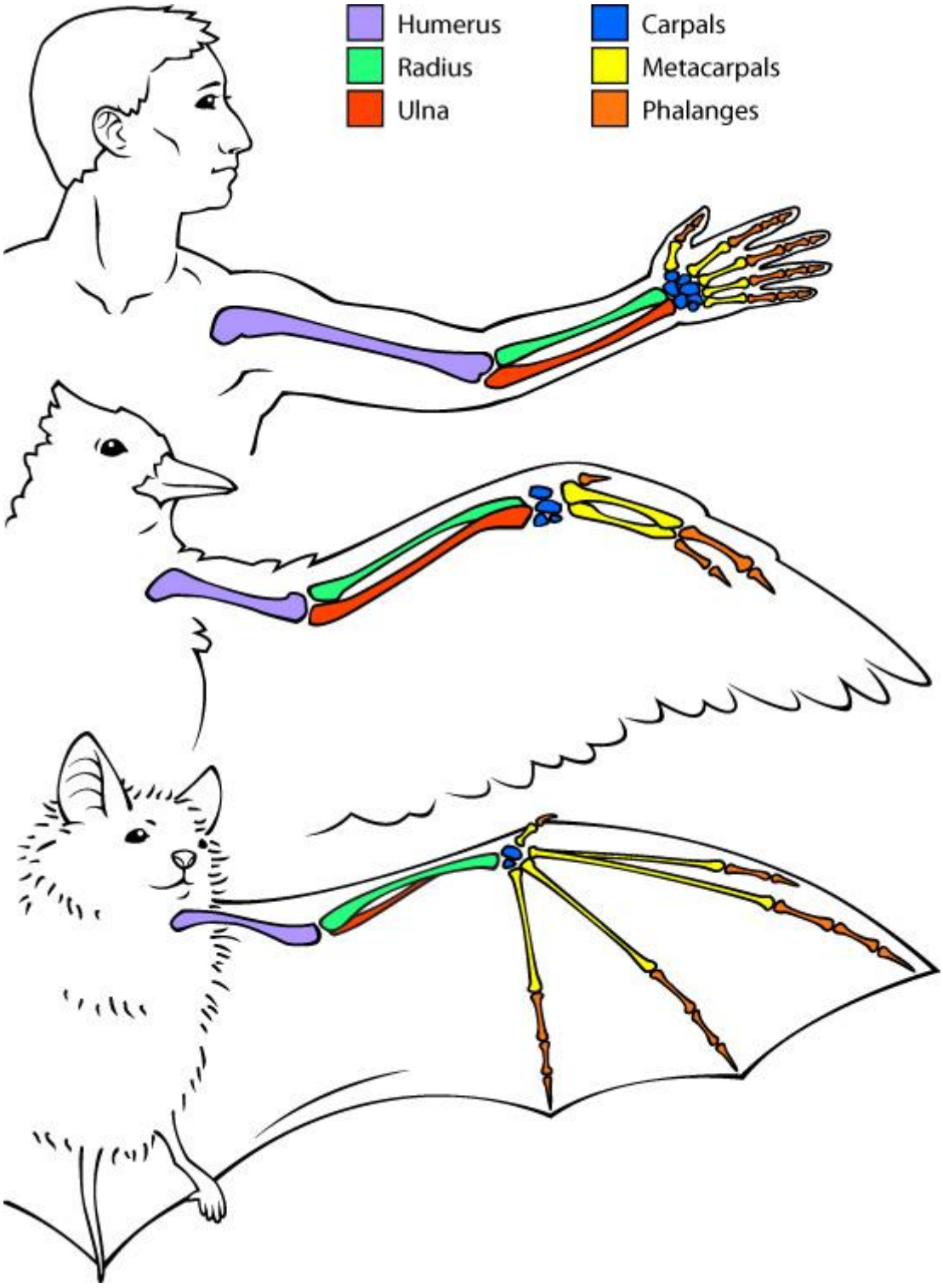
-Membrane wing



Bird Anatomy





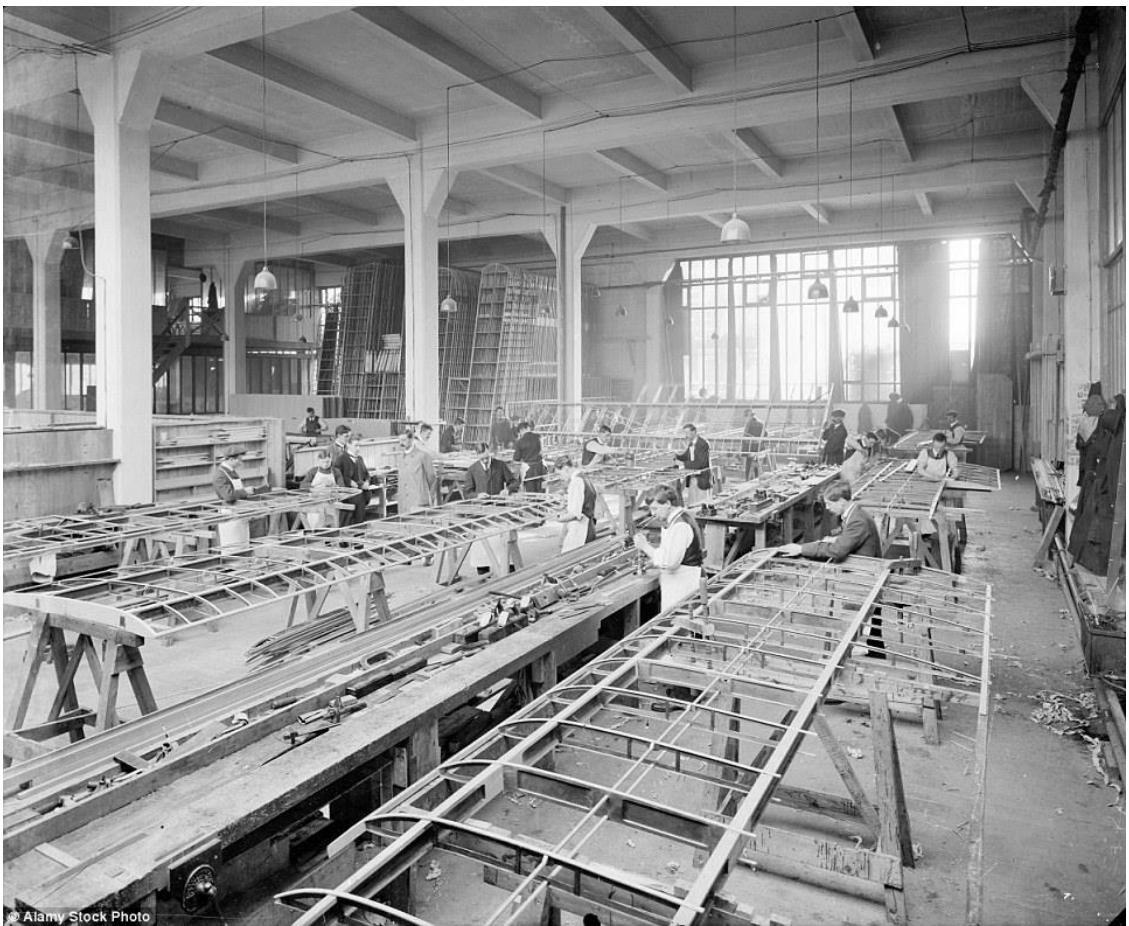


https://askabiologist.asu.edu/human-bird-and-bat-bone-comparison

Human Flight

Wright Flyer 1903

WW1 Technology



Fokker Dr I (June 1917)

Above: One of the Dr I prototypes (F I 103/17) being taxied by Werner Voss at the Jasta 10 airfield near Marckebeeke from where he was evaluating the fighter when shot down by No 56 Sqdn, RAF.

Seen in its fighter context as a formula for combining good climbing qualities with extreme lateral manoeuvrability made possible by an exceedingly small overall wing span, the triplane was an aberration from the mainstream of fighter development. It was to enjoy a brief heyday in 1917 and be obsolescing before that year's end. Indeed, of many fighter triplanes developed, but two were to see combat.

Triplane investigation in Germany dated from aviation's early pioneering days, but the catalyst in its further development for the fighter role was provided by the February 1917 operational debut of the Royal Naval Air Service's Sopwith Triplane. The *Fliegertruppen* were startled by the remarkable manoeuvrability and climb rate demonstrated by the Sopwith, Germany being panicked into launching a massive single-seat fighter triplane development effort, which, with the sole exception of one type, the Fokker Dr I, was to prove an abysmal failure. The Dr I was thus conceptually unoriginal in being engendered by the Sopwith, but it nevertheless embodied some highly innovatory features.

Designed by Reinhold Platz, the prototype—at that time known as the D VI, Fokker having still to adopt V-series designations for experimental aircraft—was an outstandingly compact triplane with *verspannungslos* (literally "without bracing"), or cantilever, wings dispensing with flying, landing and incidence wires, the necessary strength being imparted by an original single-spar arrangement, which was actually two boxspars joined vertically. The fuselage was of welded steel tubing with transverse bracing to form a rigid box-girder structure. Wing oscillation in certain flight regimes dictated introduction of thin, non-structural spruce I-type interplane struts to provide the desired rigidity.

