Aircraft Structures

Part 1 Full size aircraft

Part 2 Miniature aircraft

Bill Kuhlman

Aircraft Structures, Part 2

Miniature aircraft

Part 2 Topics

- From full size to model aircraft
- Loads on model aircraft
- Scaling structural loads
- Traditional model aircraft construction
- Composite model aircraft construction
- Scale sailplanes
- Non-scale high performance sailplanes
- Model aircraft special structural problems

Section 1

From full size to model aircraft

Types of miniature aircraft

Scale: Scaled reproduction of a full size aircraft

- Attempts to reproduce full-size geometry
- Attempts to reproduce appearance
- May reproduce construction

Non-scale: Open design for a specific task or tasks

- Structure optimized for its actual mission
- Geometry may be aerodynamically optimized
- Construction may have little resemblance to full-size aircraft



Schneider Grunau 4



Vladimir’s Models Supra Pro

What Must the Structure Do?

1. Support aerodynamic loads
2. Accomodate control system loads
3. Resist maneuver and gust loads
4. Resist torsion
5. Maintain aerodynamic shape
6. Survive vibration and fatigue
7. Support concentrated masses
8. Transmit landing loads

And...

Do all of those things at minimum practical mass.

The structure is smaller.

The engineering problems are not.

- Loads
- Load paths

- Tension
- Compression
- Shear
- Torsion
- Bending
- Buckling

- Fatigue
- Joints
- Materials
- Structural efficiency

Full size aircraft load paths:

Aerodynamic loads
> flying surfaces
> attachment points (wing carry-through)
> fuselage

Miniature aircraft load paths:

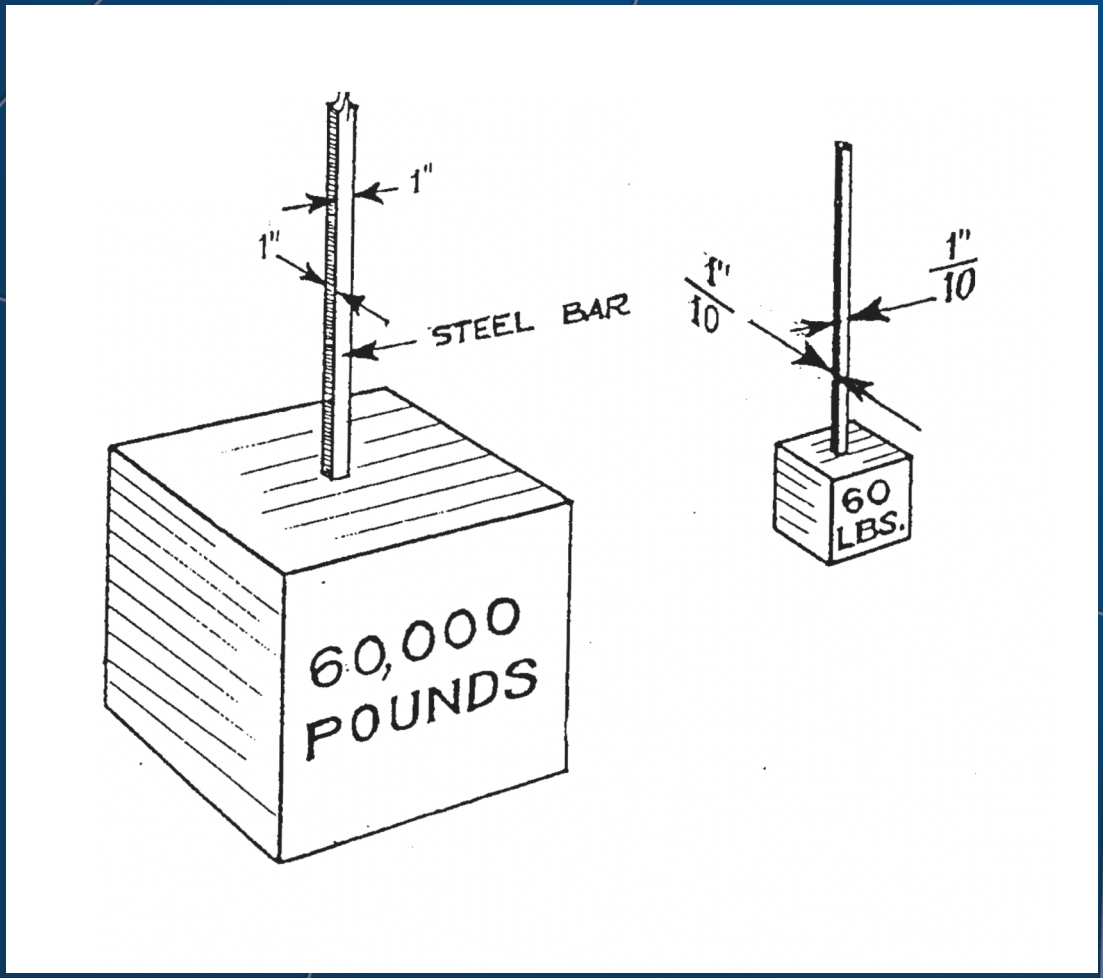
Aerodynamic loads
> flying surfaces
> attachment points (wing carry-through)
> fuselage

Central Theme

An aircraft is designed and constructed as an integrated load-management system.

The same structural principles apply to model aircraft, but scale does not reproduce those principles, it adapts them.

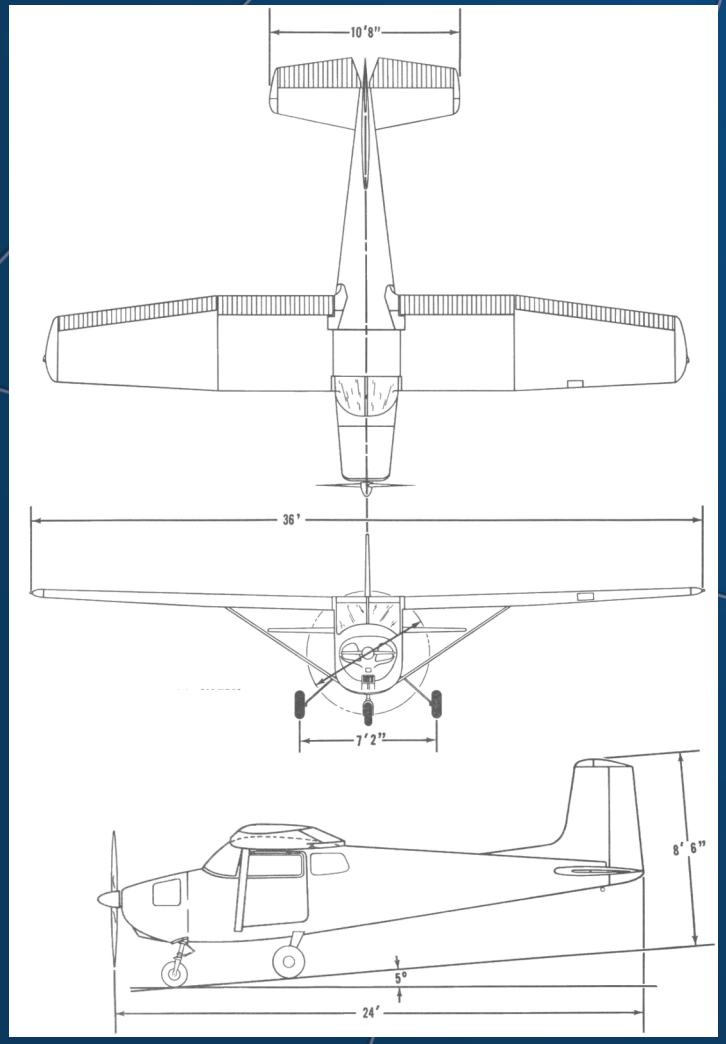
Scale effects



For 1:10 scale

- Length > L/10
- Area > S/100
- Weight > W/1000

Scale Cessna 172



	1:1	1:4
Span	36’	9’
Area	175 ft^2	10.9 ft^2
Av. chord	4.9’	1.2’
Length	25’	6.25’
Height	8.5’	2.125’
Weight	2200 lbs	34.4 lbs

But…

- Aerodynamic loading does not necessarily scale as L^3
- Acceleration, maneuvering loads and landing loads remain severe

Three types of scale

Geometric scale
- Does it look like the full-size aircraft?

Aerodynamic scale
- Does it operate at comparable Reynolds number?

Structural scale
- Do stresses, deflections, stiffness and failure modes scale proportionally?

