Lessons from the Past: The Transition from Wood to Metal Aircraft Structures

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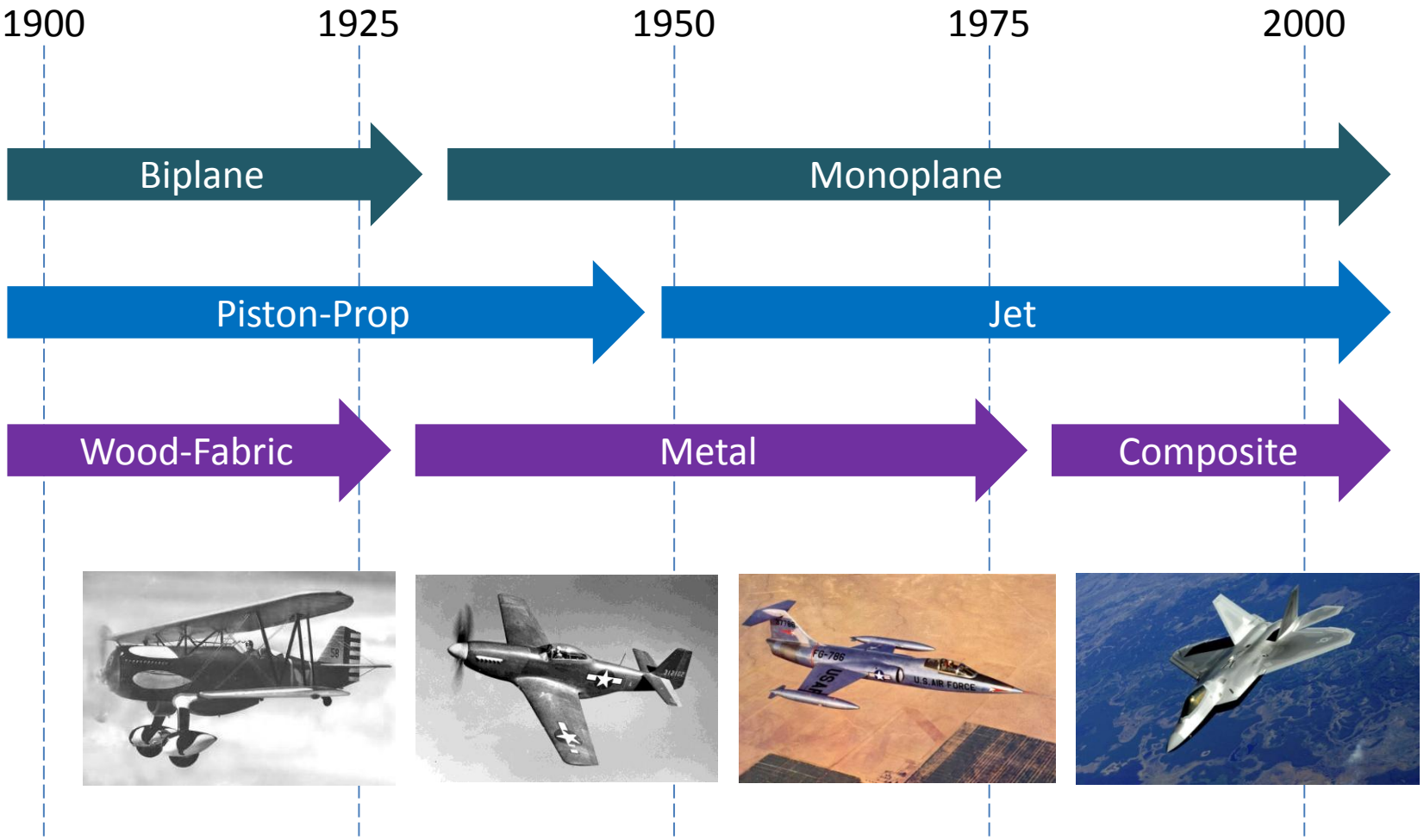
SAWE Southwest Regional Conference

November 12, 2010

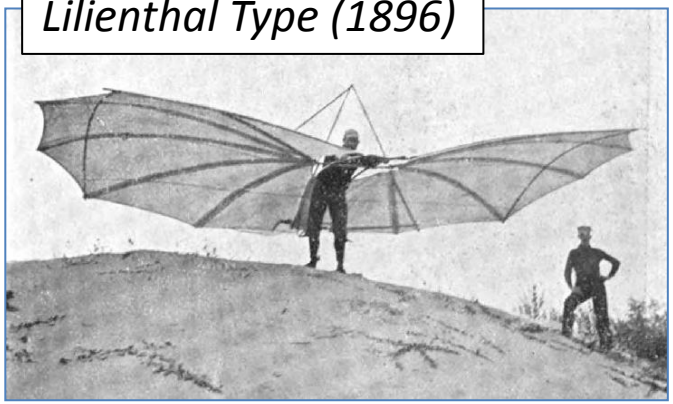
Simplified Timeline of Aviation History



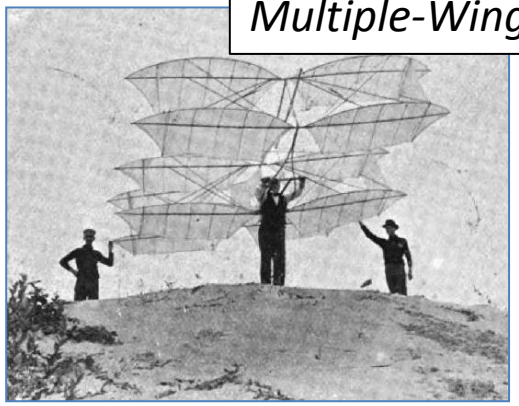
This is only a basic outline – the details are much more complicated!

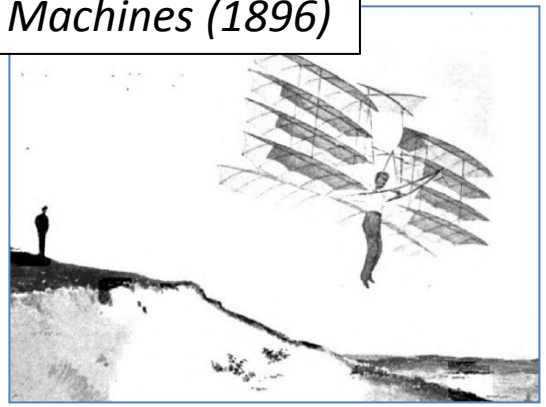
Chanute's Gliders

Lilienthal Type (1896)



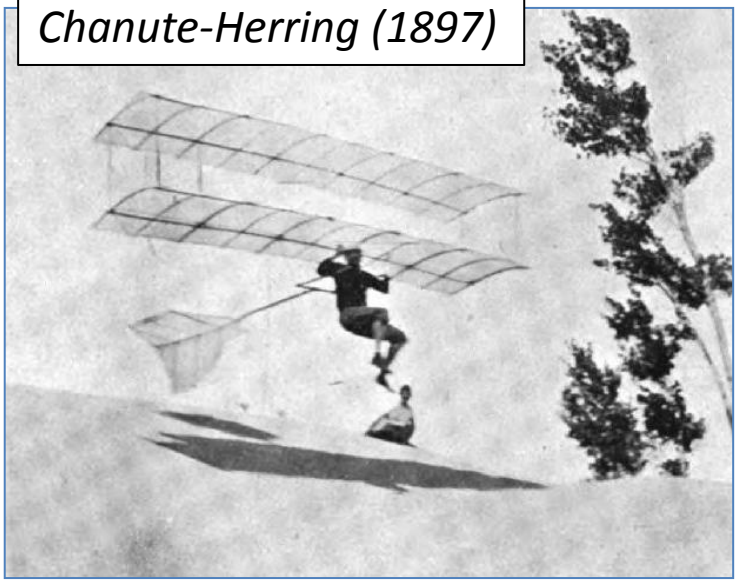
Multiple-Wing Machines (1896)