Enjoying the patronage of no less a personality than Manfred *Freiherr* von Richthofen, the triplane was ordered into production on 14 July 1917, two prototypes being tested at the Front in the following month by von Richthofen and Werner Voss. Production Dr Is reached the Front from October proving very sensitive about all axes and most taxing to fly. The Dr I, nevertheless, possessed superlative aerobatic qualities, and if a slow, low-altitude performer, it made a dangerous adversary with a skilled pilot at its controls. Its manoeuvrability was arguably second to no other fighter. In developing the Dr I, however, the *Fliegertruppe* had not comprehended the inherent limitations of the triplane configuration and its early demise was inevitable, only 320 fighters of this type being built.

SPECIFICATION: Fokker Dr I

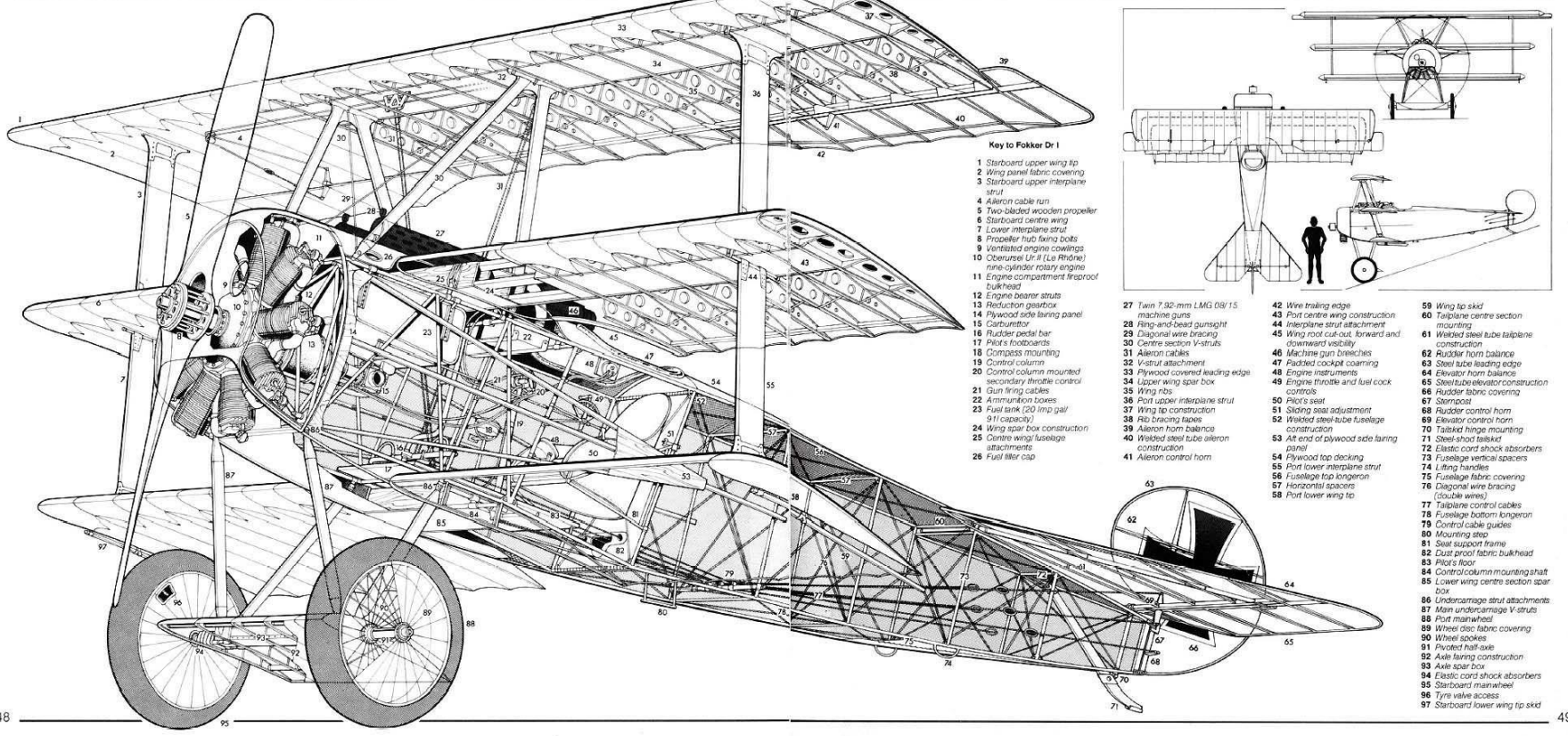
Power Plant: One Oberursel Ur II nine-cylinder rotary air-cooled engine rated at 110 hp at 1,200 rpm for take-off. Two-bladed fixed-pitch wooden propeller. Internal fuel capacity, 20 Imp gal (91 l).

Performance: Max speed, 115 mph (185 km/h) at sea level, 102·5 mph (165 km/h) at 13,125 ft (4 000 m); initial climb, 1,800 ft/min (9,15 m/sec); time to 3,280 ft (1 000 m), 2·9 min, to 9,840 ft (3 000 m), 10·1 min, to 16,405 ft (5 000 m), 23·85 min; range, 185 mls (300 km).

Weights: Empty, 894 lb (406 kg); loaded, 1,291 lb (586 kg).

Dimensions: Span, 23 ft 7 in (7,19 m); length, 18 ft 11 in (5,77 m); height, 9 ft 8 in (2,95 m); wing area, 200·86 sq ft.

Armament: Two 7,92-mm Maxim LMG 08/15 with 500 rpg.



Key to Fokker Dr I

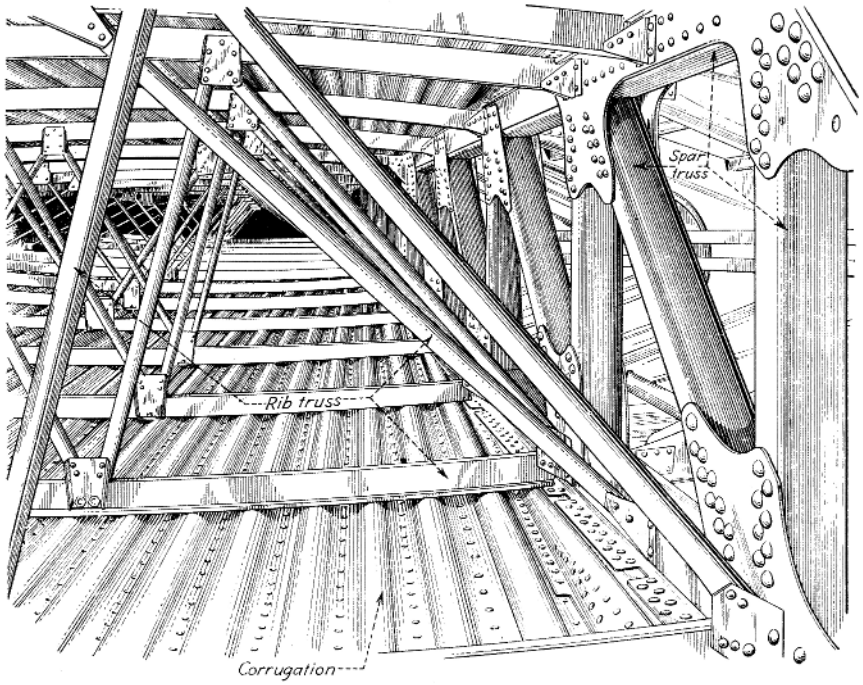
1 Starboard upper wing tip
2 Wing panel fabric covering
3 Starboard upper interplane strut
4 Aileron cable run
5 Two-bladed wooden propeller
6 Starboard centre wing
7 Lower interplane strut
8 Propeller hub fixing bolts
9 Ventilated engine cowlings
10 Oberursel Ur.II (Le Rhône) nine-cylinder rotary engine
11 Engine compartment fireproof bulkhead
12 Engine bearer struts
13 Reduction gearbox
14 Plywood side fairing panel
15 Carburettor
16 Rudder pedal bar
17 Pilot's footboards
18 Compass mounting
19 Control column
20 Control column mounted secondary throttle control
21 Gun firing cables
22 Ammunition boxes
23 Fuel tank (20 Imp gal/91l capacity)
24 Wing spar box construction
25 Centre wing/fuselage attachments
26 Fuel filler cap
27 Twin 7,92-mm LMG 08/15 machine guns
28 Ring-and-bead gunsight
29 Diagonal wire bracing
30 Centre section V-struts
31 Aileron cables
32 V-strut attachment
33 Plywood covered leading edge
34 Upper wing spar box
35 Wing ribs
36 Port upper interplane strut
37 Wing tip construction
38 Rib bracing tapes
39 Aileron horn balance
40 Welded steel tube aileron construction
41 Aileron control horn
42 Wire trailing edge
43 Port centre wing construction
44 Interplane strut attachment
45 Wing root cut-out, forward and downward visibility
46 Machine gun breeches
47 Padded cockpit coaming
48 Engine instruments
49 Engine throttle and fuel cock controls
50 Pilot's seat
51 Sliding seat adjustment
52 Welded steel-tube fuselage construction
53 Aft end of plywood side fairing panel
54 Plywood top decking
55 Port lower interplane strut
56 Fuselage top longeron
57 Horizontal spacers
58 Port lower wing tip
59 Wing tip skid
60 Tailplane centre section mounting
61 Welded steel tube tailplane construction
62 Rudder horn balance
63 Steel tube leading edge
64 Elevator horn balance
65 Steel tube elevator construction
66 Rudder fabric covering
67 Sternpost
68 Rudder control horn
69 Elevator control horn
70 Tailskid hinge mounting
71 Steel-shod tailskid
72 Elastic cord shock absorbers
73 Fuselage vertical spacers
74 Lifting handles
75 Fuselage fabric covering
76 Diagonal wire bracing (double wires)
77 Tailplane control cables
78 Fuselage bottom longeron
79 Control cable guides
80 Mounting step
81 Seat support frame
82 Dust proof fabric bulkhead
83 Pilot's floor
84 Control column mounting shaft
85 Lower wing centre section spar box
86 Undercarriage strut attachments
87 Main undercarriage V-struts
88 Port mainwheel
89 Wheel disc fabric covering
90 Wheel spokes
91 Pivoted half-axle
92 Axle fairing construction
93 Axle spar box
94 Elastic cord shock absorbers
95 Starboard mainwheel
96 Tyre valve access
97 Starboard lower wing tip skid