Section 2

Loads on model aircraft

Loads Acting on a Model Aircraft

FORCES

- Lift
- Weight
- Drag
- Thrust
- Aerodynamic moments
- Inertial moments

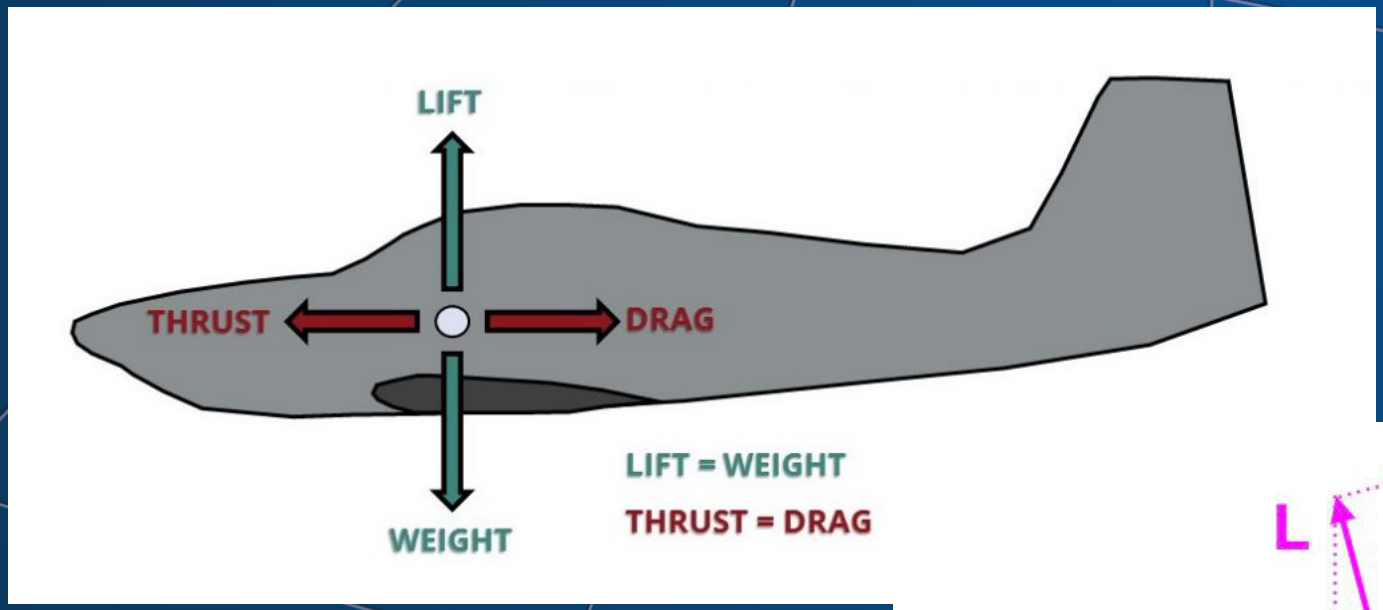
STRESSES

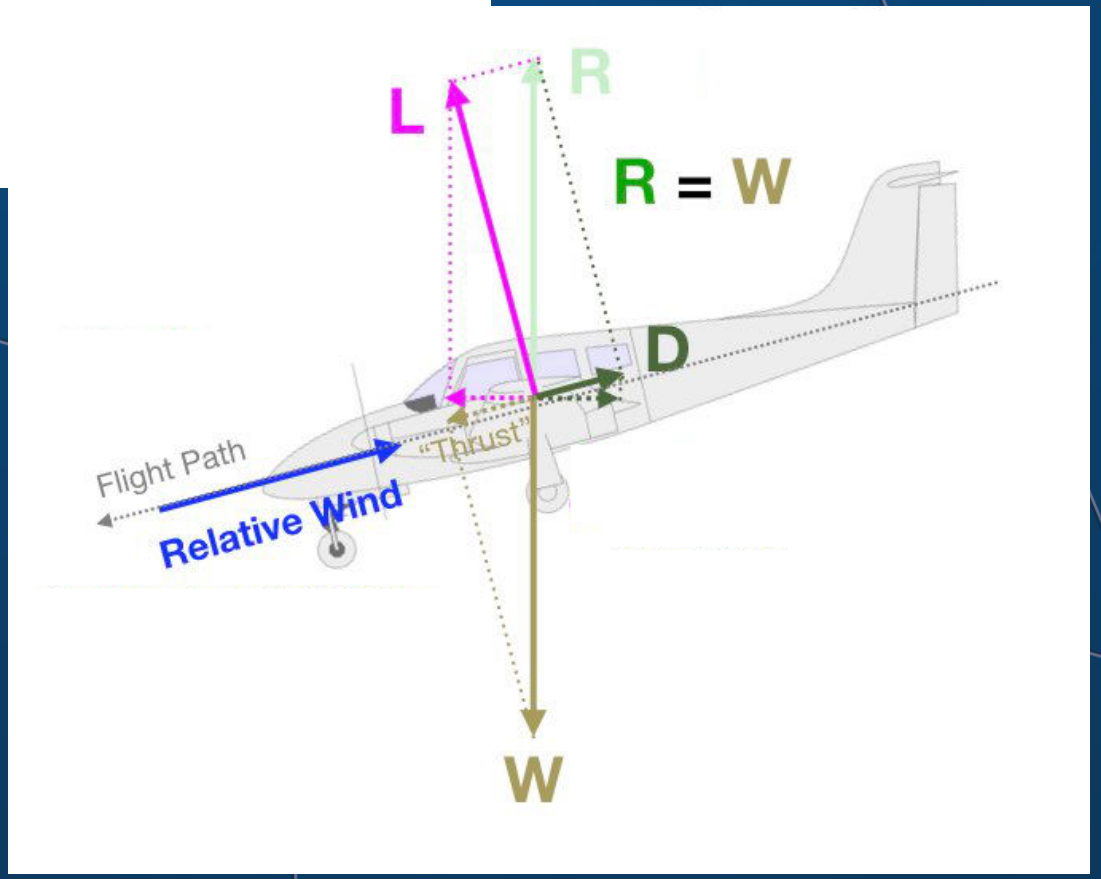
- Tension
- Compression
- Bending
- Shear
- Torsion

Loads Acting on a Model Aircraft

FORCES

- Lift
- Weight
- Drag
- Thrust
- Inertial moments
- Aerodynamic moments


LIFT
THRUST
DRAG
WEIGHT
LIFT = WEIGHT
THRUST = DRAG


L
R
R = W
D
"Thrust"
Flight Path
Relative Wind
W

1. INITIAL BALANCE (Static Equilibrium)

A teeter-totter (massless) is balanced by positioning the fulcrum so that the torques (moments) about the fulcrum are equal.

BALANCE CONDITION:

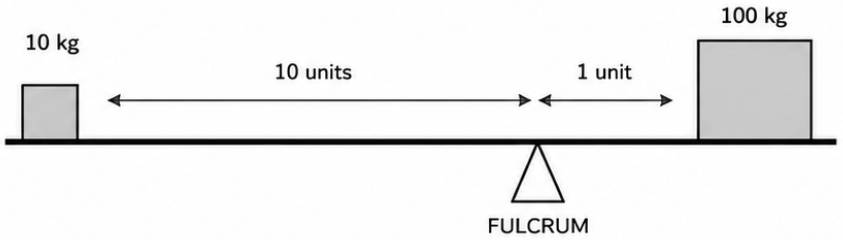
$$m_1 \cdot d_1 = m_2 \cdot d_2$$

where:

m_1, m_2 = masses on each side (kg)

d_1, d_2 = perpendicular distances from fulcrum to each mass (units)

(massless teeter-totter)



Example:	Check:	
$m_1 = 10$ kg, $d_1 = 10$ units	$m_1 \cdot d_1 = 10 \cdot 10 = 100$	⇒ Balanced
$m_2 = 100$ kg, $d_2 = 1$ unit	$m_2 \cdot d_2 = 100 \cdot 1 = 100$	

2. MOMENTS OF INERTIA about the Fulcrum

The moment of inertia of a point mass about a pivot (fulcrum) is:

POINT MASS MOMENT OF INERTIA:

$$I = m \cdot r^2$$

where:

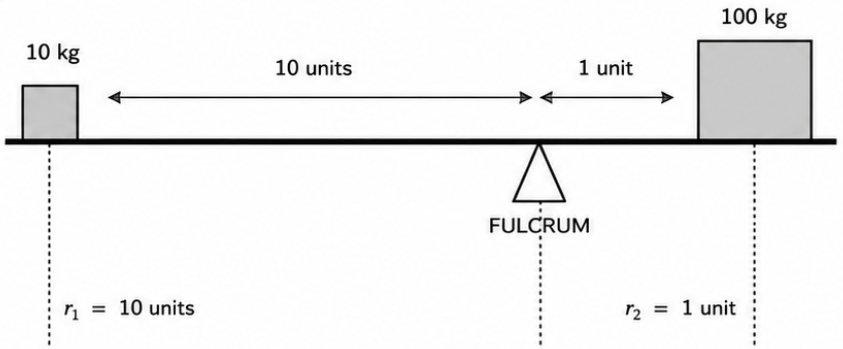
I = moment of inertia (kg·units^2)

m = mass (kg)

r = perpendicular distance from fulcrum to the mass (units)

Total moment of inertia (two masses):

$$I_{total} = m_1 d_1^{\,2} + m_2 d_2^{\,2}$$



Moment of inertia of 10 kg mass:	Moment of inertia of 100 kg mass:	Total moment of inertia:
$I_1 = m_1 r_1^2 = 10 \cdot (10)^2 = 1000$ kg·units^2	$I_2 = m_2 r_2^2 = 100 \cdot (1)^2 = 100$ kg·units^2	$I_{total} = I_1 + I_2 = 1000 + 100 = 1100$ kg·units^2

Moment of inertia for a balanced teeter-totter

Simply...

$$\text{mass}_1 \bullet \text{distance}_1^{\,2} = \text{mass}_2 \bullet \text{distance}_2^{\,2}$$

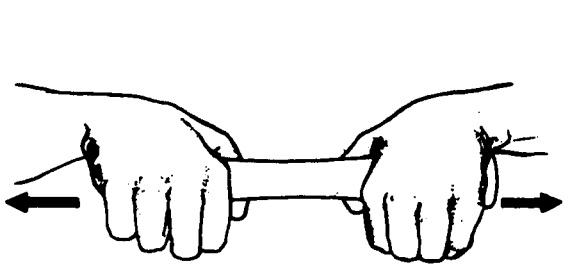
Aerodynamic moments

Moment	Axis	Typical cause	Aircraft effect
Pitching moment	Lateral axis	Wing lift acting at a distance from CG; tail force	Nose-up or nose-down rotation
Rolling moment	Longitudinal axis	Unequal lift between left and right wings; ailerons	Bank/roll
Yawing moment	Vertical axis	Side force from rudder, fin, or asymmetric drag	Nose left/right
Hinge moment	Control-surface hinge axis	Aerodynamic pressure distribution on elevator, aileron, rudder, etc.	Tends to rotate the control surface
Propeller torque reaction	Longitudinal axis	Engine/propeller torque	Aircraft rolls opposite propeller rotation
Adverse yaw	Vertical axis	Differential drag from aileron deflection	Yaws opposite the intended roll

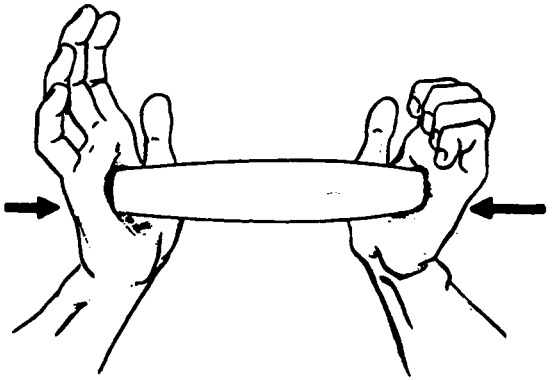
Loads Acting on a Model Aircraft

STRESSES

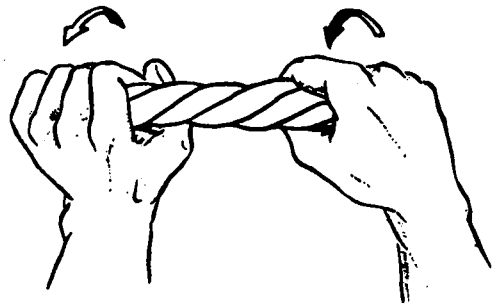
- Tension
- Compression
- Bending
- Shear
- Torsion