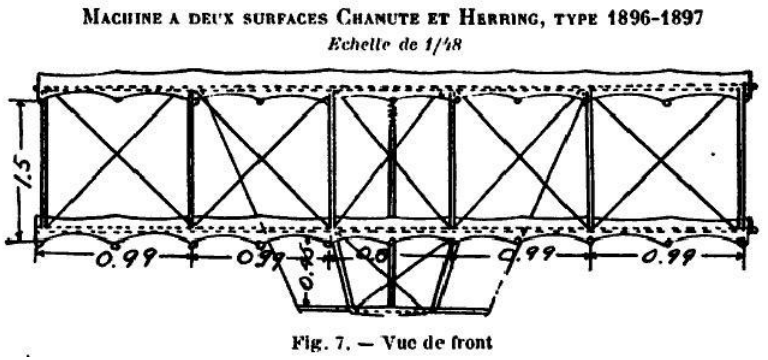


Photos: Gliding Experiments, Octave Chanute, Journal of the Western Society of Engineers, 1897

Chanute-Herring (1897)



Pratt Truss (Front View)



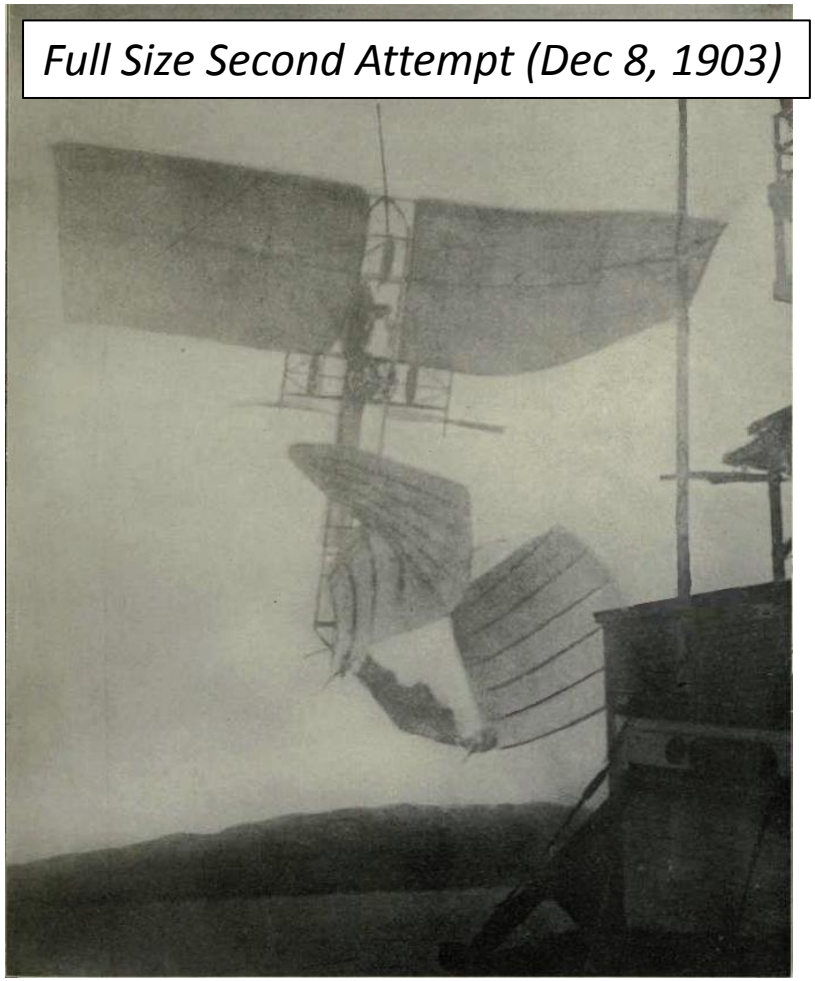
Trussed biplane balanced structural and aerodynamic needs

Langley's Aerodromes

Powered Scale Model (Aug 8, 1903)

Full Size First Attempt (Oct 7, 1903)

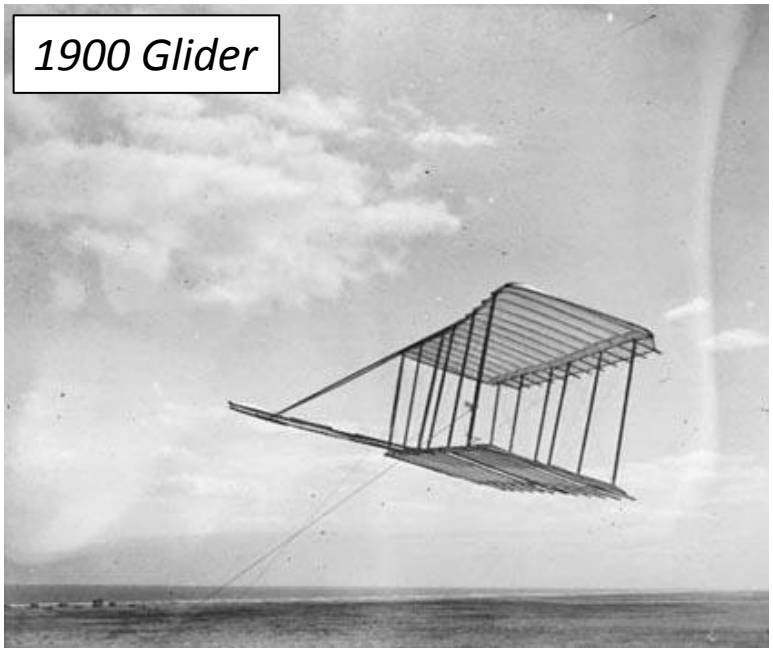
Full Size Second Attempt (Dec 8, 1903)

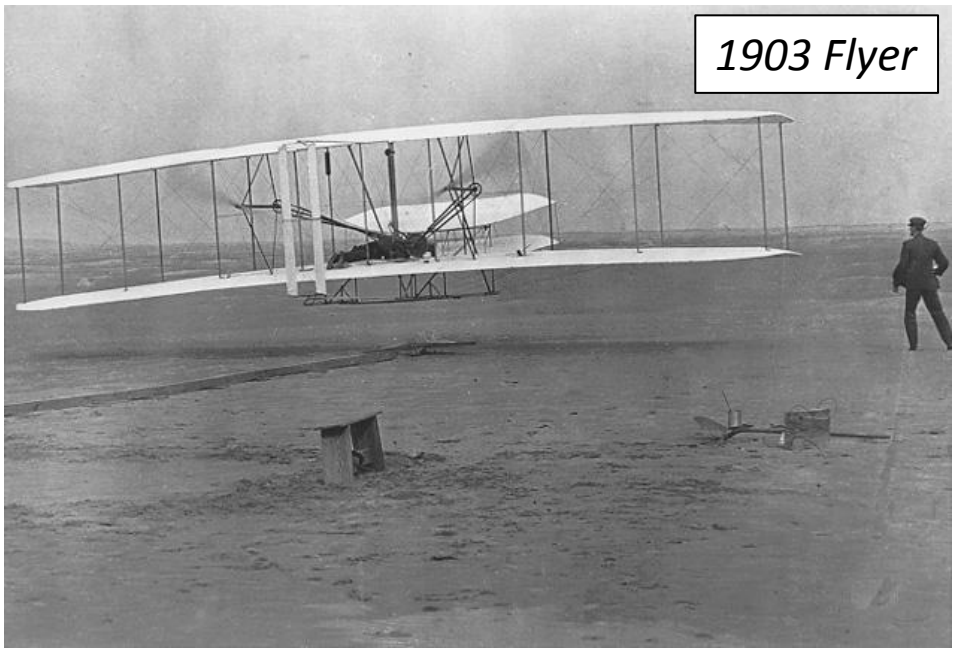


Structural weakness contributed to Langley's failures

Photos: Langley Memoir on Mechanical Flight, Smithsonian, 1911

Wright Brothers





Quotes from *The Papers of Wilbur and Orville Wright*:

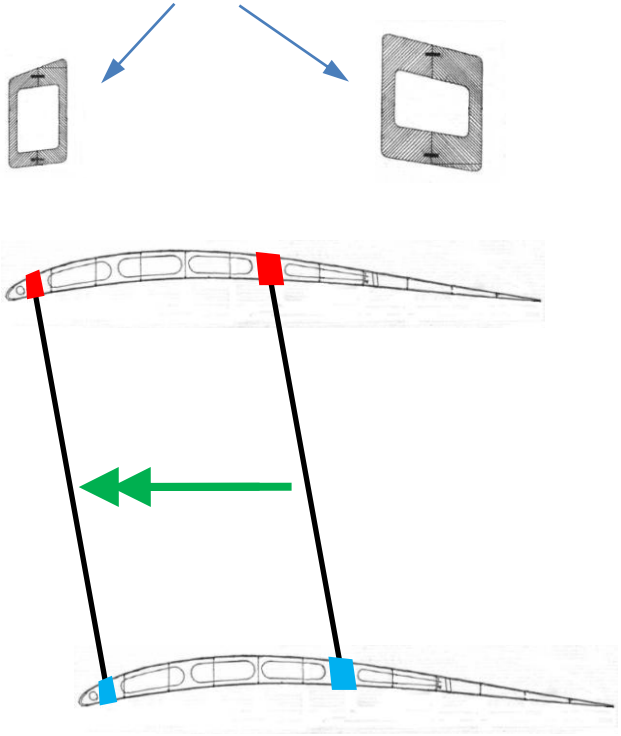
(Sep. 23, 1900) I am constructing my machine to sustain about five times my weight and am testing every piece.

(Dec. 2, 1903) We hung it on its wing tips some days ago and loaded the front set of trussing to more than six times its regular strain in the air.

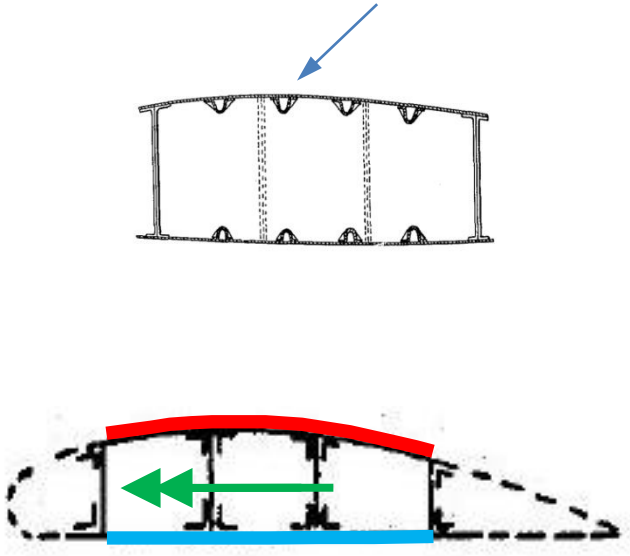
Photos: www.ascho.wpafb.af.mil

Wing Structure & Airfoils

Stocky wood sections



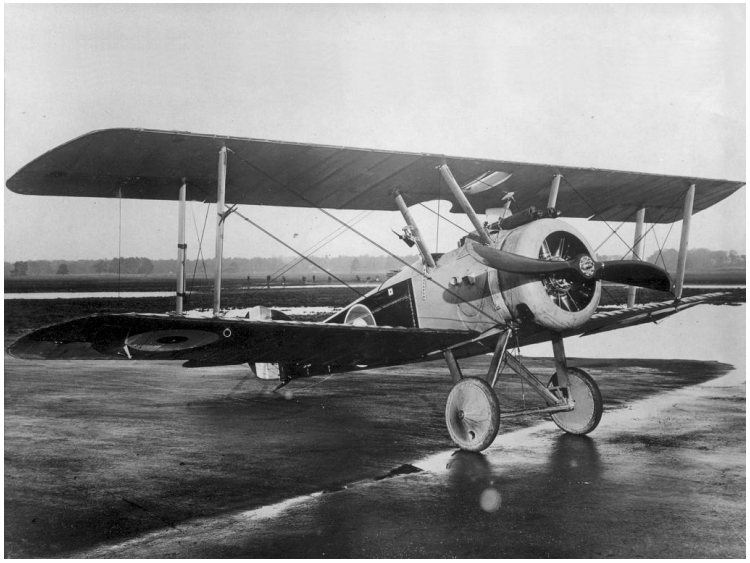
Thin metal skins with stiffeners



BIPLANE
Lent themselves to thin early airfoils

MONOPLANE
Required thicker airfoils for strength

Wooden Biplane Dominant



Wing Structure

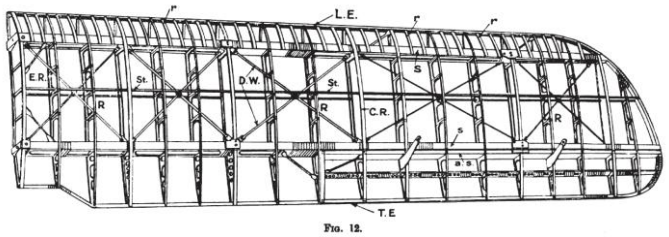


Fig. 12.

Fuselage Structure

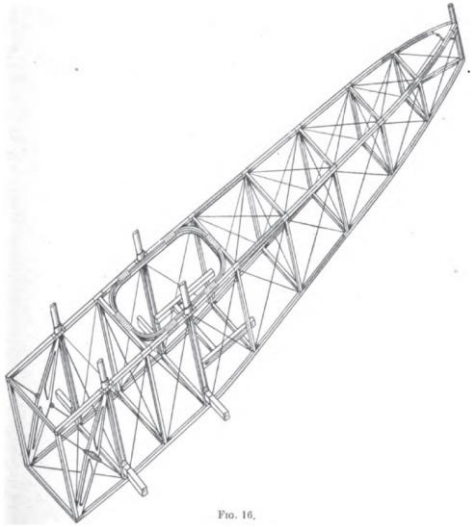
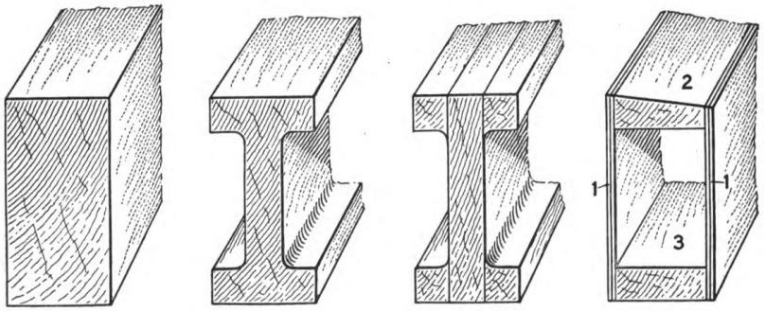