Junkers J1 (1915)

Blechesel = Tin Donkey

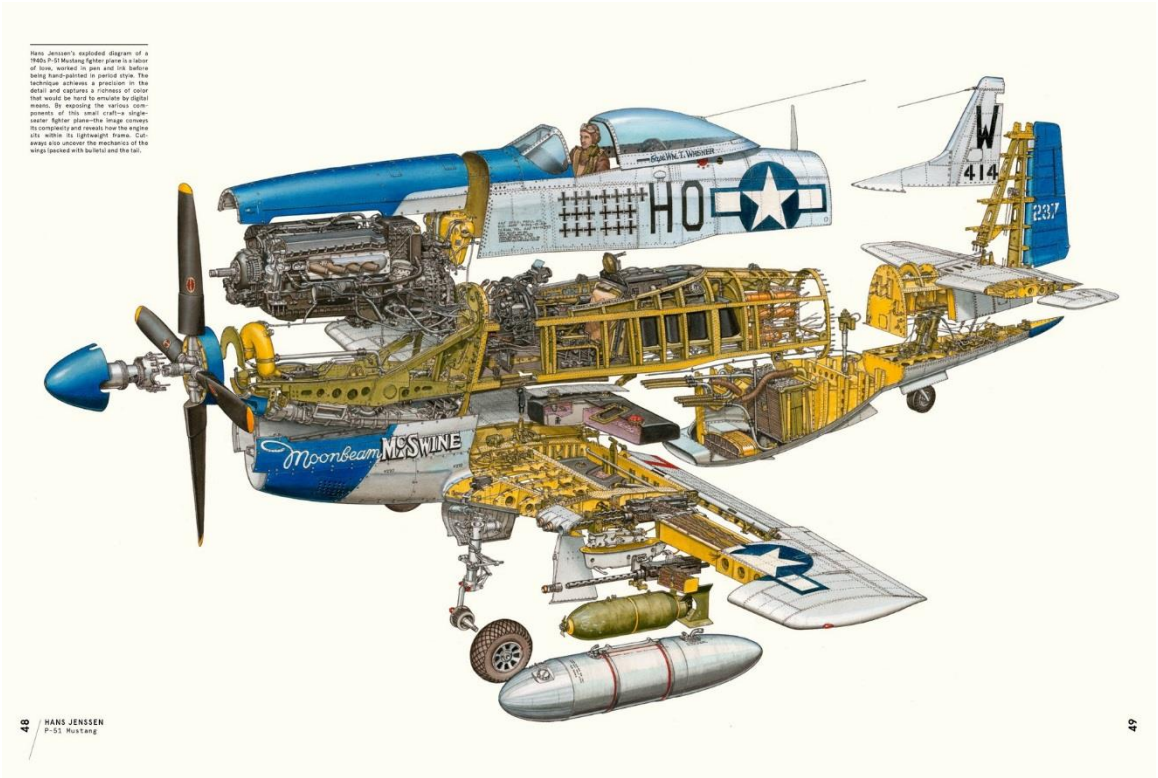
+Metal Cantilever Wings

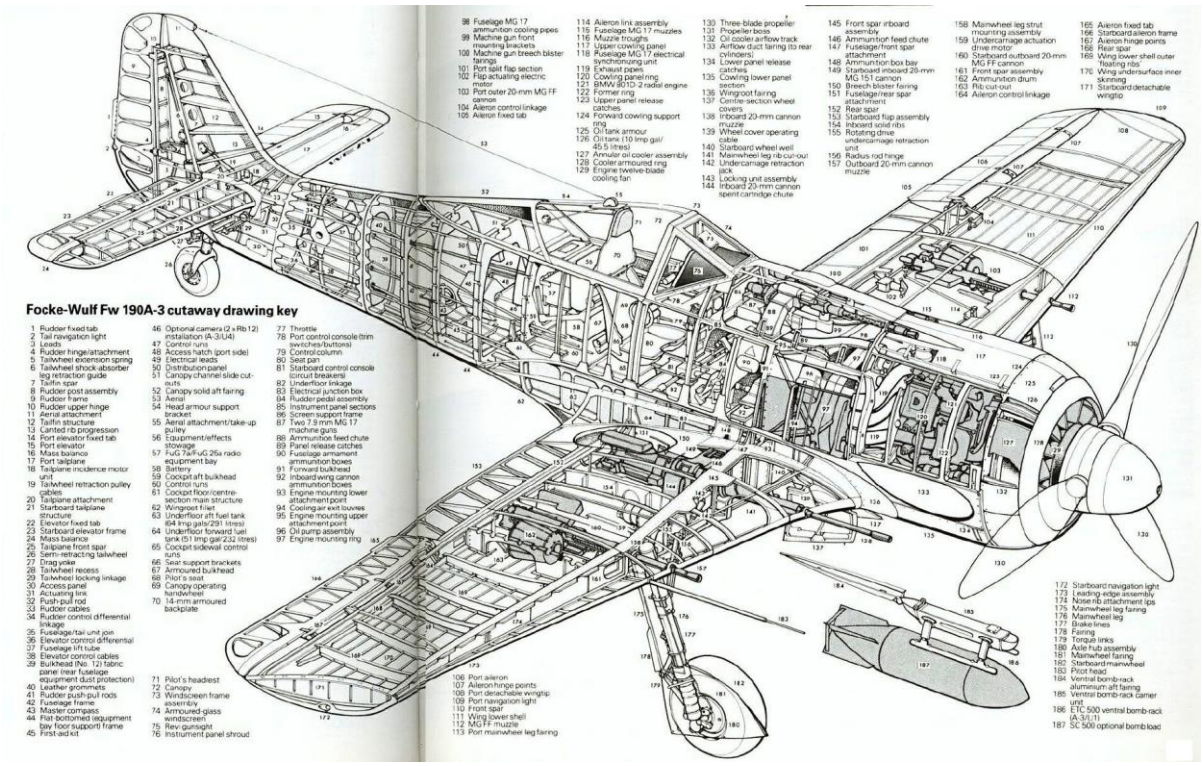
+2 decades advanced



Closeup of internal wing structure showing attachment details of spar truss, rib truss, and corrugations.