(a) Tension



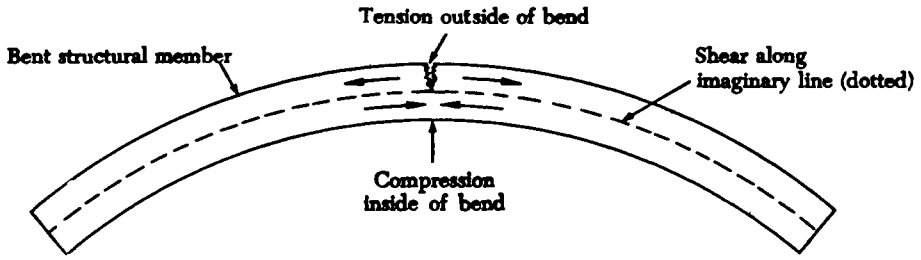
(b) Compression



(c) Torsional

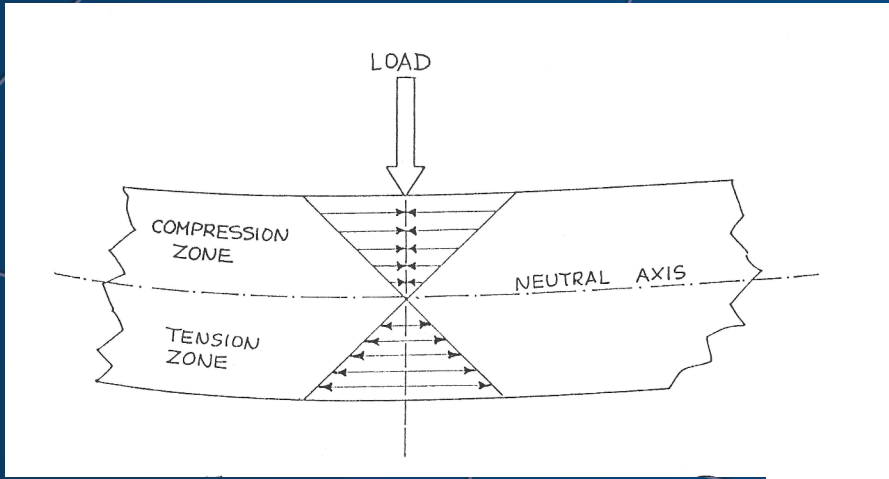


(d) Shear

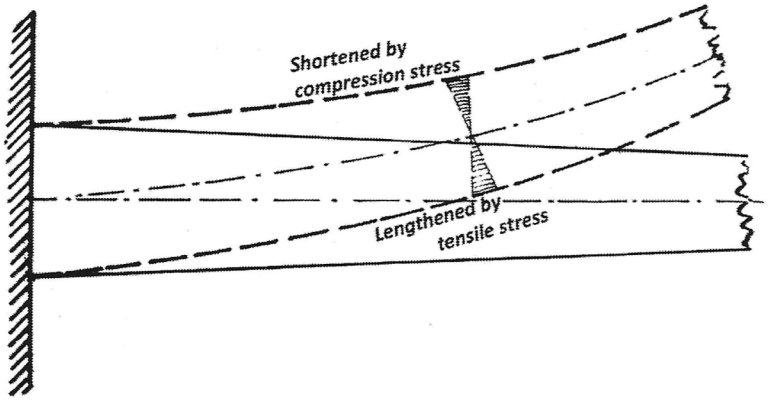


(e) Bending (the combination stress)

Effect of lift on wing bending



Beam bending under load



Wing bending due to lift

Scaling wing loading

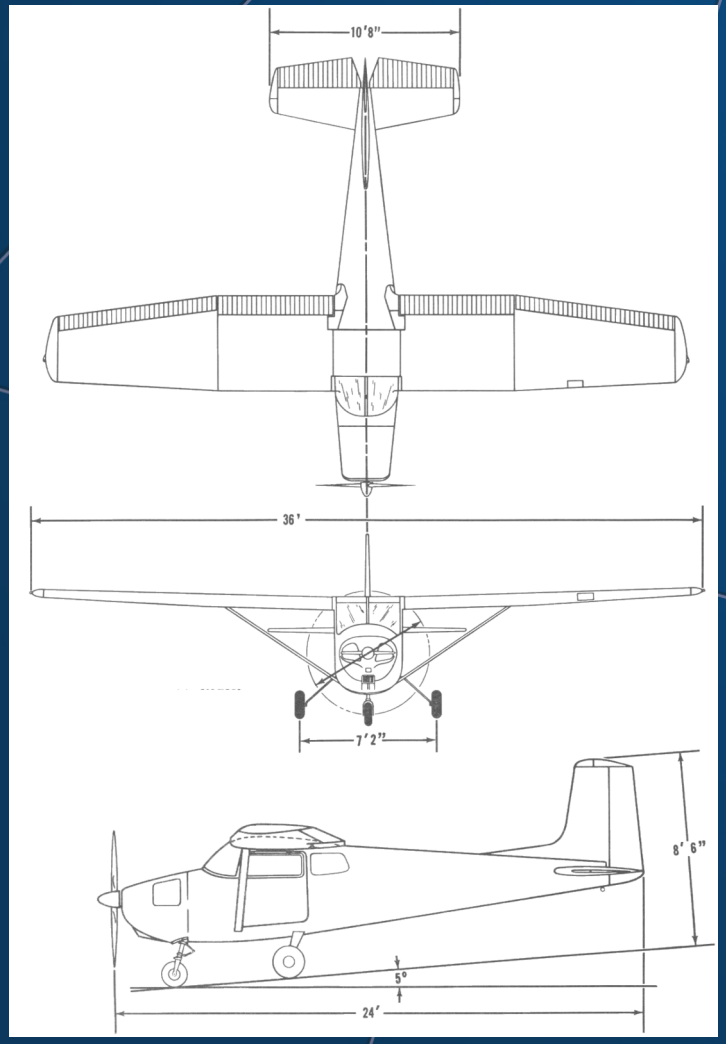
Length (L) => L^1

Area => L^2

Volume (Weight) => L^3

Wing loading => L^3 / L^2

Scale Cessna 172

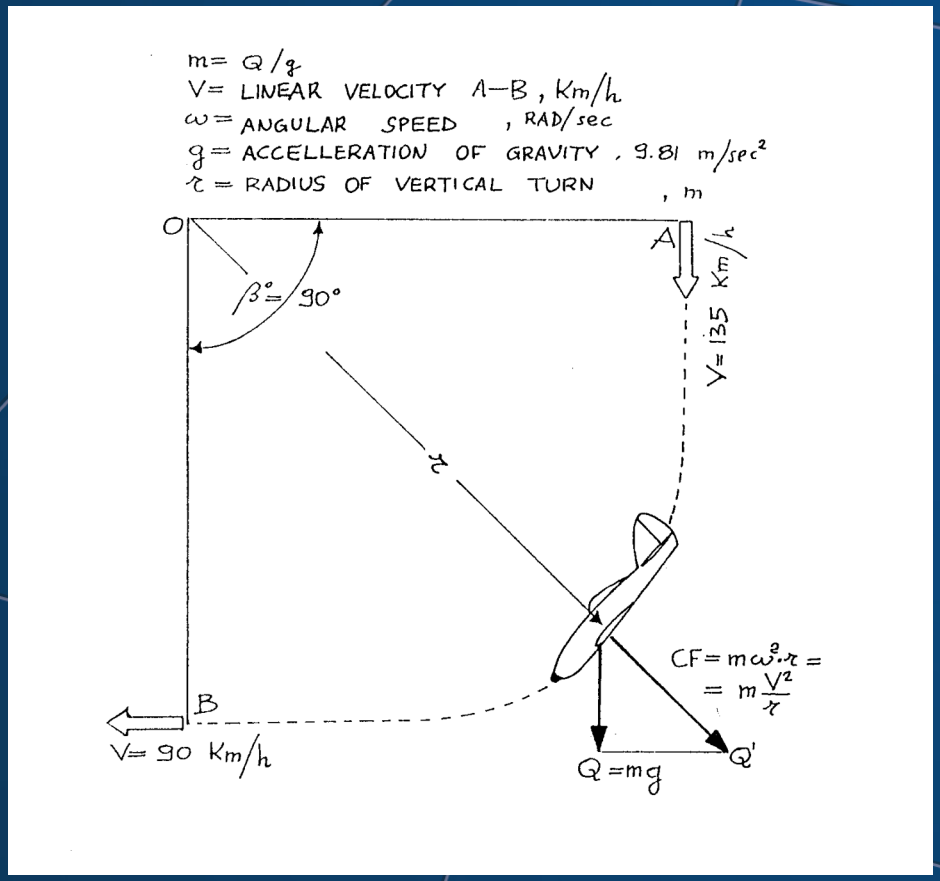


	1:1	1:4
Span	36’	9’
Area	175 ft^2	10.9 ft^2
Av. chord	4.9’	1.2’
Length	25’	6.25’
Height	8.5’	2.125’
Weight	2200 lbs	34.4 lbs
Wing loading	12.6 lbs/ft^2	3.1 lbs/ft^2

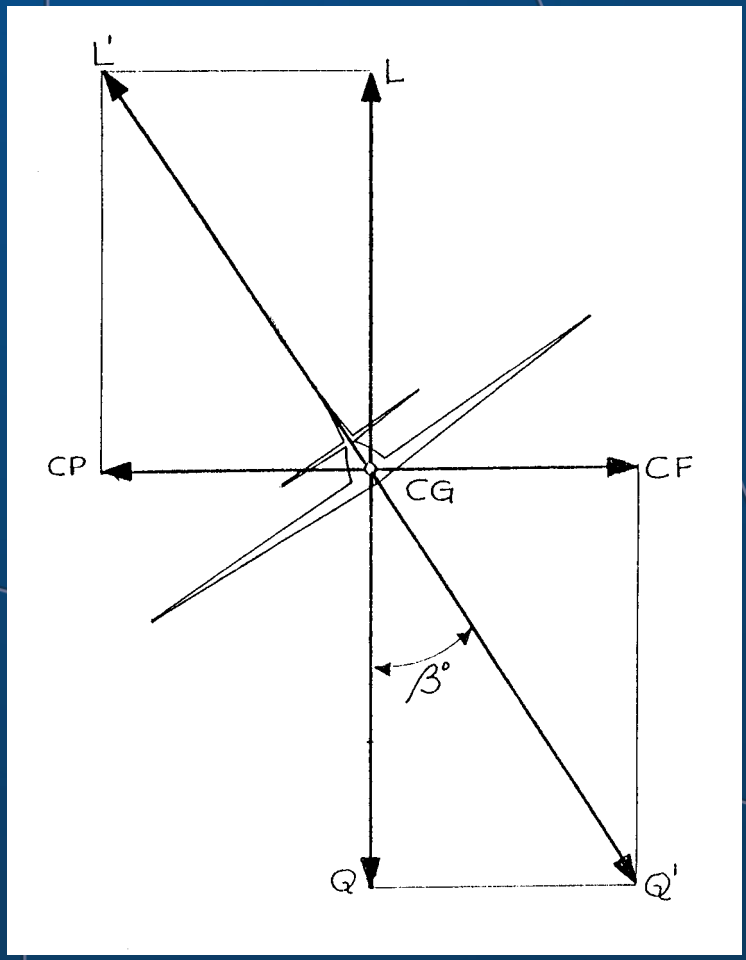
Higher wing loading means...