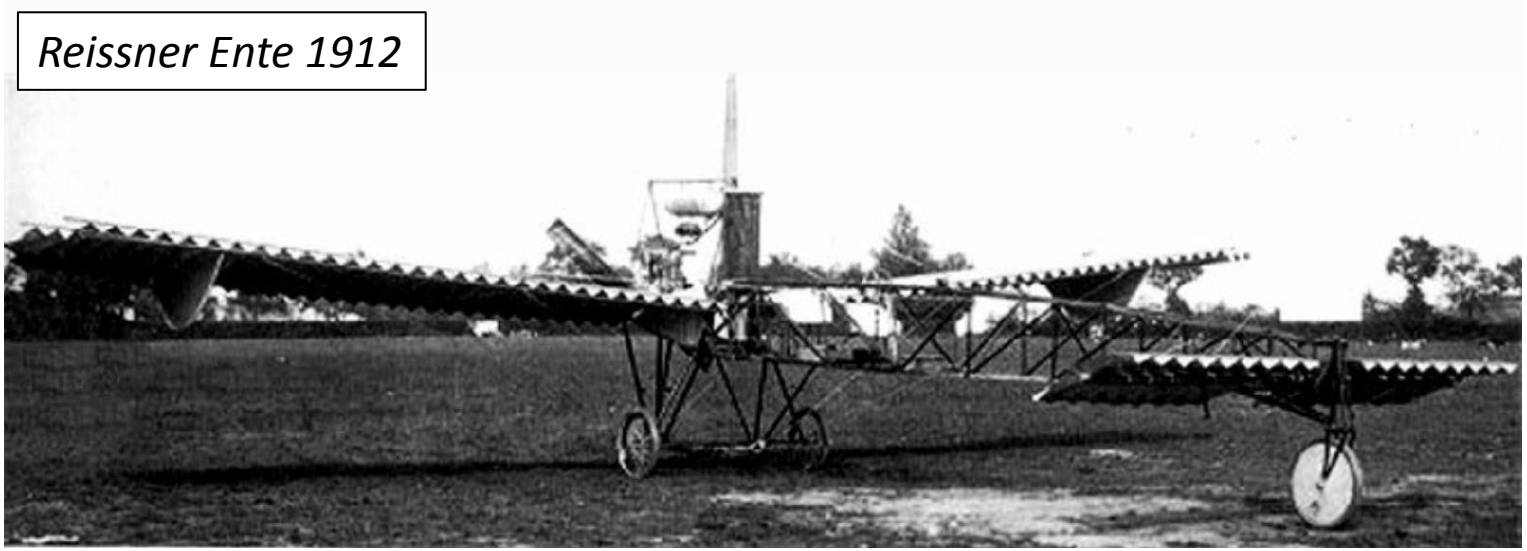
Fig. 16.

Typical Wood Spars

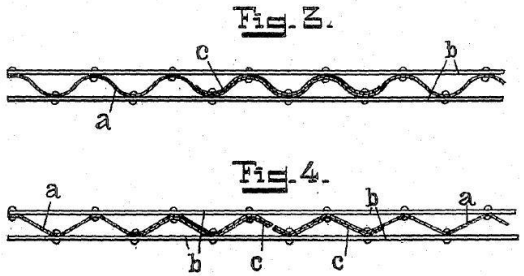


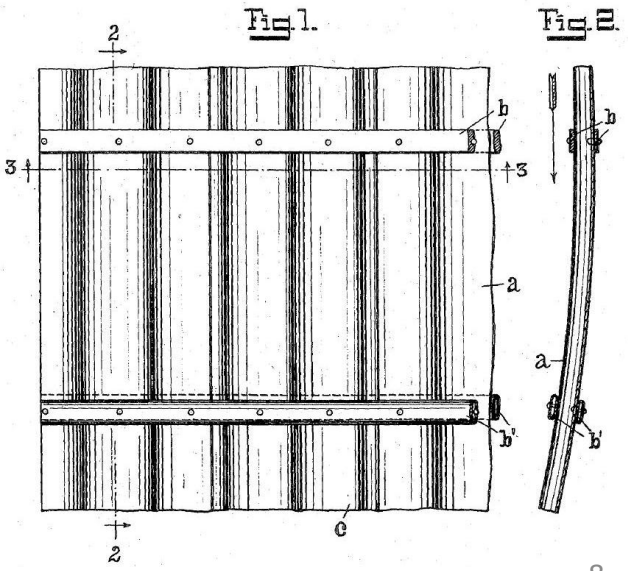
Early German All-Metal Aircraft

Reissner Ente 1912



Reissner Patent 1910

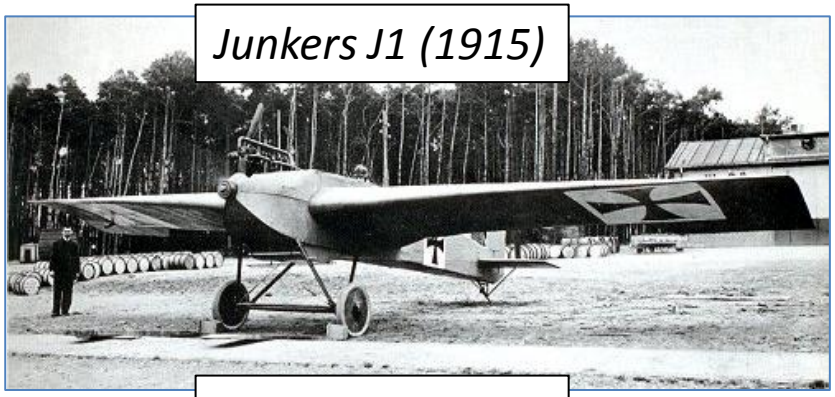




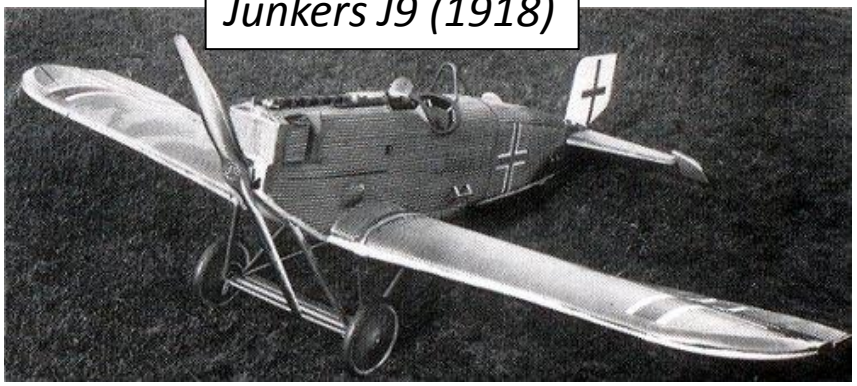
Metal aircraft construction was experimented with even before World War One

Junkers Metal Aircraft

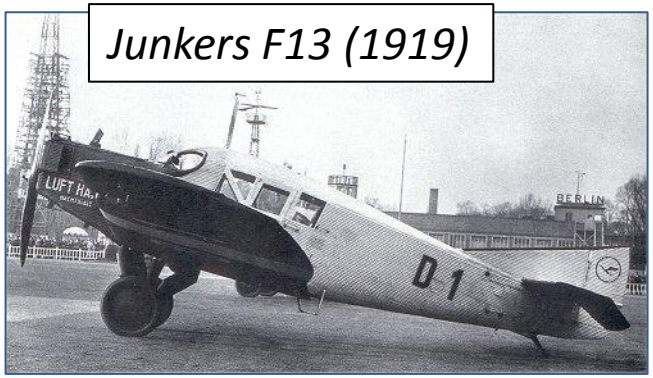
Junkers J1 (1915)