Mid 1940s Technology





Cessna 170 Wing Structure

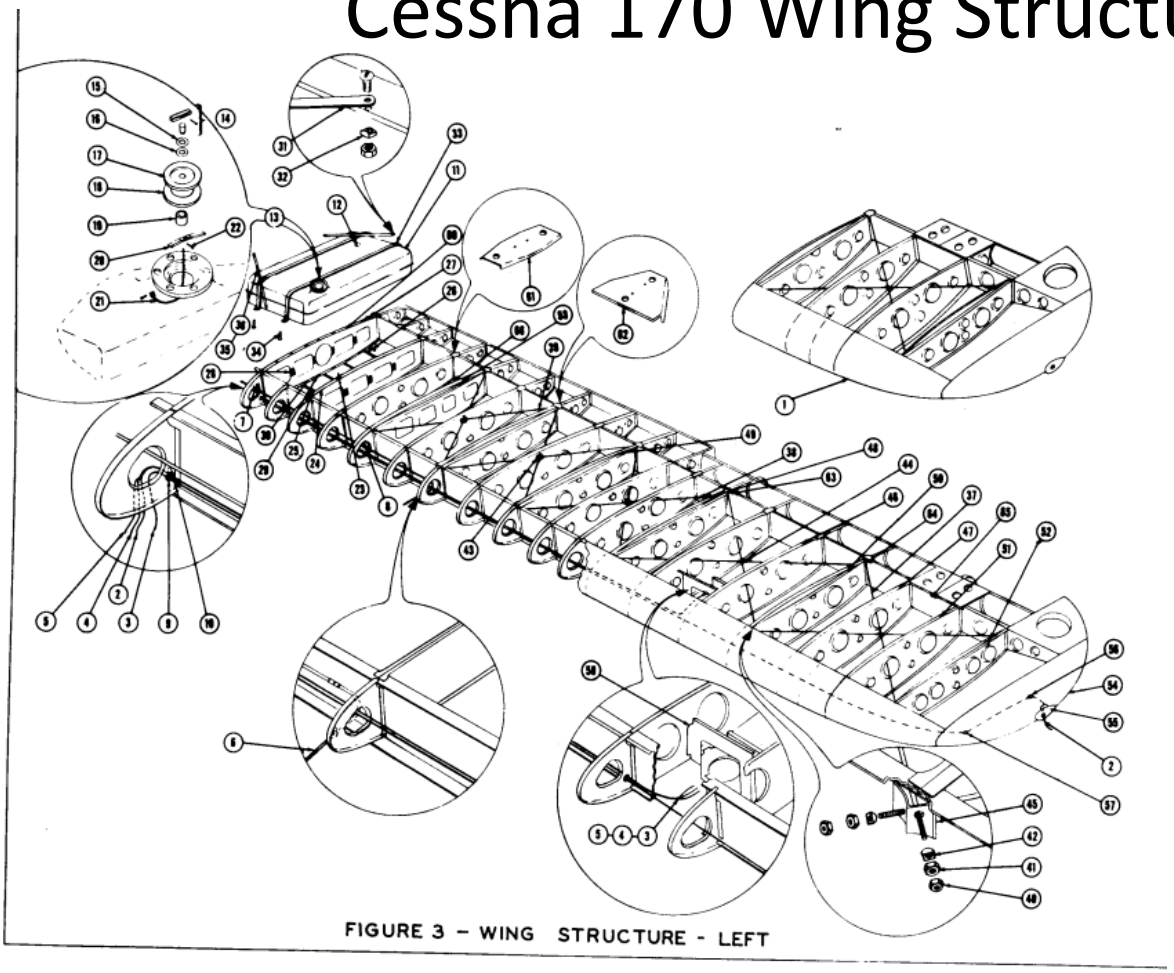
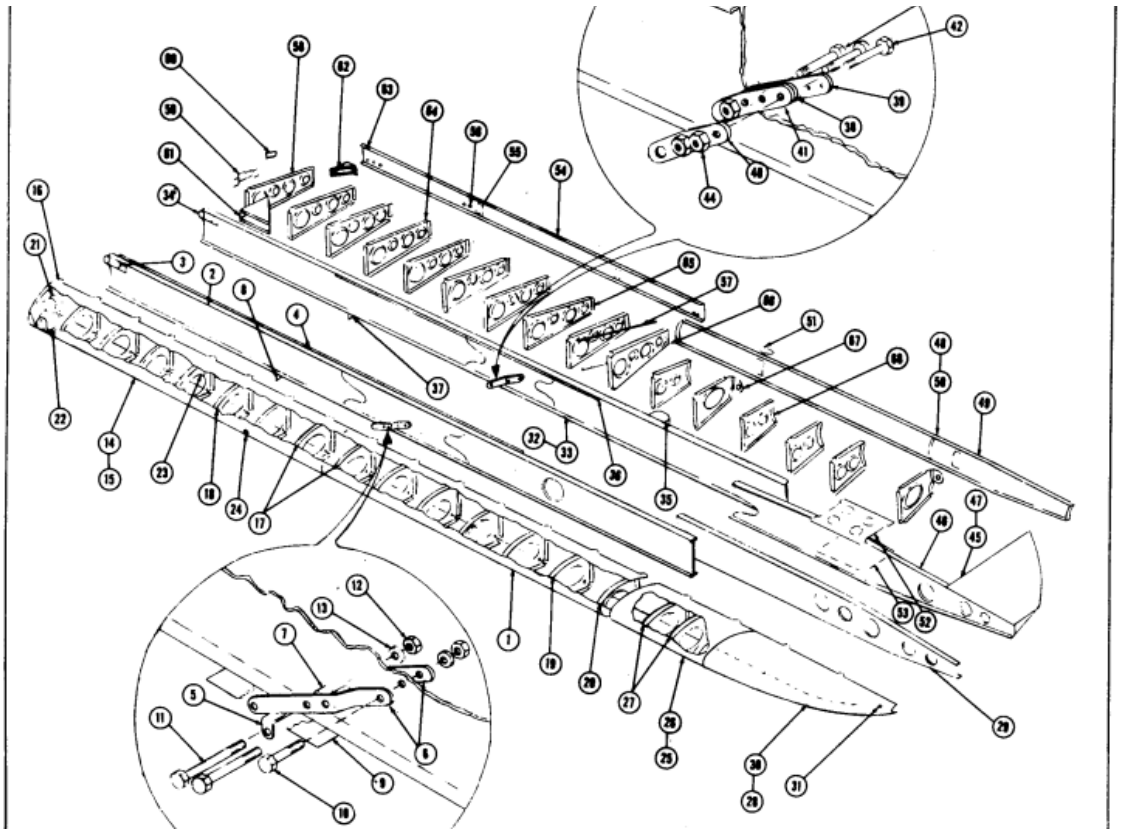
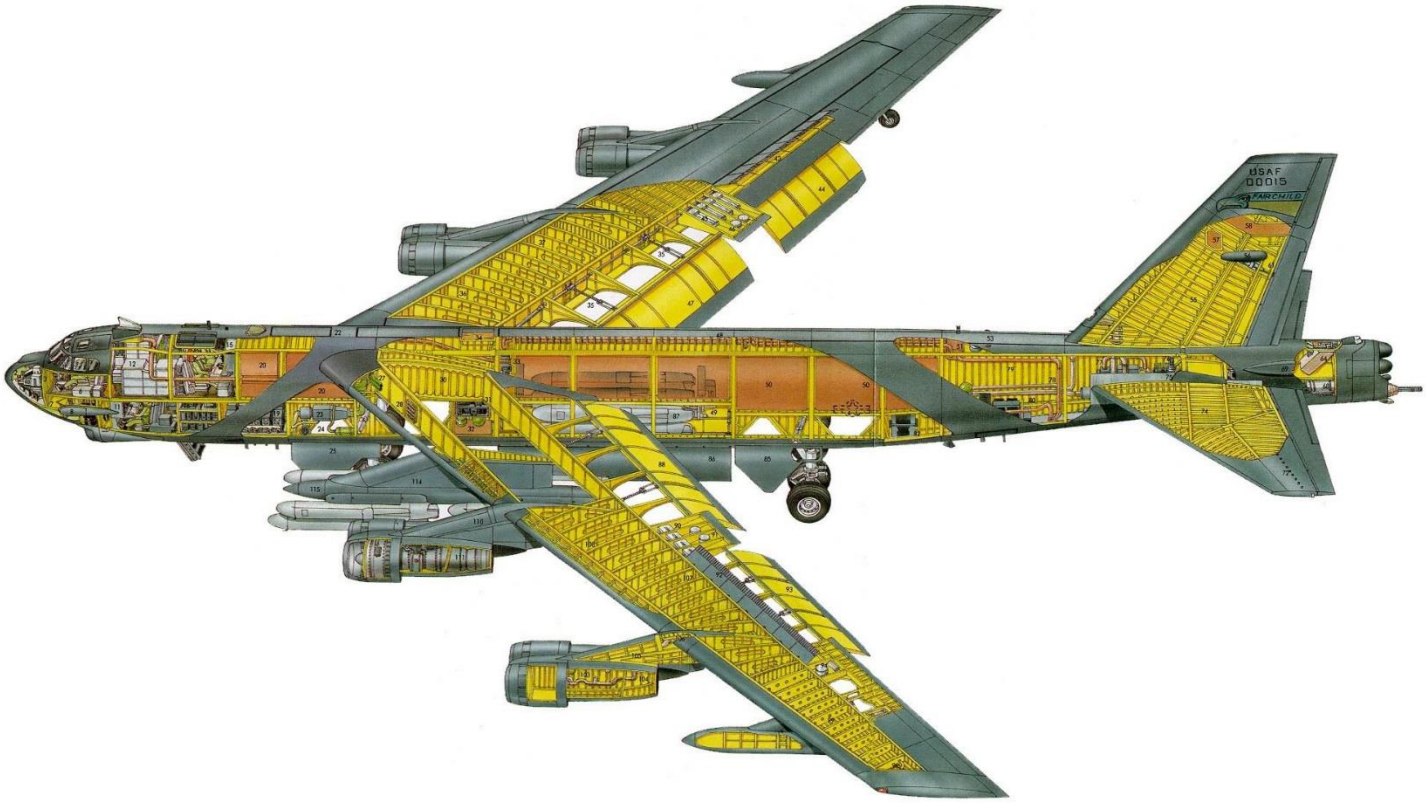