- Higher flight speed
- Greater loads during maneuvers
- Higher kinetic energy
- Greater landing energy

G loading



Pull-up
Total loading =
n x Weight/Area
Where n = load factor



Coordinated turn
Total loading =
n x Weight/Area
Where n = load factor

Dynamic loads

- Maneuvers
- Flutter
- Landing
- Launching
- Abrupt control movement
- Winch launch
- Hi-start launch
- Dynamic soaring
- Slope racing turns
- Hard landings

The basic load paths

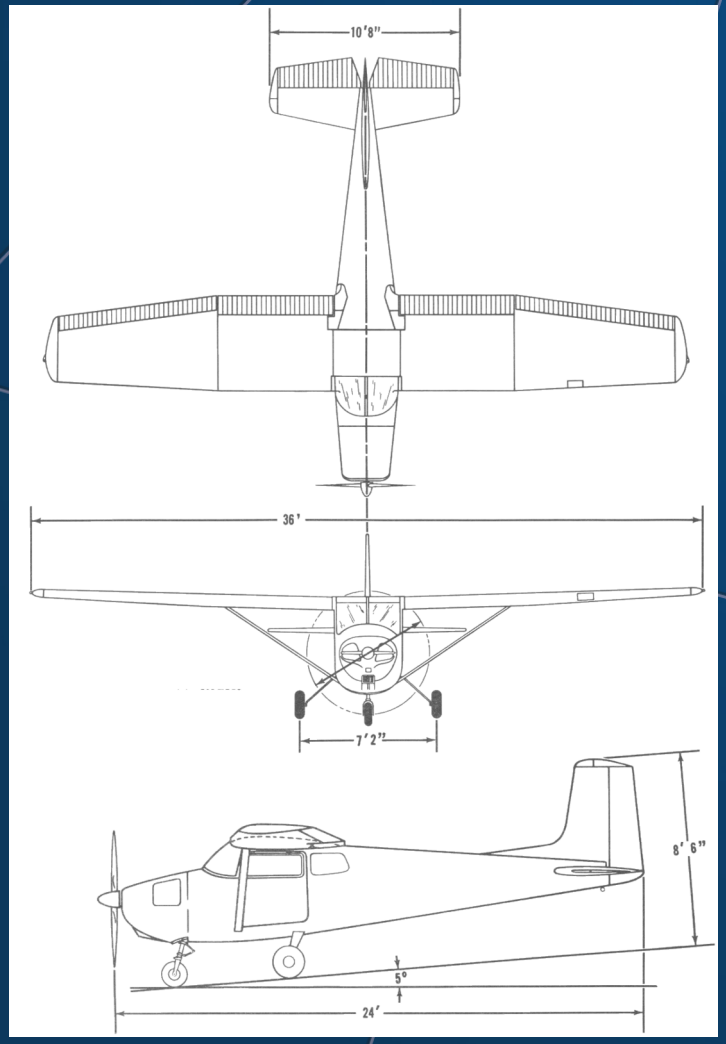
Lift =>
Wing =>
Joiner/Carry-through =>
Fuselage

Ground =>
Wheel/Skid =>
Fuselage =>
Joiner/Carry-through =>
Wings

Section 3

Scaling structural loads

Scale Cessna 172



	1:1	1:4
Span	36’	9’
Area	175 ft^2	10.9 ft^2
Av. chord	4.9’	1.2’
Length	25’	6.25’
Height	8.5’	2.125’
Weight	2200 lbs	34.4 lbs
Wing loading	12.6 lbs/ft^2	3.1 lbs/ft^2
Flying speed	108 kts	54 kts (27 kts)

Structural weight of a model Aircraft

- ¼-size bolts
- ¼-thickness spar caps
- ¼ thickness skins
- ¼ size hinges

- Strong enough?
- Too flexible?

Or

- Too Stiff?
- Unnecessarily heavy?

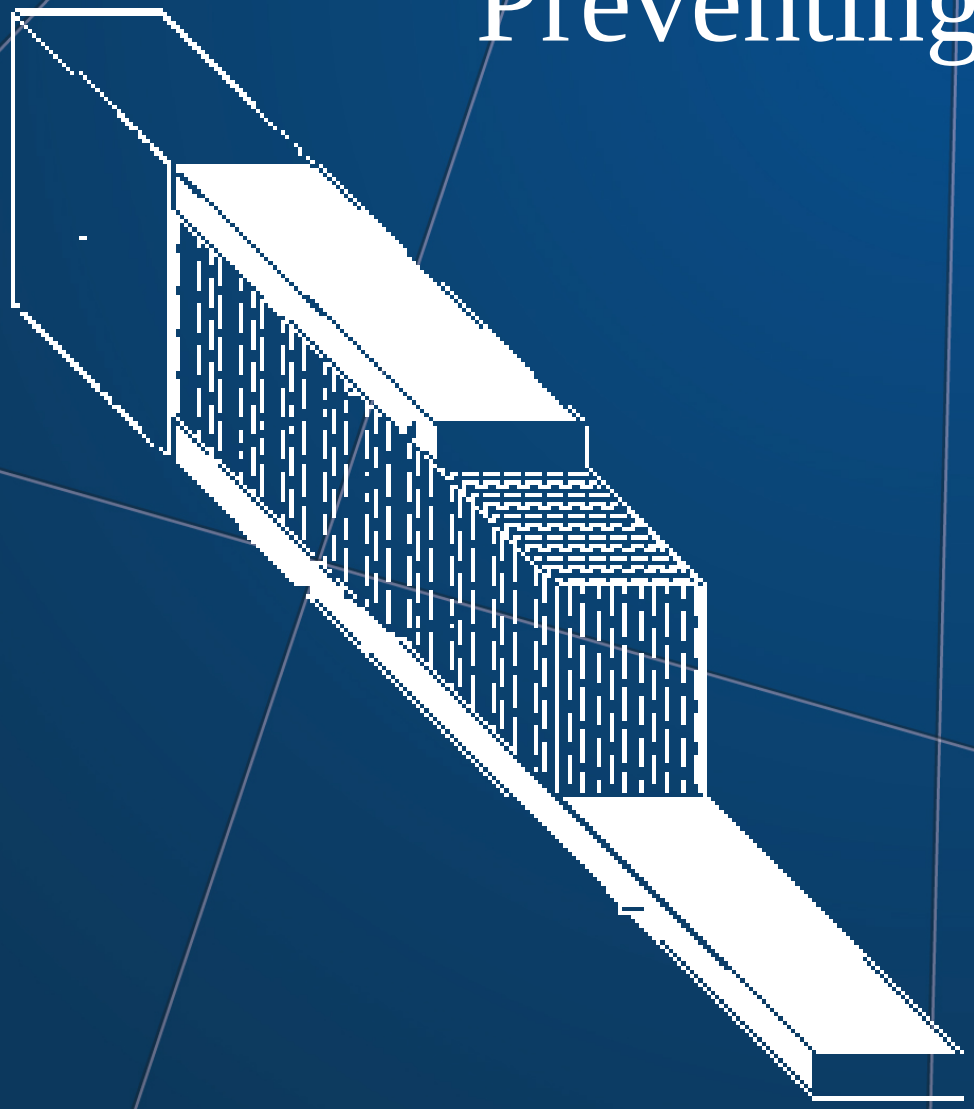
Buckling loads

Euler's critical load

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

As structural dimensions shrink, members become more susceptible to local buckling

Preventing spar buckling



Surface becomes structure

- Covering contributes to torsional stiffness
- Sheeting prevents rib buckling
- Adhesive joints transfer loads
- Composite (“sandwich”) skin contributes to bending stiffness

Covering materials

- Tissue
- Silk
- MonoKote, MicaFilm
- Polyester dress lining
- Plywood
- Fiberglass, Kevlar, carbon fiber
-

Matrix materials

- Dope
- Polyurethane
- Vinyl (Poly-Fiber)
- Polyester resin
- Epoxy resin
- Acrylics
-

Structural scale vs aerodynamic scale

A model that is geometrically scaled

may be structurally different,

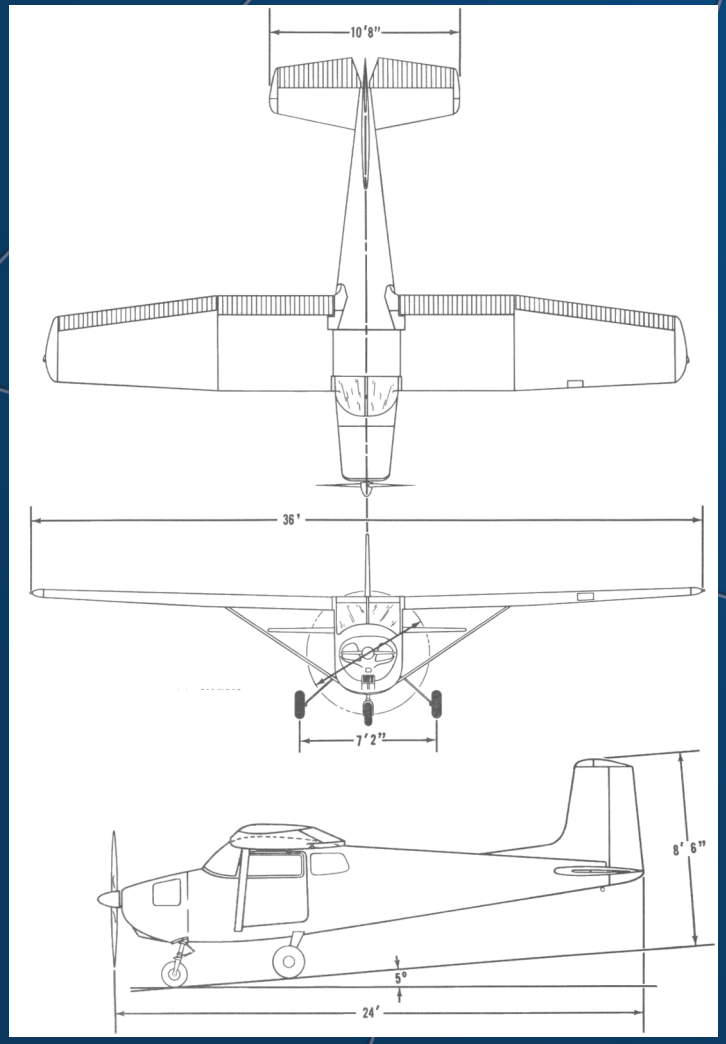
but

it is definitely aerodynamically different

Aerodynamic scale & Reynolds number

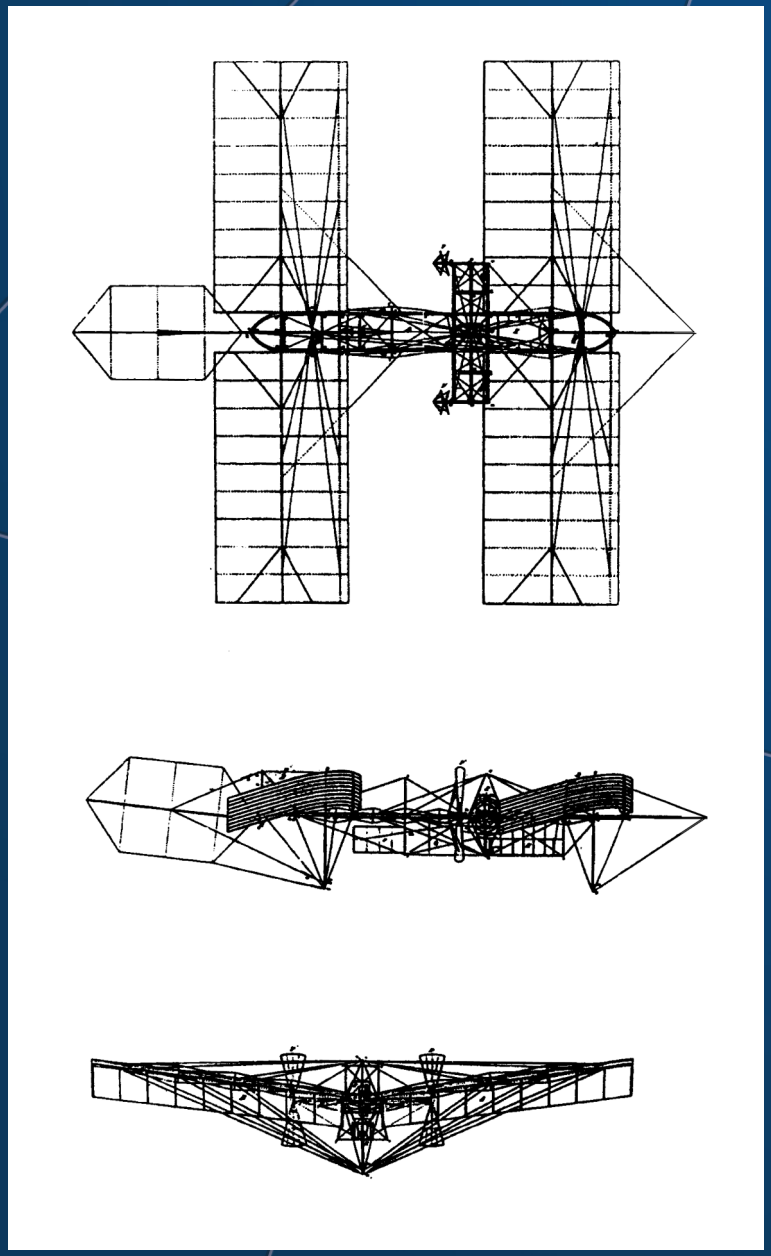
- Different boundary layer
- Different transition behavior
- Different maximum lift coefficient
- Different drag coefficient
- Different stall behavior