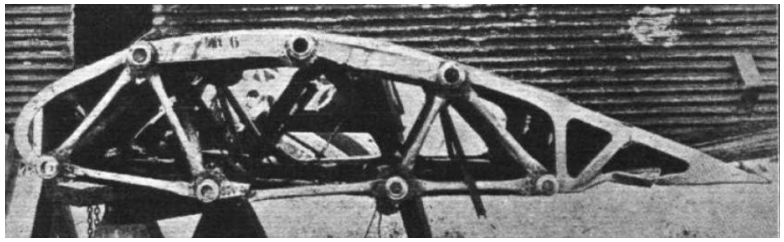
Junkers J9 (1918)

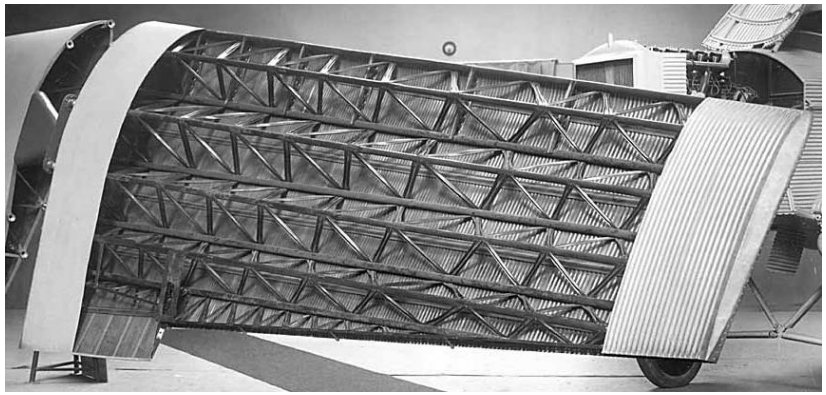


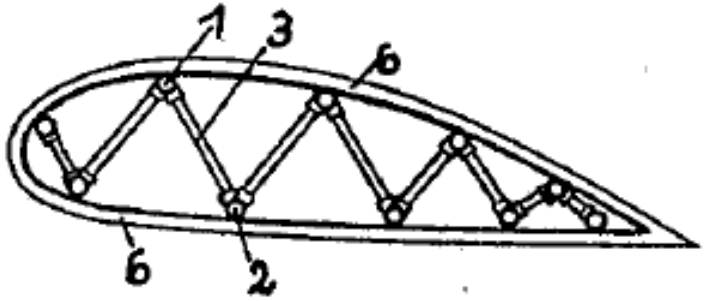
Junkers F13 (1919)



http://www.junkers.de.vu/

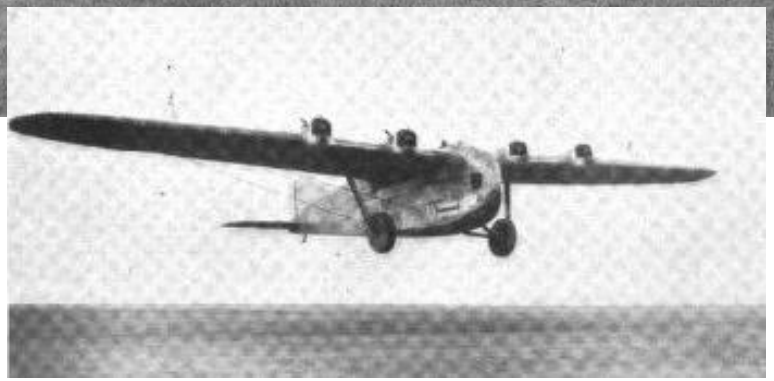


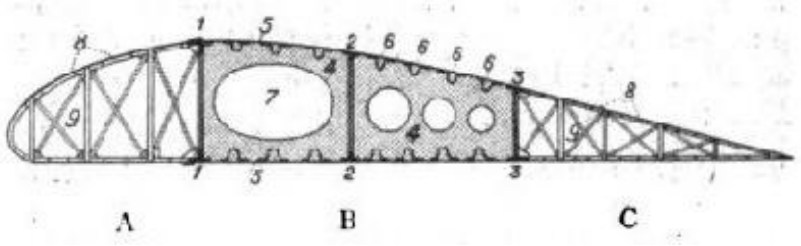




Rohrbach Metal Aircraft

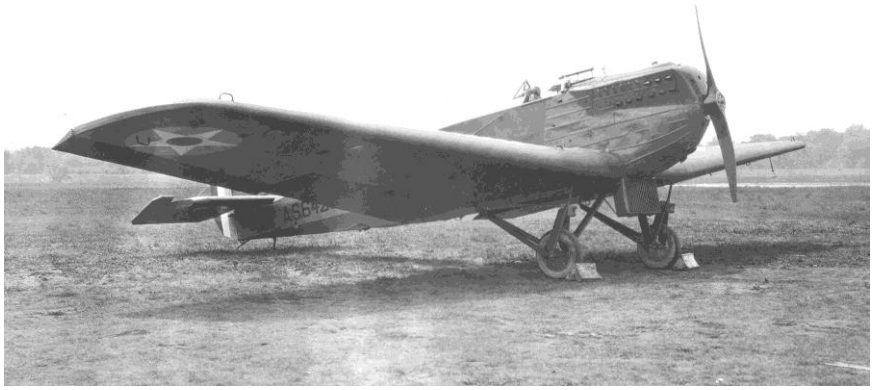
Zeppelin-Staaken (Rohrbach) E.4/20 (1920)