FIGURE 3 – WING STRUCTURE - LEFT





Boeing KC-135 Cutaway Drawing Key

1 Detachable radome
2 Weather radar scanner
3 Radar array
4 Forward pressure bulkhead
5 Forward fuselage structure
6 Pilot's side console
7 Rudder pedal assembly
8 Central console
9 Instrument panel
10 Windscreen defrost/rain removal
11 Windscreen panels
12 Co-pilot's seat
13 Eyebrow windows
14 Ditching external handholds
15 Overhead console
16 Crew instructor's seat
17 Pilot's seat
18 Crew instructor's console
19 Escape spoiler
20 Entry and escape hatch
21 Nosewheel hydraulic actuator
22 Entry/escape tunnel
23 Crew entry door
24 Ladder
25 Twin nosewheels
26 Fuselage frame
27 AC power shield
28 Electrical equipment racks
29 Supernumerary crew station
30 Navigator's stool (celestial observation)
31 Navigator's seat
32 Navigator's instrument panel
33 Overhead storage rack
34 Celestial observation windows
35 Window defrost
36 Electronics rack
37 Flight deck door
38 Circuit breaker panel
39 Toilet
40 Battery
41 Cargo door frame
42 Forward fuselage underfloor fuel tanks (four tanks): capacity 5,800 US gal (21 955 l)
43 Floor support beam
44 Cargo deck: 5,000 lb and 10,000 lb (2 268–4 540 kg) tie-down fittings
45 Cargo door hinges
46 Main cabin air supply risers (starboard)
47 Door upper frame
48 Cabin air duct
49 Fuselage frame
50 Engine inlet nose cowl
51 No 3 engine nacelle
52 Oil filler access
53 Surge bleed outlet
54 Nacelle pylon
55 Pylon strut access
56 Wing leading-edge
57 No 3 main fuel tank: capacity 2,275 US gal (8 612 l)
58 Fuel filler access
59 Starboard inner pylon light (fuselage illumination)
60 Pylon strut attachment
61 Wing front spar
62 No 4 main tank: capacity 2,062 US gal (7 805 l)
63 Leading-edge wing flap
64 No 4 engine nacelle
65 No 4 engine fuel air starter tank
66 Oil cooler chin intake scoop
67 Engine inlet nose cowl
68 Nacelle pylon
69 Dry bays
70 No 4 reserve tank capacity 434 US gal (1 643 l)
71 Wing outer leading-edge
72 Starboard navigation light
73 Starboard wingtip
74 Starboard outer aileron
75 Aileron lockout mechanism
76 Flap torque tube linkage
77 Aileron balance tab
78 Actuating links
79 Bus quadrant
80 Starboard outer spoilers
81 Starboard outer flap
82 Flap track
83 Snubber
84 Trim actuator
85 Aileron control tab
86 Starboard inner aileron
87 Hinge fairing
88 Actuator linkage
89 Starboard inner double-slotted flap
90 Flap track
91 Starboard inner spoilers
92 Wing rear spar
93 Dorsal identification light
94 Cabin air duct
95 Starboard midships escape hatch
96 Centre-facing troop seating (80)
97 Troop seat support rails
98 Centre-section wing tank: capacity 7,306 US gal (3 314 l)
99 Port midships escape hatch
100 Wing centre-section top skin
101 Keel beam antenna bay
102 Bulkhead section
103 Fuselage light (wing illumination)
104 Wingroot/fuselage fillet plate
105 Front spar pick-up point
106 Port landing lights
107 Air-conditioning pack (port) intake scoop
108 Leading-edge structure
109 Wing front spar
110 Inboard wing stringers
111 No 2 main tank inner wall: capacity 2,275 US gal (8 612 l)
112 Stiffeners
113 Engine bleed air manifold
114 Water injection manifold
115 Four-wheel main landing-gear
116 Torsion links
117 Landing-gear trunnion
118 Wing rear spar
119 Angled ribs
120 Pylon/wing fairing
121 Pylon strut access
122 No 2 engine pylon
123 Nacelle
124 Engine inlet nose cowl
125 Oil cooler chin intake scoop
126 Pratt & Whitney J57-P-59W turbojet
127 Engine drive alternators
128 Oil tank
129 Tail pipe
130 Exhaust outlet cone
131 Nacelle support aft fairing
132 Leading-edge wing flap
133 Wing ribs
134 Lower surface inner stringers
135 No 1 main tank: capacity 2,062 US gal (7 805 l)
136 Front spar
137 Fuel filler access
138 Strengtheners
139 Dry bays
140 Pylon fairing
141 Strut access
142 Hinged cowling panels
143 Engine inlet nose cowl
144 Nacelle frame
145 Pylon structure
146 Pylon support strut
147 Fixed aft panels
148 Nacelle support aft fairing
149 Wing outer leading-edge
150 No 1 reserve tank: capacity 434 US gal (1 643 l)
151 Rear spar
152 Port navigation light
153 Port wingtip
154 Port outer aileron
155 Aileron control tab
156 Bus quadrant
157 Port outer double-slotted flap
158 Port outer spoilers
159 Port inner aileron
160 Aileron control tab
161 Hinge fairing
162 Port inner double-slotted flap
163 Port inner spoilers
164 Wing fillet flap
165 Undercarriage attachment fairing
166 Port landing-gear well
167 Landing-gear pivot
168 Side strut
169 Undercarriage retraction strut
170 Rear spar pick-up point
171 Bulkhead section
172 Cargo deck
173 Soundproofing/insulation lining
174 Cabin air duct
175 Cargo traversing rails
176 Cargo sling/hoist
177 Midships emergency rescue cut-out points
178 Aft fuselage underfloor fuel tanks (five tanks): capacity 6,378 US gal (24 143 l)
179 Cabin side window
180 Bulkhead stations
181 Wingroot fairing
182 Fuselage skinning
183 Aft escape hatch (starboard only)
184 Aft fuselage structure
185 Conditioned air connection (Arctic capability)
186 Boom operator's air duct (window demist)
187 Aft emergency rescue cut-out points
188 Cargo deck opening (boom operator's position access)
189 Boom operator's station
190 Boom hoist/telescope controls
191 Student's/observer's pallet (starboard)
192 Boom operator's pallet
193 Instructor's pallet (port)
194 Scanning side window
195 Boom operator's pressure window
196 Inward-opening fairing door (with window)
197 Pod pivot/attachment boom fairing
198 Cargo deck
199 Aft pressure bulkhead
200 Fin root fairing
201 Fairing formers
202 AN/APN-69 receiver transmitter
203 Tailfin spar attachment points
204 Auto pilot servo
205 Aft bulkhead
206 Aft upper deck tank: capacity 2,174 US gal (8 230 l)
207 Tank support beam
208 Pod line
209 Aerial refuelling boom (stowed)
210 Tailplane jack screw
211 Tailplane support fitting
212 Tailplane centre-section
213 Tailplane end plate
214 Ribs
215 Port tailplane
216 Elevator torque tube
217 Elevator internal balance panel
218 Port elevator
219 Elevator control tab
220 Tailplane actuator tab
221 Boom ruddervators
222 Boom neck fairing
223 Tail navigation light
224 Crash locator beacon
225 Aft frame
226 Tab hinge fairing
227 Rudder trim tab
228 Starboard elevator
229 Rudder anti-balance tab
230 Fairing
231 Rudder frame
232 Rudder post
233 Rudder internal balance panel
234 Rudder control quadrant
235 AN/APN-69 radar beacon antenna
236 VOR antenna
237 Fin leading-edge
238 Fin structure
239 Rudder fixed trailing edge
240 Rudder upper hinge
241 HF antennae
242 HF probe antenna
243 Aerial refuelling boom (deployed)
244 Boom operator's window
245 Scanning side window
246 Underfloor aft fuel tanks (five)
247 Air-conditioning pack intake scoop
248 Cargo door (open)
249 Underfloor forward fuel tanks (four)
250 Refuelling envelope central director lights