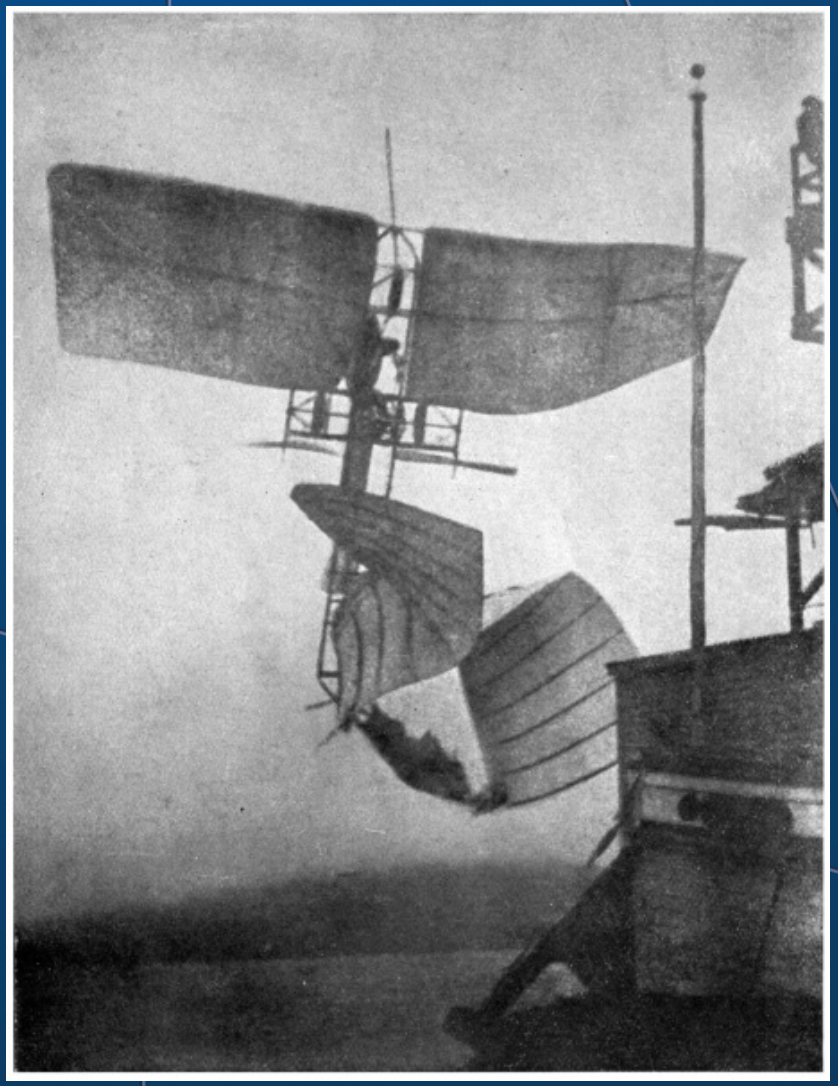
Scale Cessna 172



	1:1	1:4
Weight	2200 lbs	8.6 lbs
Wing loading	12.6 lbs/ft^2	0.78 lbs/ft^2
Cruise speed	108 kts	27 kts
Reynolds number	6200k	390k
Stall speed	43 kts	10.8 kts
Reynolds number	2500k	155k

Samuel Langley *Aerodrome*





Section 4

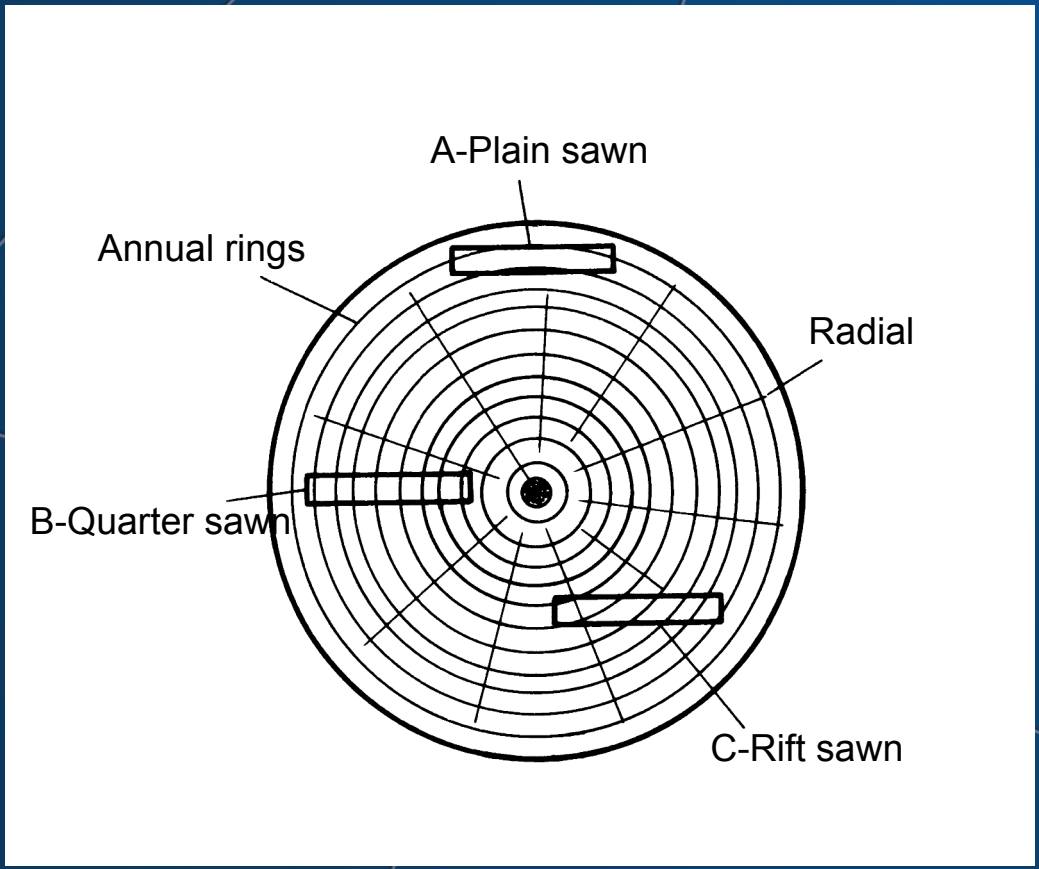
Traditional model aircraft construction

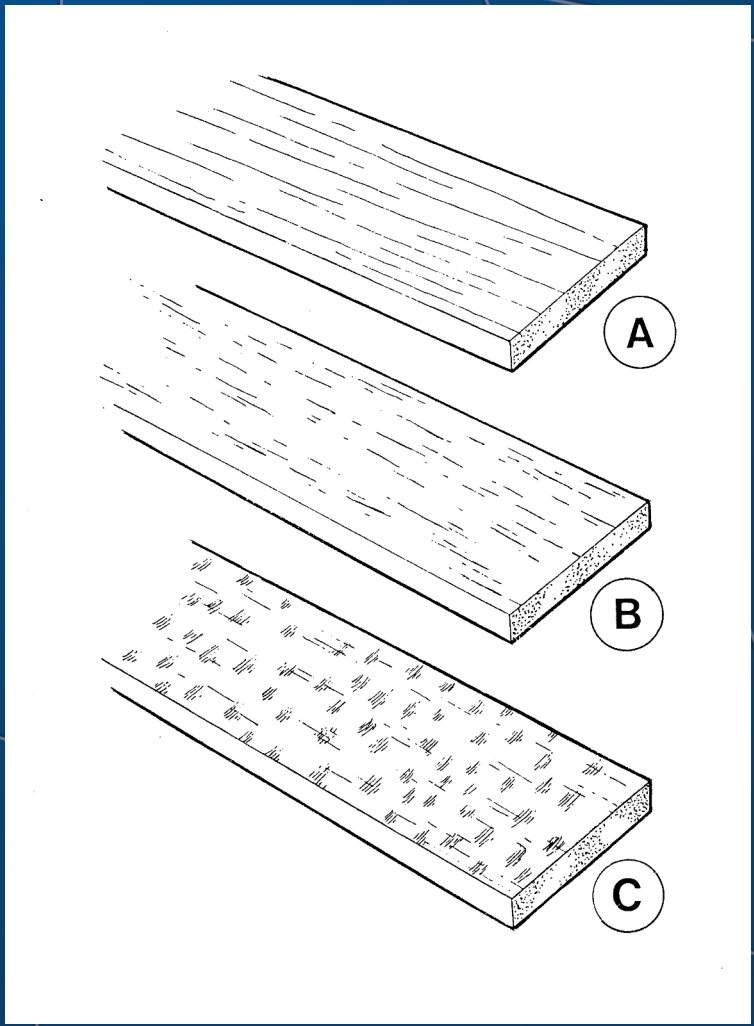
Materials

- Balsa
- Spruce
- Plywood / Lite-ply
- Basswood
- Hardwood
- Wire
- Tissue / film covering

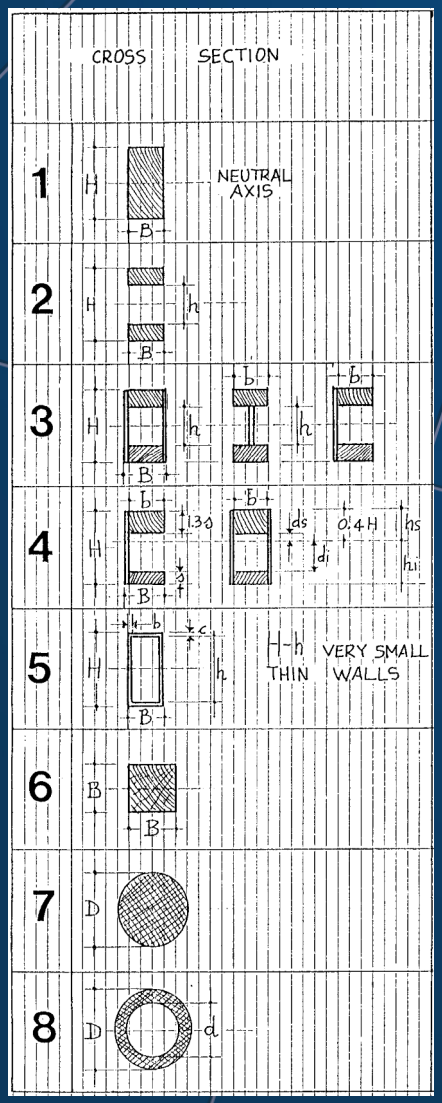
Balsa

- Very low density
- Good strength-to-weight ratio
- Directional properties
- Different densities
- Grain orientation