Gallaudet DB-1

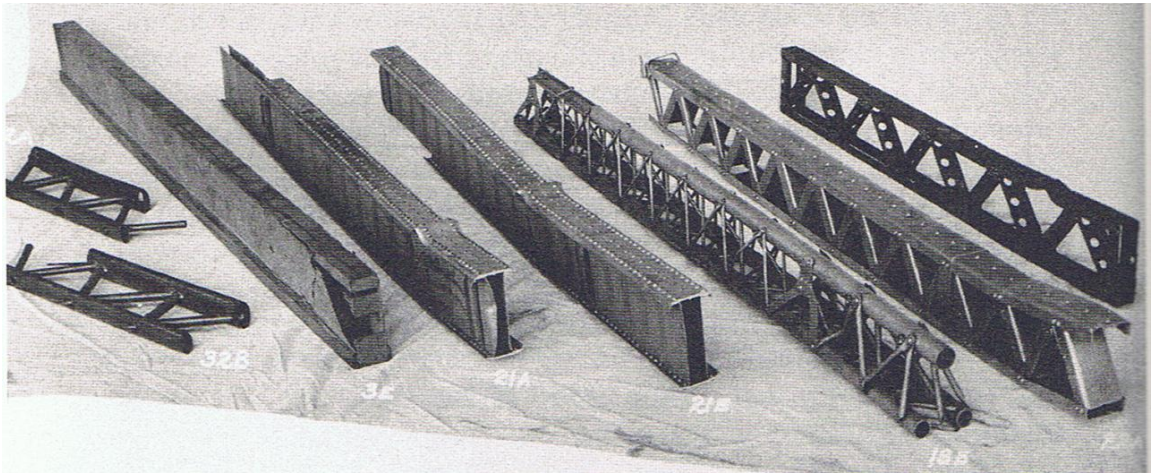
Photos: www.nationalmuseum.af.mil



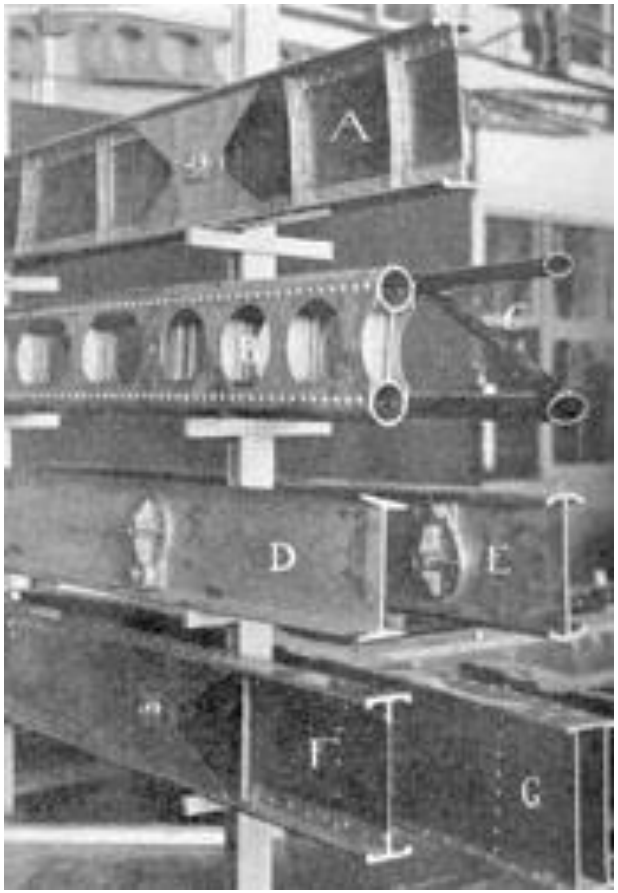
- Experimental Day Bomber (1920-23)
  - Over weight (5969 vs. 3800 lbs)
  - Under strength (overly flexible, local buckling)
  - Over cost

Immature design methods for light metal structures

Metal Spar Tests (1925-27)

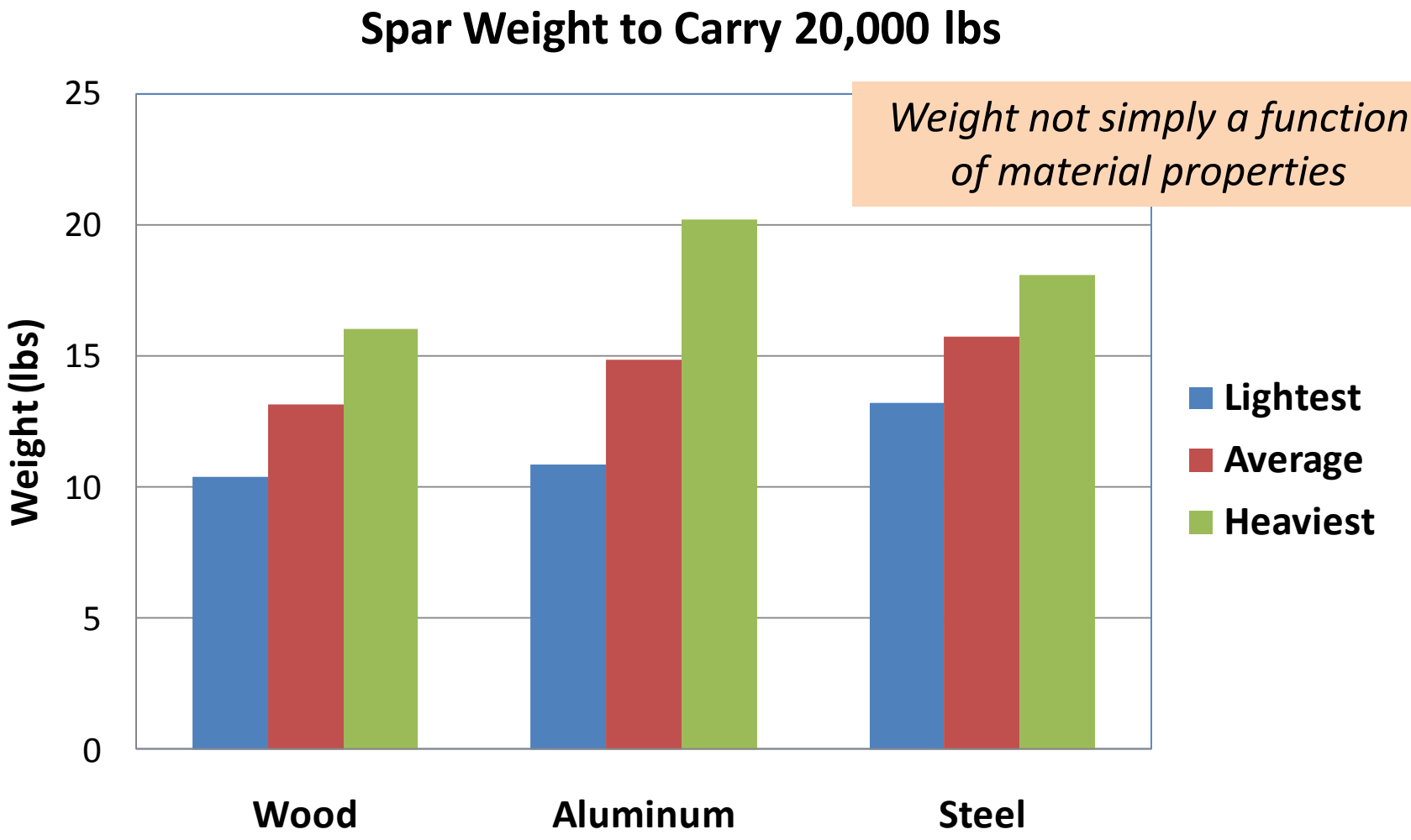


Photos: www.ascho.wpafb.af.mil



- U. S. Army Air Corps Test Program
  - Various materials and concepts designed for same loads
  - 15 wood spars
  - 42 aluminum spars
  - 8 steel spars

Spar Test Results



Significant variation between designs of the same material

TWA Flight 599

New York Times Headlines from 1931

(Apr 1) KNUTE ROCKNE DIES WITH SEVEN OTHERS IN MAIL PLANE DIVE; Ship's Engine Fails Above the Clouds, Wing Rips Off, Craft Falls on Kansas Farm.

(May 5) GOVERNMENT BANS 35 FOKKER PLANES; They Cannot Be Used to Carry Passengers Until After a Rigid Inspection.

(May 9) FOKKER PLANES PUT TO GOVERNMENT TEST; Field Inspectors Delve Into Wing Structure of the 35 Disputed Machines.

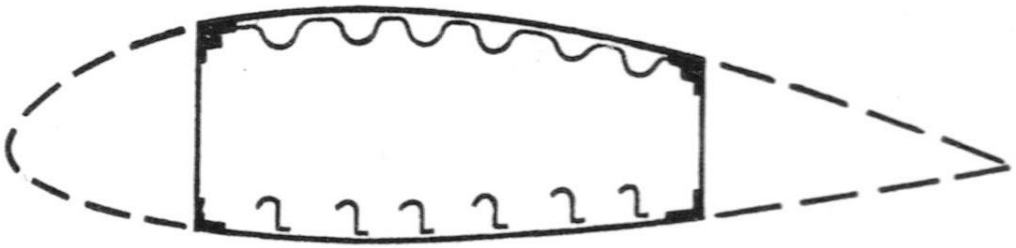
Fokker F-10A Transport

Although not the primary reason for the incident, the discovery of deterioration of glued wing joints led to a loss of confidence in this model specifically, as well as wood construction generally.