Boeing KC-135A Stratotanker Specification

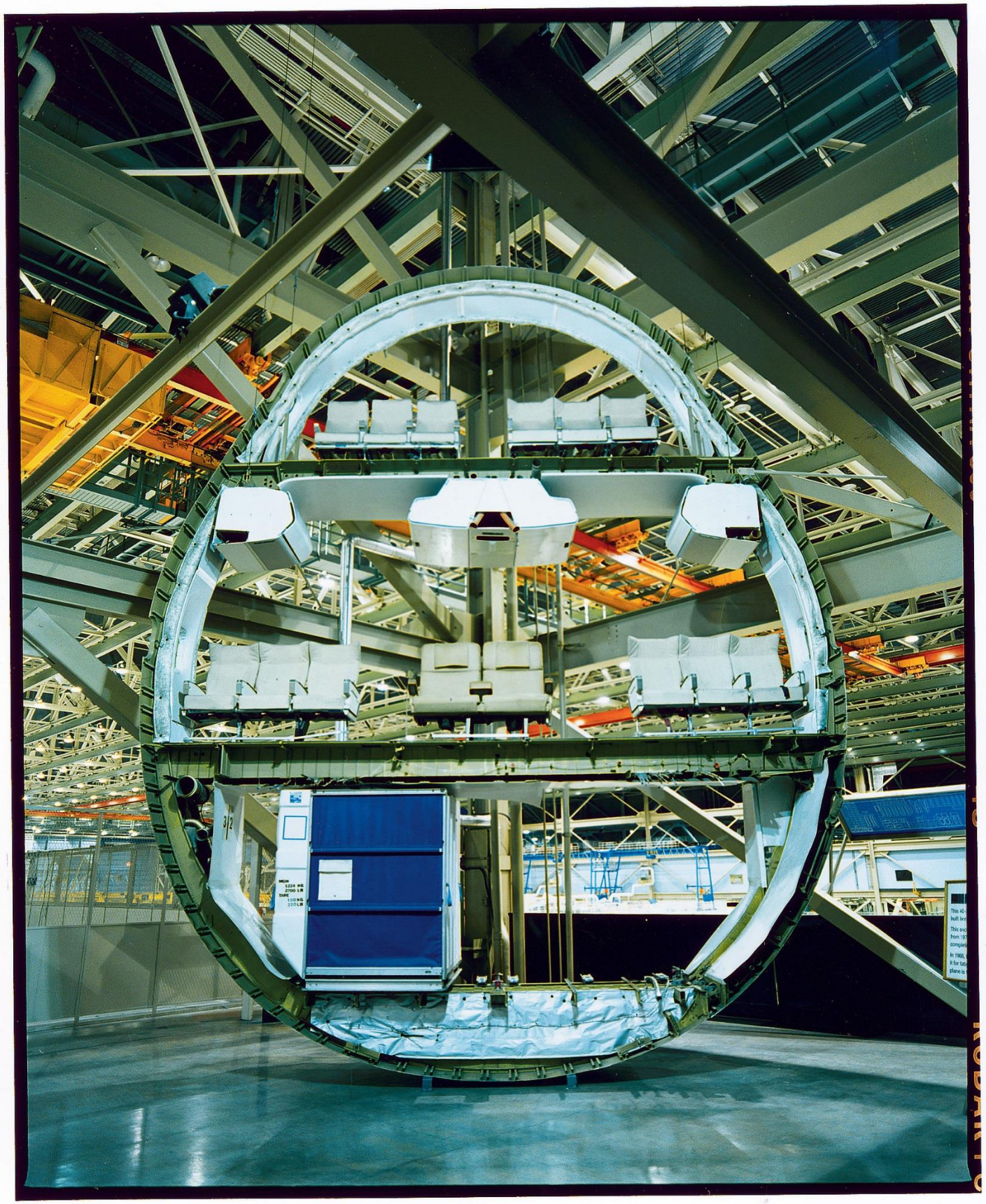
Power Plant: Four Pratt & Whitney J57-P-59W turbojets each rated at 13,750 lb st (6 237 kgp) for take-off, with water injection. Fuel capacity, 31,200 US gal (118 105 l) in integral tanks in each wing, bladder tanks in centre section, fore and aft underfloor in the fuselage and above deck in the rear fuselage.

Performance: Typical cruising speed, max load refuelling mission, 532 mph (856 km/h) at 35,000 ft (10 668 m); initial rate of climb, 1,290 ft/min (6,55 m/sec); one engine-out climb rate, 580 ft/min (29,5 m/sec); time to 34,500 ft (9 300 m), 27 min; critical field length, max weight, ISA + 17 deg C at sea level, 13,700 ft (4 176 m); mission radius, 3,000 naut mls (5 552 km) to offload 24,000 lb (10 886 kg) fuel, 2,000 naut mls (3 700 km) to offload 74,000 lb (33 566 kg) fuel, 1,000 naut mls (1 850 km) to offload 120,000 lb (54 432 kg) fuel.

Weights: Operating weight empty, 106,306 lb (48 220 kg); normal take-off weight, 301,600 lb (136 806 kg); max overload weight, 316,000 lb (143 338 kg).

Dimensions: Span, 130 ft 10 in (39,88 m); length overall, 134 ft 6 in (40,99 m); height overall, 41 ft 8 in (12,69 m); wing area, 2,433 sq ft (226,03 m²); sweepback, 35 deg on quarter chord line; dihedral, 7 deg constant; undercarriage track, 22 ft 1 in (6,73 m); wheelbase, 45 ft 8 in (13,92 m).

Boeing 747 Fuselage Cross-Section



Composite Aircraft

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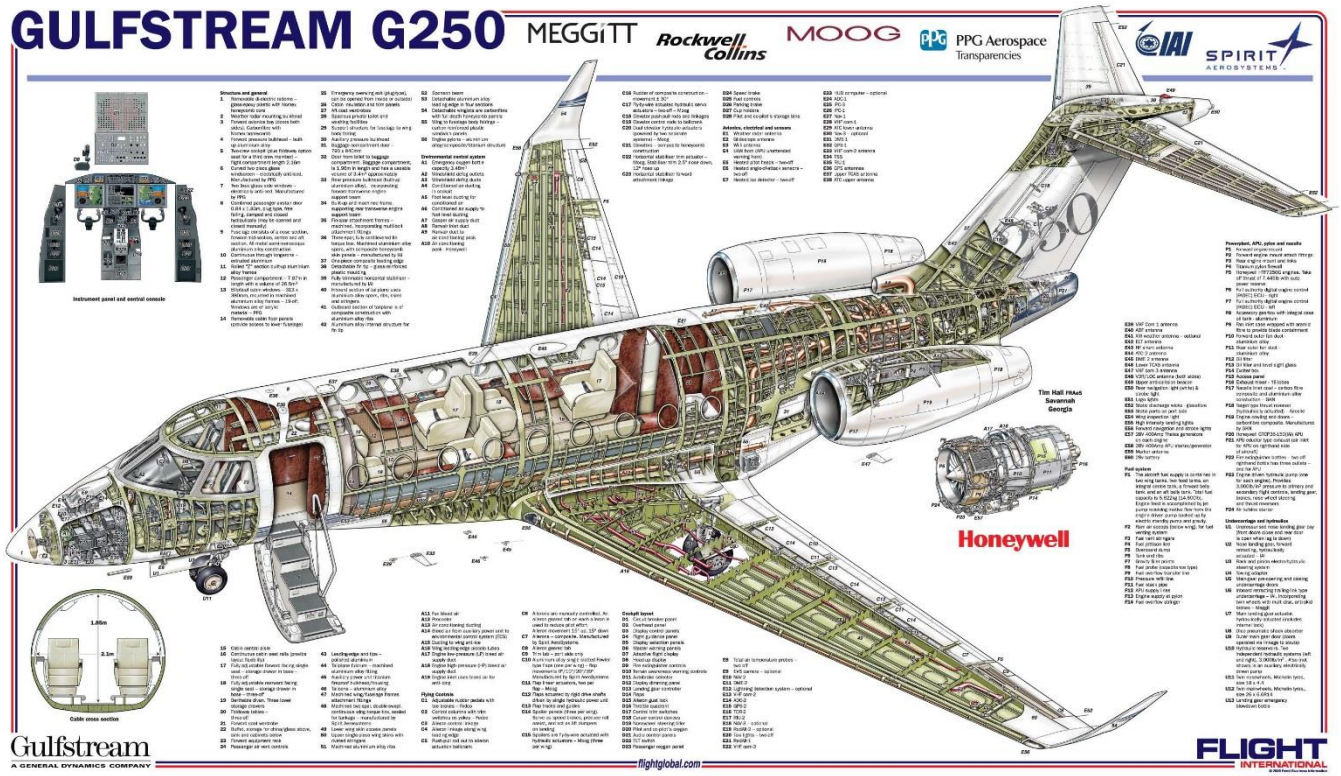