A-Plain sawn
Annual rings
Radial
B-Quarter sawn
C-Rift sawn

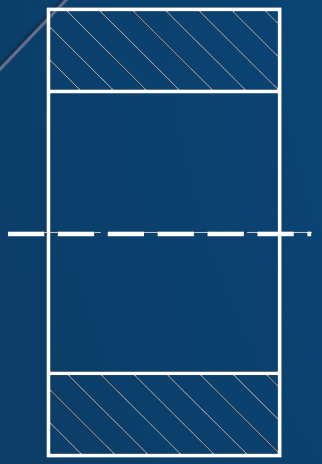

A
B
C

Spar construction

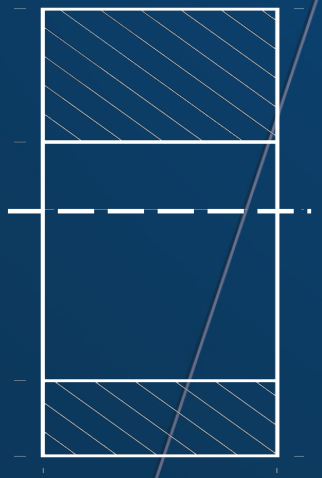


- Solid rectangular spar
- Spar caps of equal size
- Spar caps of equal size with webbing
- Spar caps of different size with webbing
- Thin wall hollow spar
- Solid square spar
- Round spar
- Hollow round spar

Spar caps

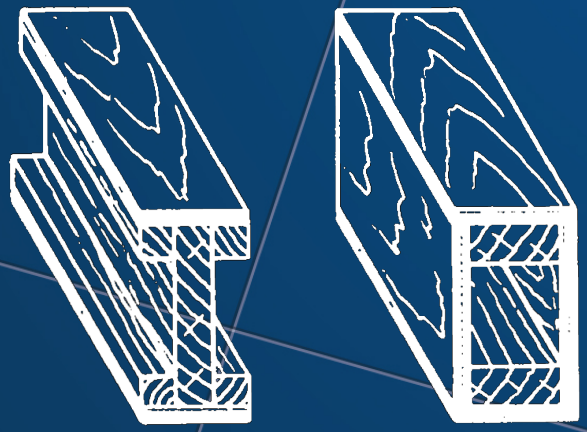


Wood tends to be roughly twice as strong in tension than in compression.



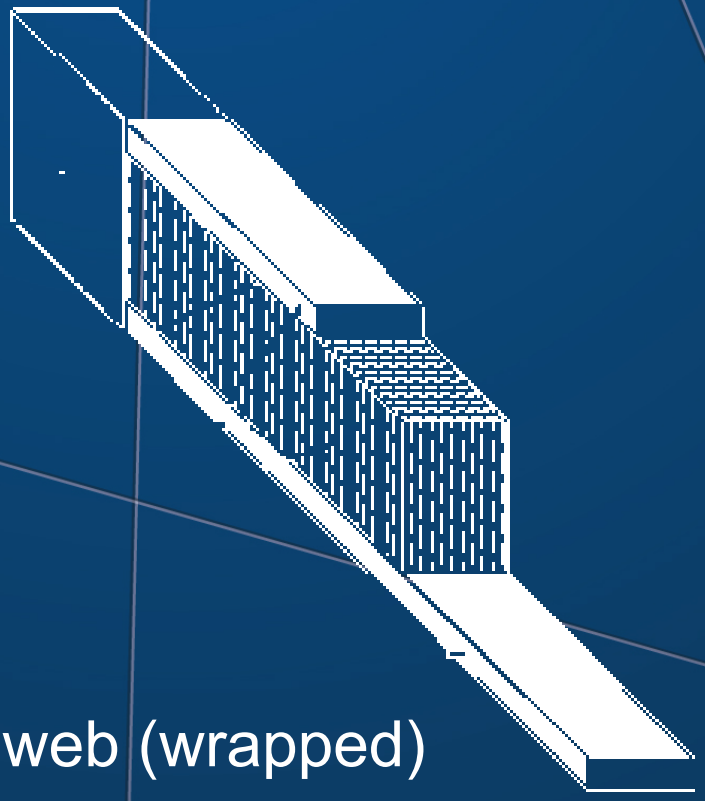
Upward loads are very much higher than downward loads. Unequal spar cap thickness inhibits buckling of the upper spar cap under compression loads.

Basic spar shear webs



I-beam

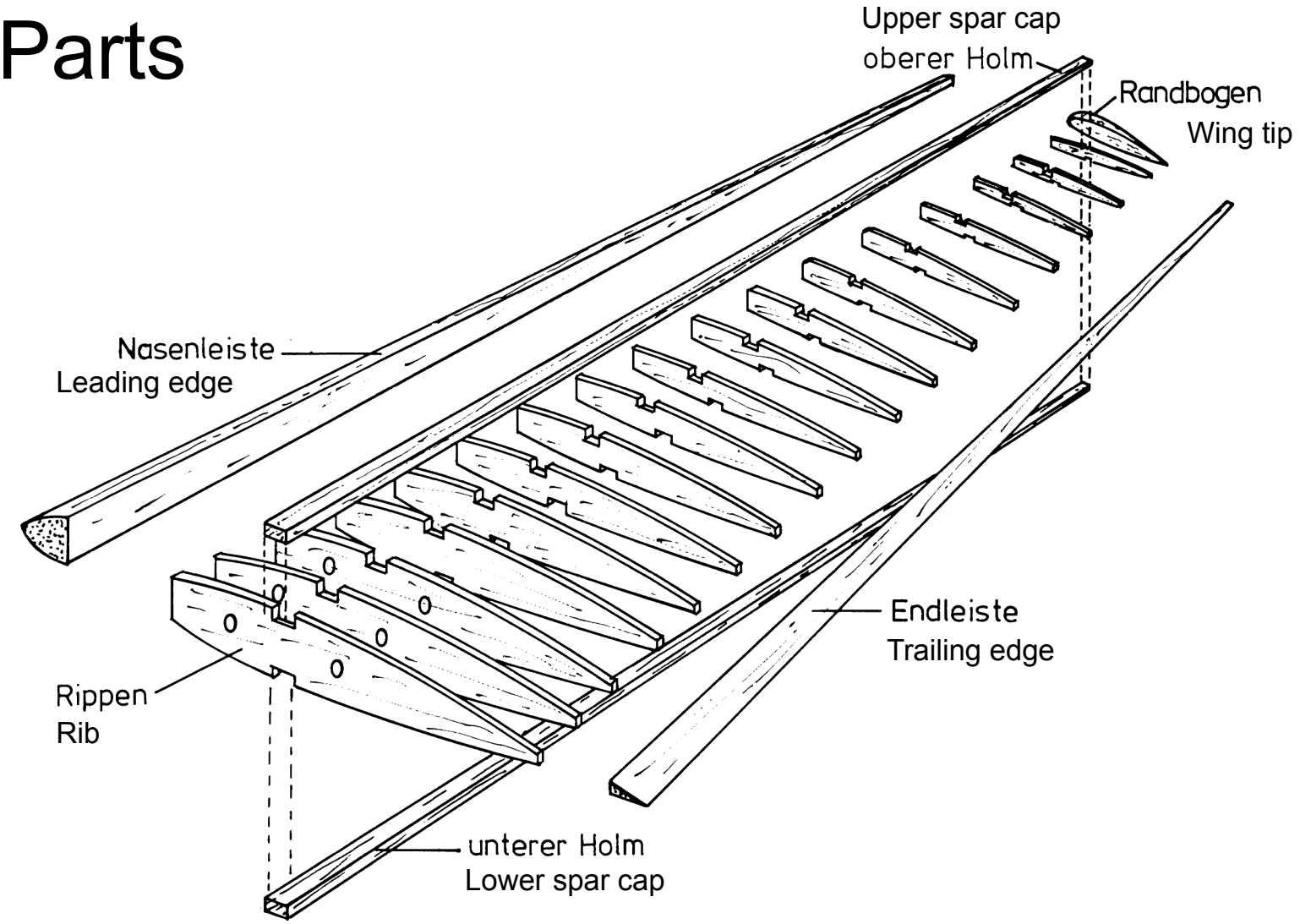
Box spar



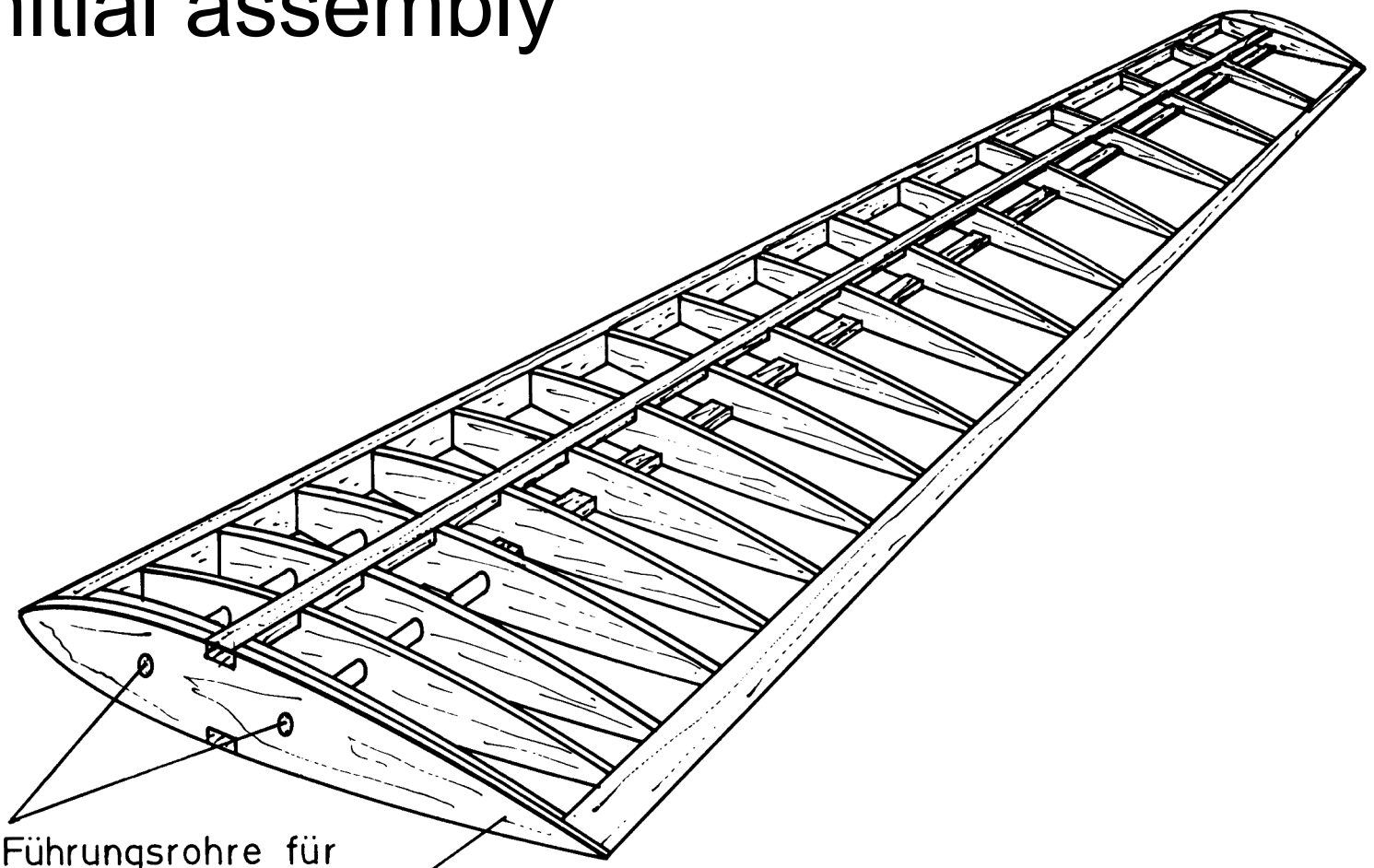
Full width shear web (wrapped)