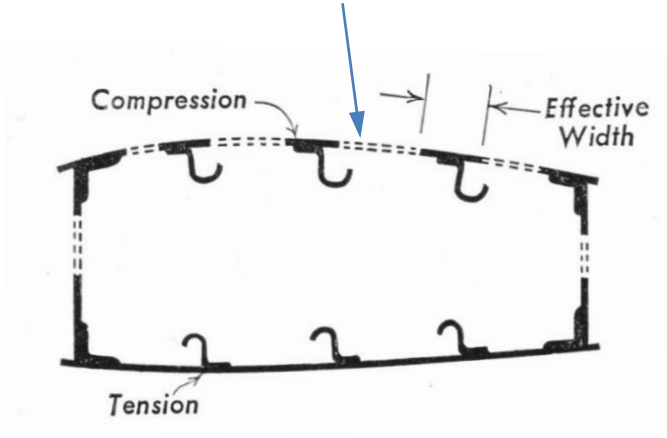
Convinced many that time for wood aircraft was over

Local Buckling & Diagonal Tension

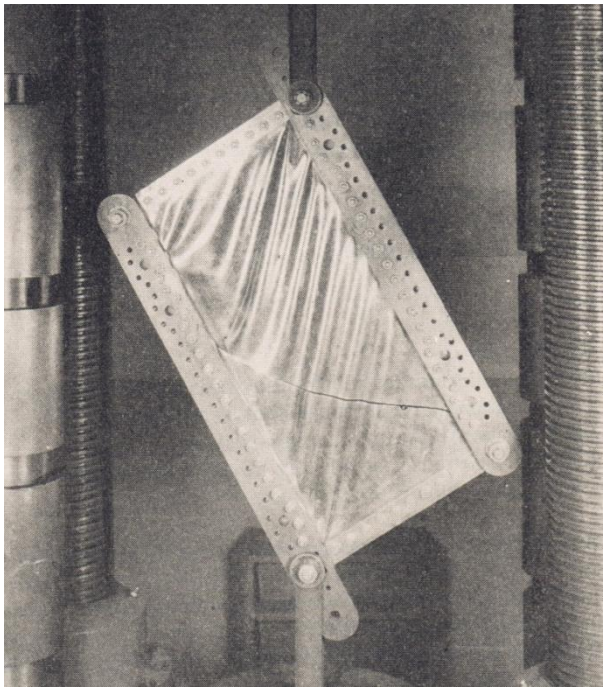
Wing Box Cover

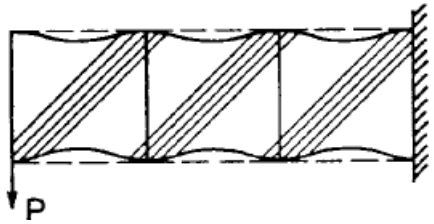


Compression buckling of skin between stiffeners



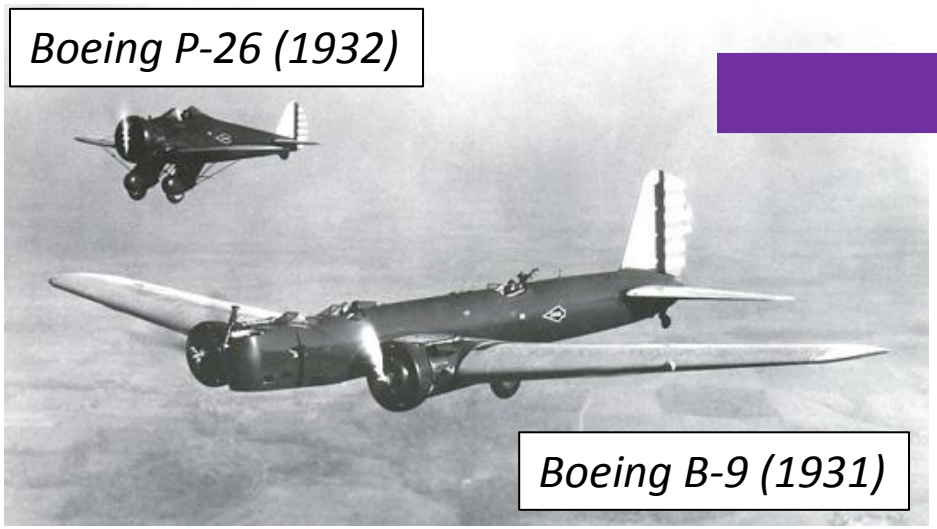
Shear Web





Postbuckling design allowed lighter weight metal structures

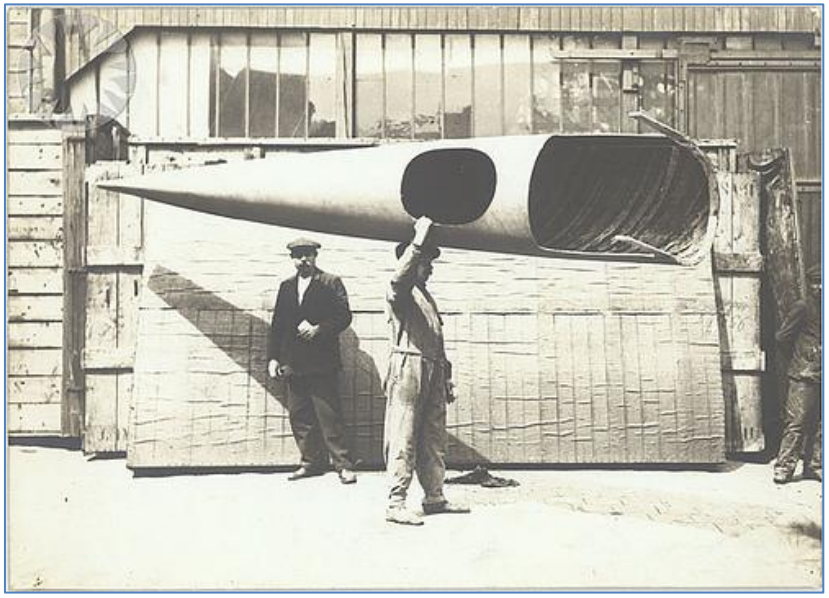
Boeing & Douglas Metal Airliners



Photos: www.ascho.wpafb.af.mil

Photos: www.nasm.si.edu

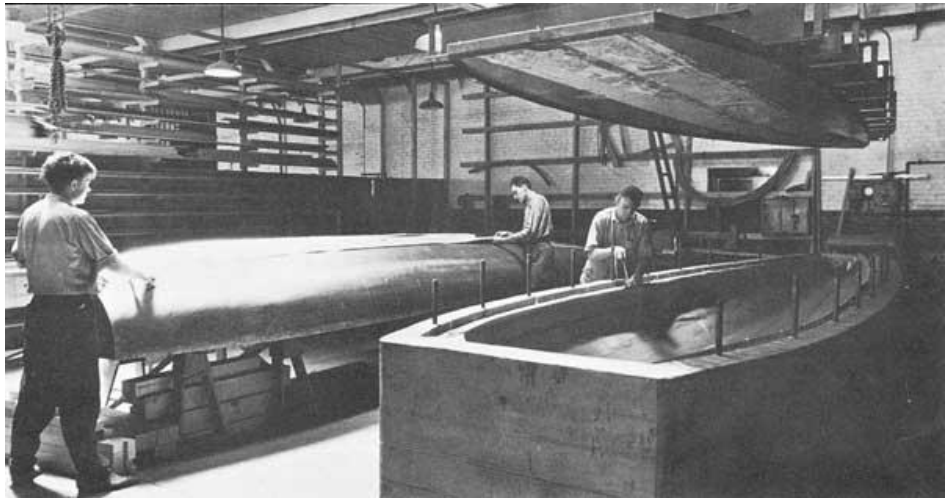
Other Options…

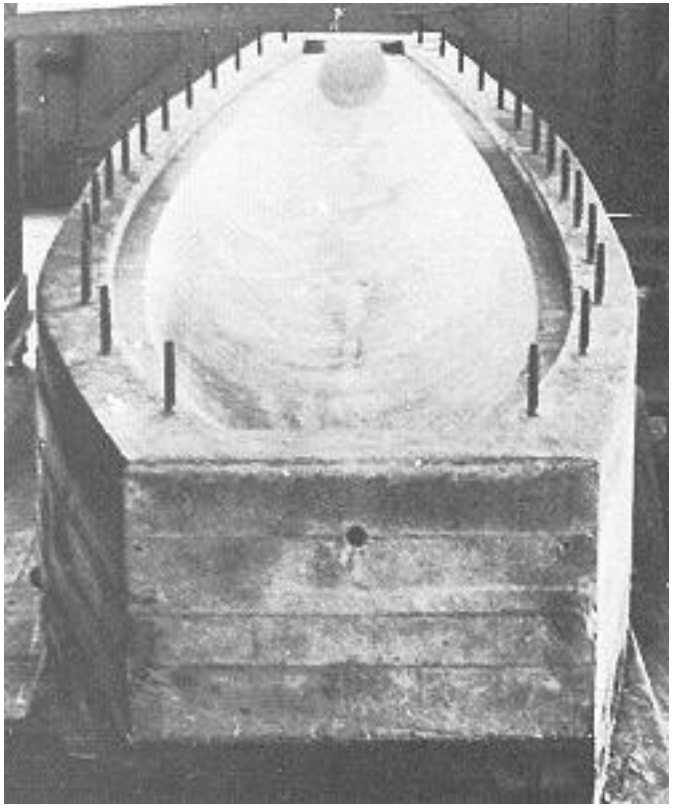


- Deperdussin Racer (1912-13)
  - Streamlined monocoque shell built from 3 layers of wood veneer
  - Fastest airplane of its day (100 mph 1912, 126 mph 1913)

Thin layers of molded wood rather than fabric covered "sticks" & wires

Loughead S-1 Sport Biplane (1920)

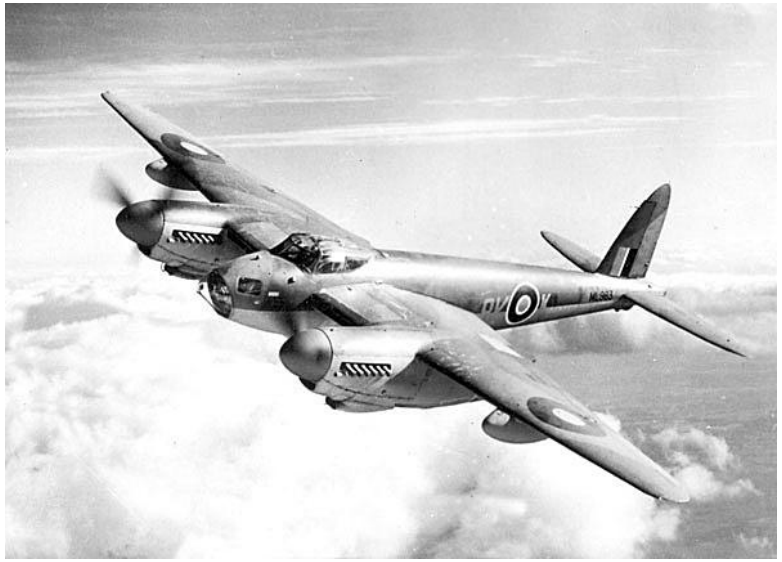


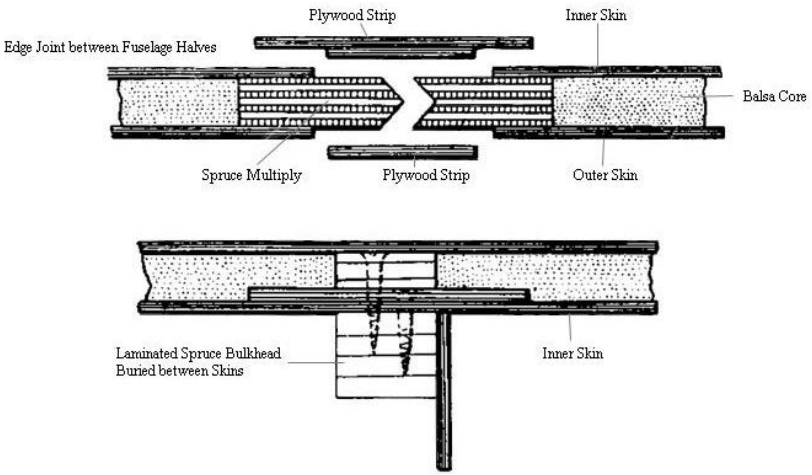


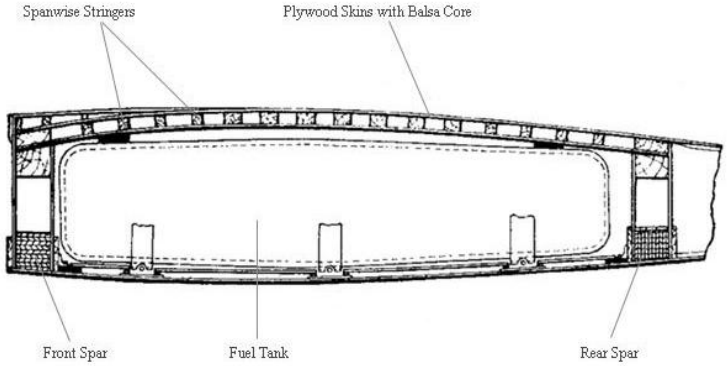
Patent: *Process of Manufacturing Curved Forms of Plywood or Fibrous Compositions,*
Malcolm Loughead, Allen H. Loughead,