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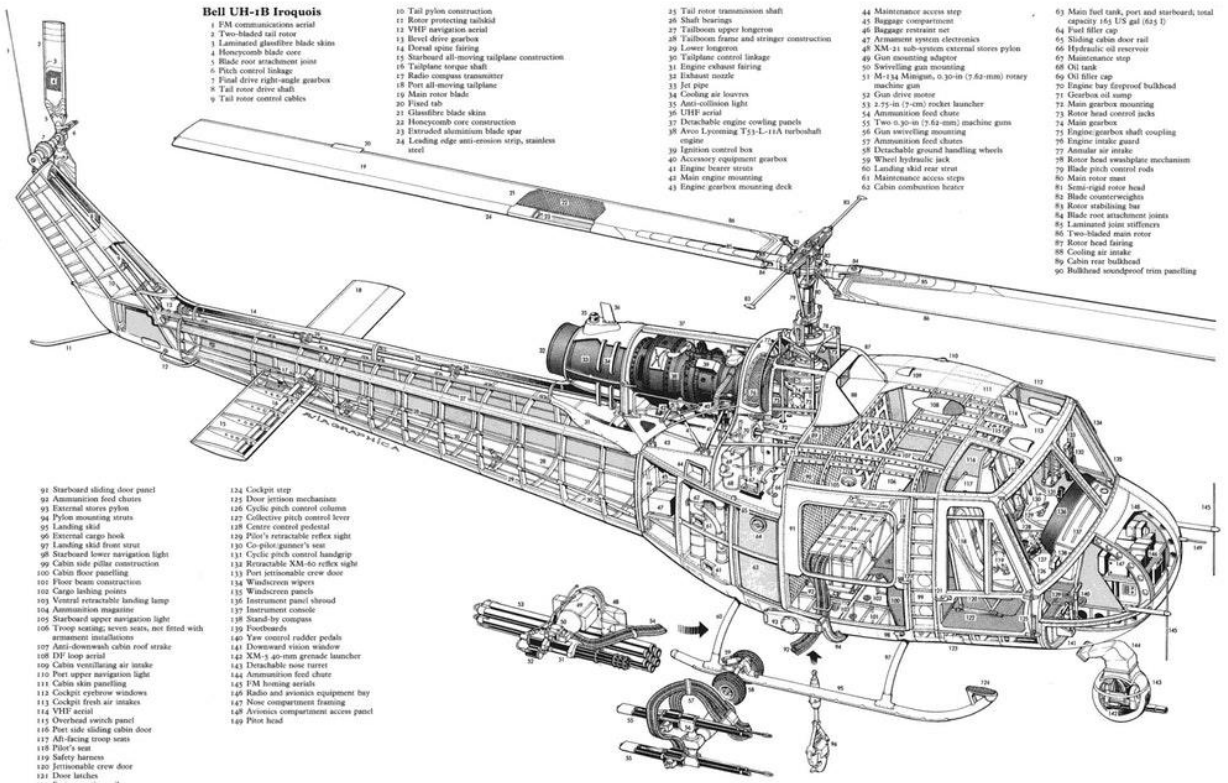
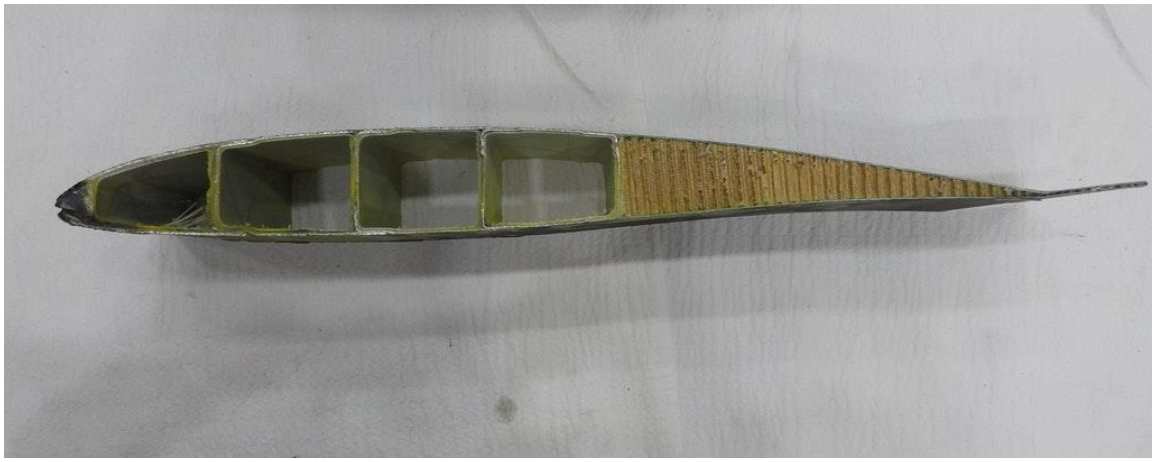


1 FM communicaicions aerial
2 Two-bladed tail rotor
3 Laminated glassfibre blade skins
4 Honeycomb blade core
5 Blade root attachment joint
6 Pitch control linkage
7 Final drive right-angle gearbox
8 Tail rotor drive shaft
9 Tail rotor control cables
10 Tail pylon construction
11 Rotor protecting tailskid
12 VHF navigation aerial
13 Bevel-drive gearbox
14 Dorsal spine fairing
15 Starboard all-moving tailplane construction
16 Tailplane torque shaft
17 Radio compass transmitter
18 Port all-moving tailplane
19 Main rotor blade
20 Fixed tab
21 Glassfibre blade skins
22 Honeycomb core construction
23 Extruded aluminium blade spar
24 Leading edge anti-erosion strip, stainless steel
25 Tail rotor transmission shaft
26 Shaft bearings
27 Tailboom upper longeron
28 Communications system electronics
29 Lower longeron
30 Tailplane control linkage
31 Engine exhaust fairing
32 Exhaust nozzle
33 Jet pipe
34 Cooling air louvres
35 Anti-collision light
36 UHF aerial
37 Detachable engine cowling panels
38 Avco Lycoming T53-L-11A turboshaft engine
39 Ignition control box
40 Accessory equipment gearbox
41 Engine bearer struts
42 Main engine mounting
43 Engine gearbox mounting deck
44 Maintenance access step
45 Baggage compartment
46 Baggage restraint net
47 Armament system electronics
48 XM-21 sub-system external stores pylon
49 Gun mounting adaptor
50 Swivelling gun mounting
51 M-134 Minigun, 0.30-in (7.62-mm) rotary machine gun
52 Gun drive motor
53 2.75-in (7-cm) rocket launcher
54 Ammunition feed chute
55 Two 0.30-in (7.62-mm) machine guns
56 Gun swivelling mounting
57 Ammunition feed chutes
58 Detachable ground handling wheels
59 Wheel hydraulic jack
60 Landing skid rear strut
61 Maintenance access steps
62 Cabin combustion heater
63 Main fuel tank, port and starboard; total capacity 163 US gal (625 l)
64 Fuel filler cap
65 Sliding cabin door rail
66 Hydraulic oil reservoir
67 Maintenance step
68 Oil tank
69 Oil filler cap
70 Engine bay fireproof bulkhead
71 Gearbox oil sump
72 Main gearbox mounting
73 Rotor head control jacks
74 Main gearbox
75 Engine/gearbox shaft coupling
76 Engine intake guard
77 Annular air intake
78 Rotor head swashplate mechanism
79 Blade pitch control rods
80 Main rotor mast
81 Semi-rigid rotor head
82 Blade counterweighs
83 Rotor stabilising bar
84 Blade root attachment joints
85 Laminated joint stiffeners
86 Two-bladed main rotor
87 Rotor head fairing
88 Cooling air intake
89 Cabin rear bulkhead
90 Bulkhead soundproof trim panelling
91 Starboard sliding door panel
92 Ammunition feed chutes
93 External stores pylon
94 Pylon mounting struts
95 Landing skid
96 External cargo hook
97 Landing skid front strut
98 Starboard lower navigation light
99 Cabin side pillar construction
100 Cabin floor panelling
101 Floor beam construction
102 Cargo lashing points
103 Ventral retractable landing lamp
104 Ammunition magazine
105 Starboard upper navigation light
106 Troop seating; seven seats, not fitted with armament installations
107 Anti-downwash cabin roof strake
108 DF loop aerial
109 Cabin ventilating air intake
110 Port upper navigation light
111 Cabin skin panelling
112 Cockpit eyebrow windows
113 Cockpit fresh air intakes
114 VHF aerial
115 Overhead switch panel
116 Port side sliding cabin door
117 Aft-facing troop seats
118 Pilot's seat
119 Safety harness
120 Jettisonable crew door
121 Door latches
122 Seat mounting rails
123 Control system access panel
124 Cockpit step
125 Door jettison mechanism
126 Cyclic pitch control column
127 Collective pitch control lever
128 Centre control pedestal
129 Pilot's retractable reflex sight
130 Co-pilot/gunner's seat
131 Cyclic pitch control handgrip
132 Retractable XM-60 reflex sight
133 Port jettisonable crew door
134 Windscreen wipers
135 Windscreen panels
136 Instrument panel shroud
137 Instrument console
138 Stand-by compass
139 Footboards
140 Yaw control rudder pedals
141 Downward vision window
142 XM-1 40-mm grenade launcher
143 Detachable nose turret
144 Ammunition feed chute
145 FM homing aerials
146 Radio and avionics equipment bay
147 Nose compartment framing
148 Avionics compartment access panel
149 Pitot head