Construction of a basic wood wing

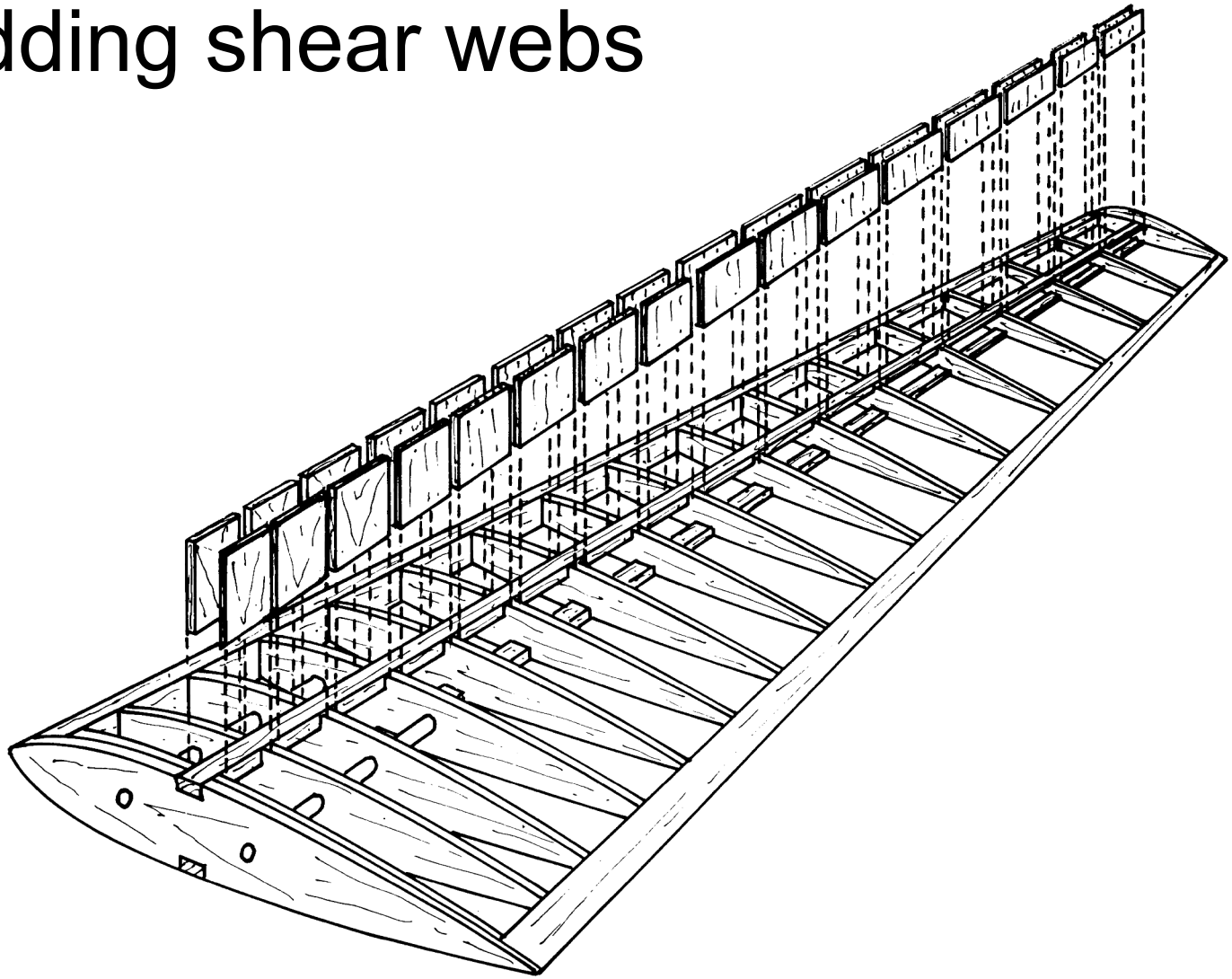
Parts


Upper spar cap
oberer Holm
Randbogen
Wing tip
Nasenleiste
Leading edge
Endleiste
Trailing edge
Rippen
Rib
unterer Holm
Lower spar cap