John K. Northrop, Anthony Stadlman

Similar process later used in famous Lockheed Vega

DeHavilland Mosquito (1940)







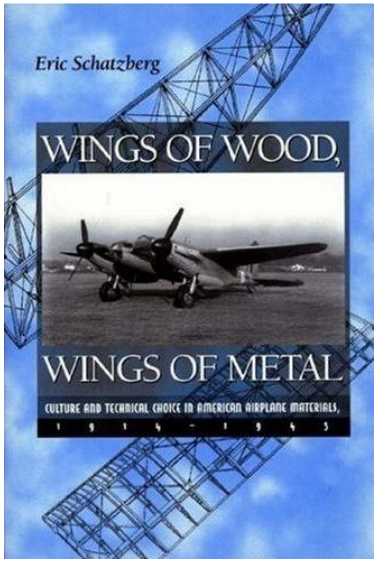
Highly successful wood airplane, while most were metal

Conclusions

- History is often presented as a logical series of events; reality is more complex
- Minimum weight structure depends on more than simply material selection (e.g. design efficiency & fabrication quality)
- Metal aircraft structures were not instant success; persistent experimentation was required to understand unique failure modes & develop new design methods
- The wood → metal transition has some similarities to the ongoing metal → composite transition (topic for another talk…?)

References

1. Wings of Wood, Wings of Metal: Culture and Technical Choice in American Airplane Materials 1914-1945, Eric Schatzberg, Princeton University Press, 1999
2. History of Flight Vehicle Structures 1903-1990, D. Paul & D. Pratt, Journal of Aircraft, Vol. 41, No. 5, 2004
3. Wood to Metal: The Structural Origins of the Modern Airplane, Peter L. Jakab, Journal of Aircraft, Vol. 36, No. 6, 1999



Thank you!