Apache Helicopter Blade



Westland Helicopter Blade

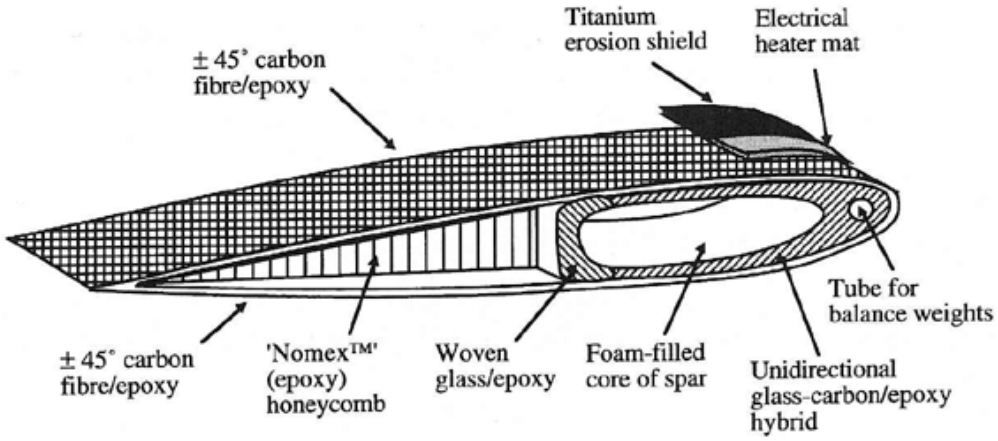
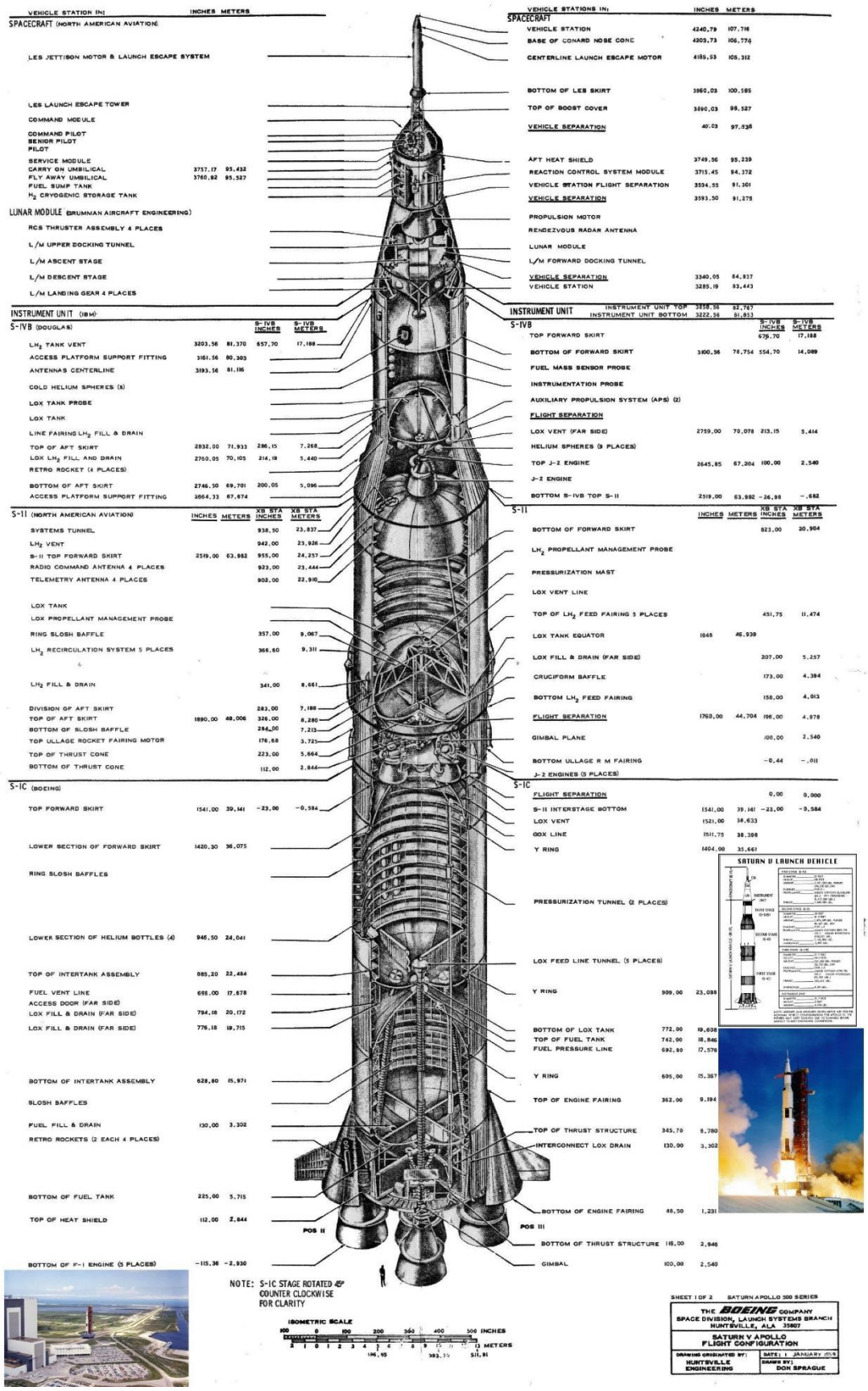


Fig. 12.4 Schematic section through a typical composite construction for a helicopter rotor blade. (Courtesy of Westland Helicopters.)

Saturn V + Apollo = 6.5×10^6 lbs

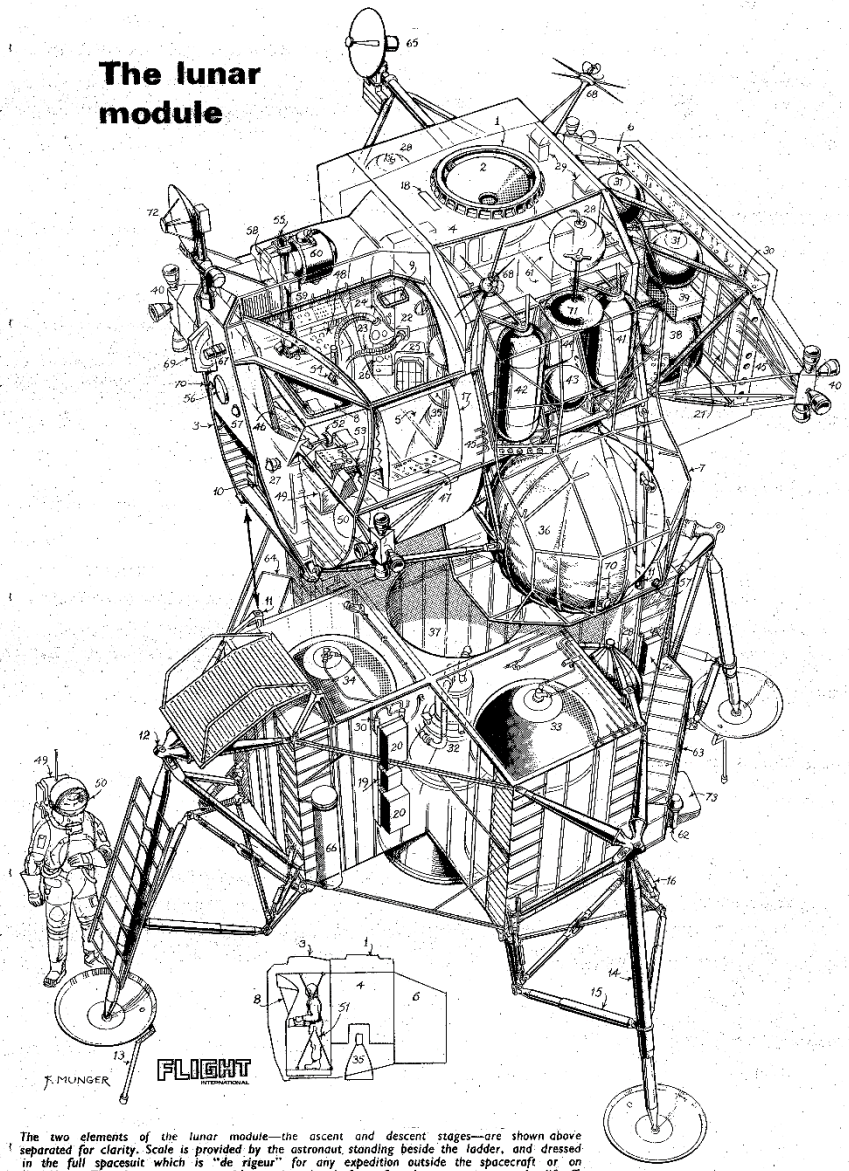


Lunar Module

-Ascent: 4700 lbs dry

10000 lbf gross

-Descent: 23000 lbs



The two elements of the lunar module—the ascent and descent stages—are shown above separated for clarity. Scale is provided by the astronaut standing beside the ladder, and dressed in the full spacesuit which is "de rigeur" for any expedition outside the spacecraft or on the Moon. The descent stage provides a launch platform for the ascent stage. At lift-off, the upper-stage engine exhausts through the central tunnel in the lower stage

Orion Capsule

By U.S. Navy -


MTV-P02
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