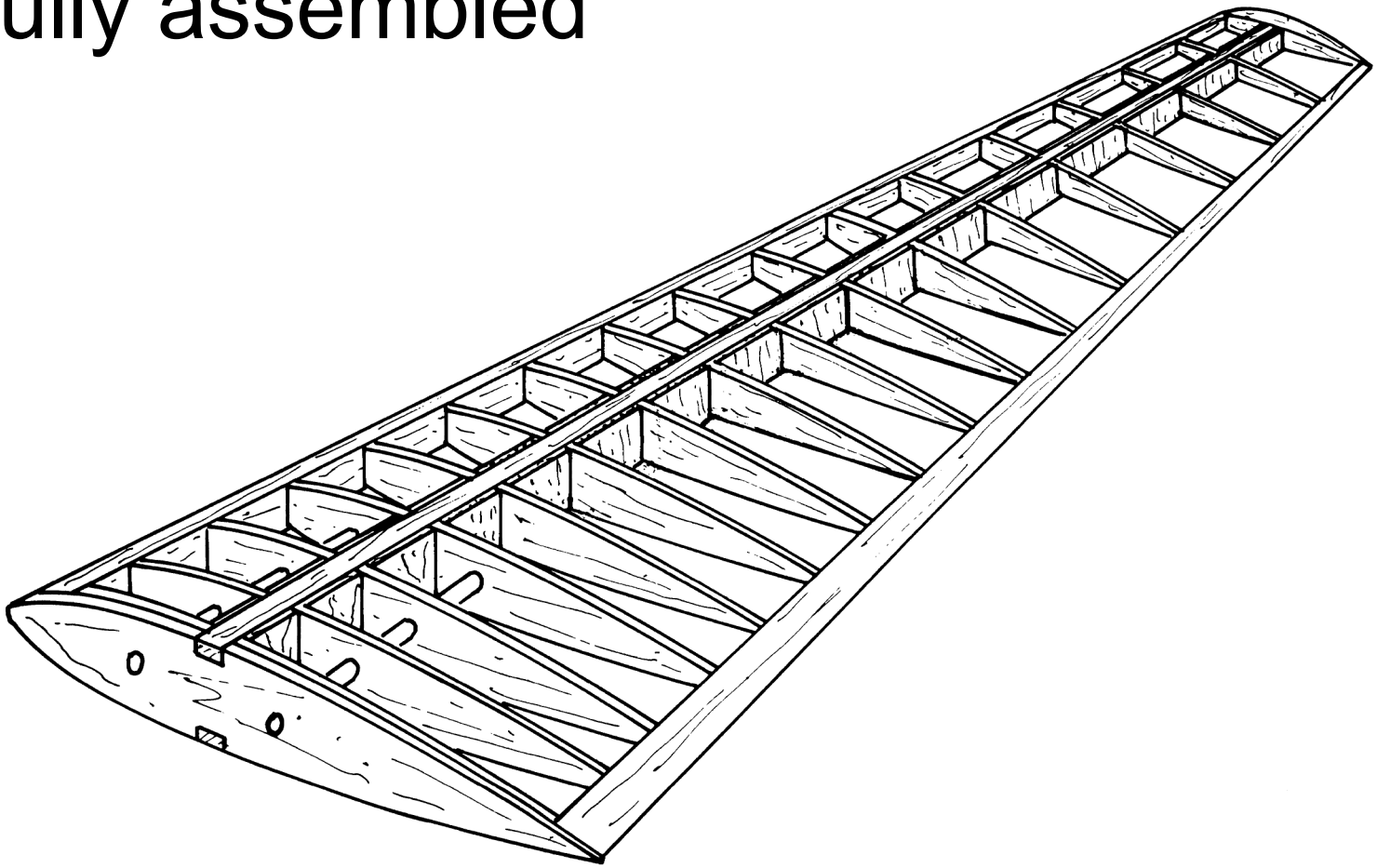
Initial assembly



Adding shear webs



Fully assembled



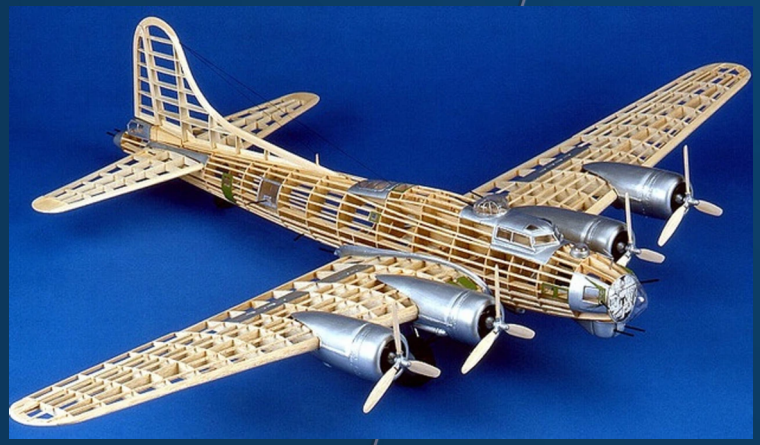
The D-box

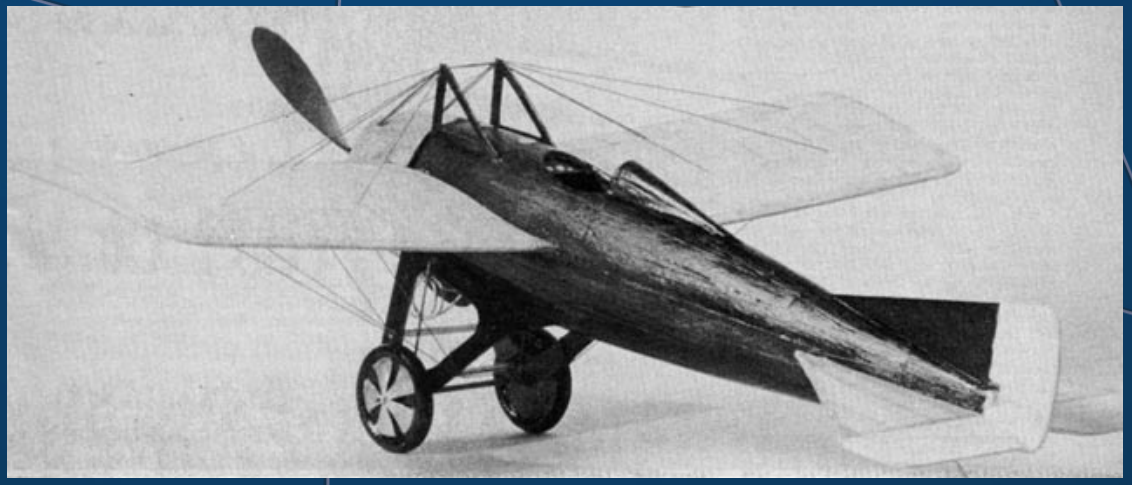


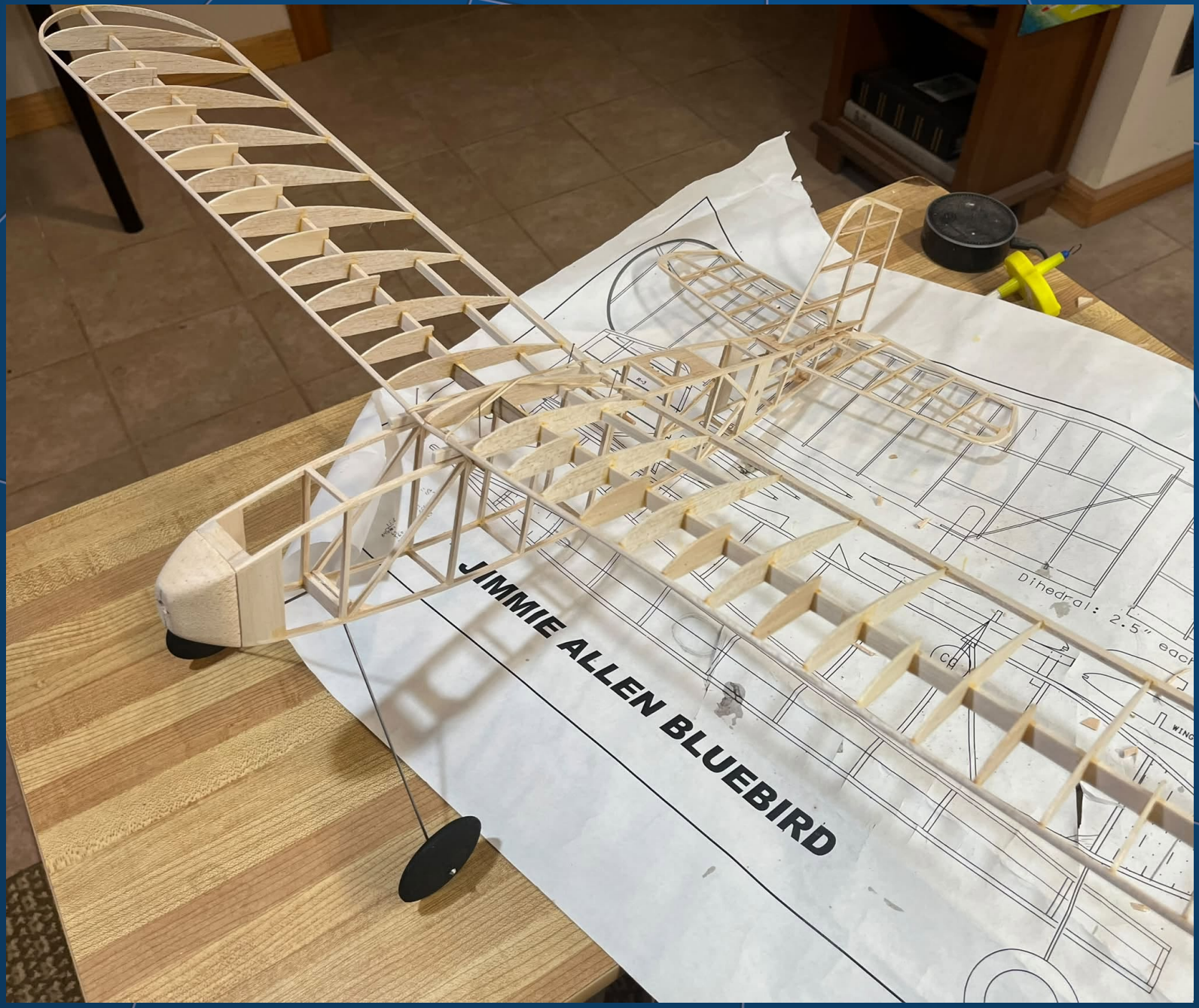
Fuselage construction

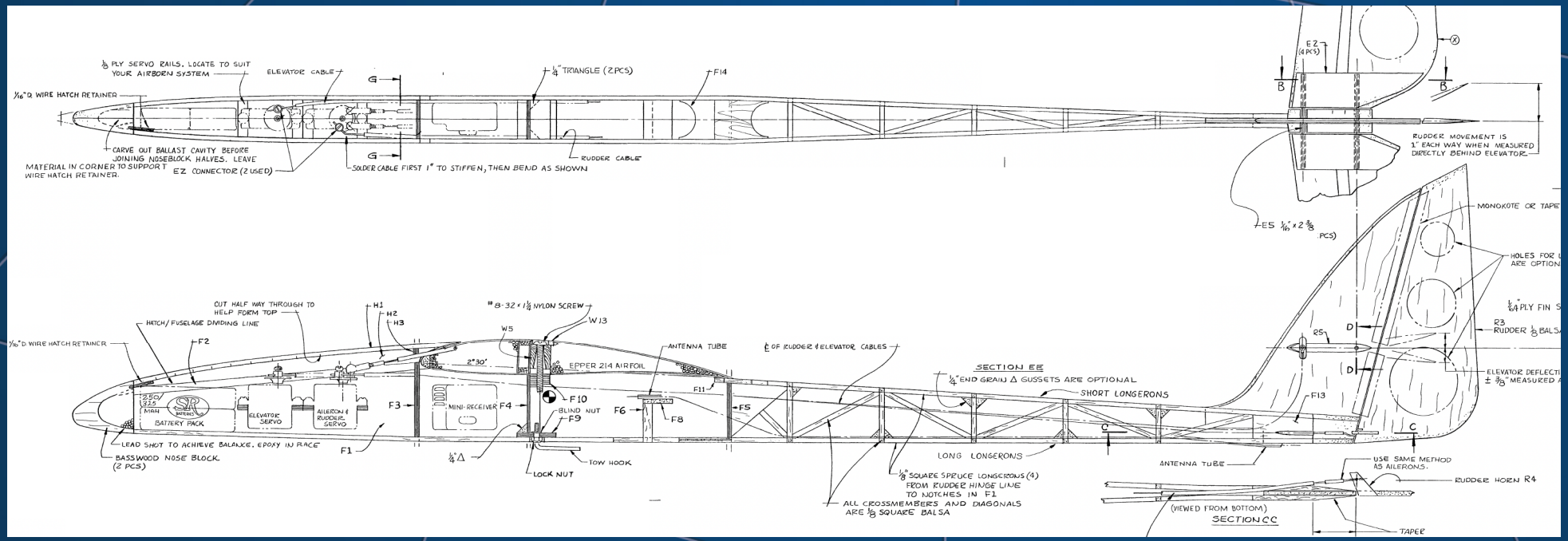




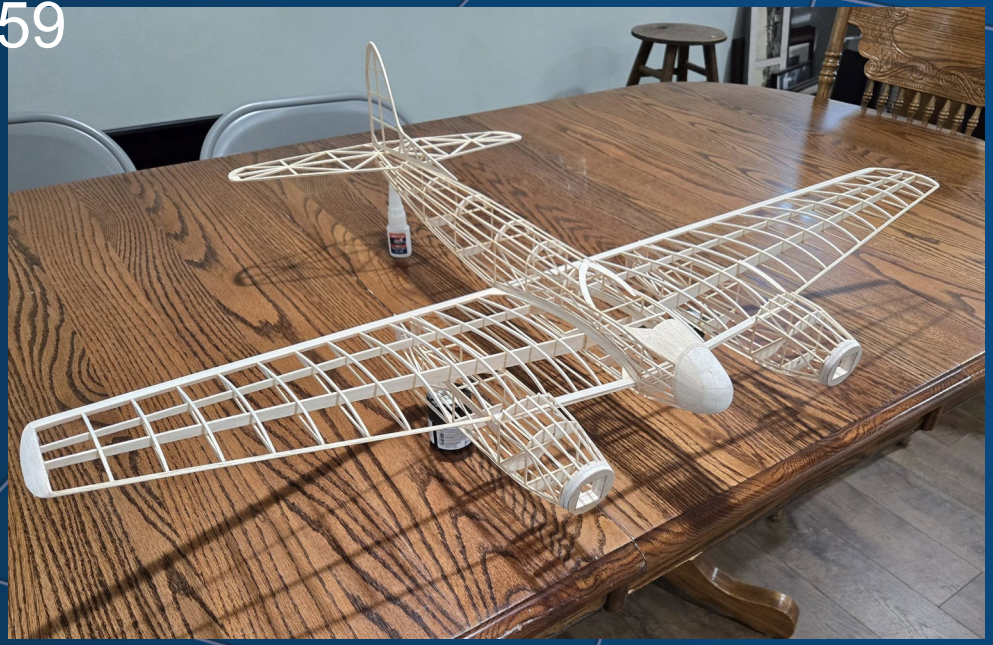


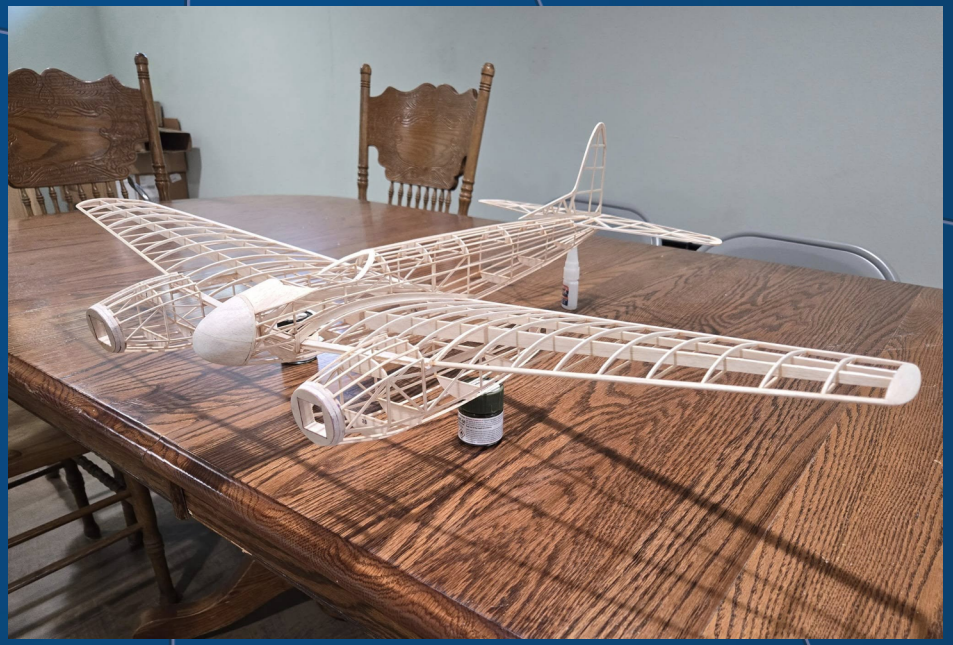



JIMMIE ALLEN BLUEBIRD
Dihedral: 2.5" each

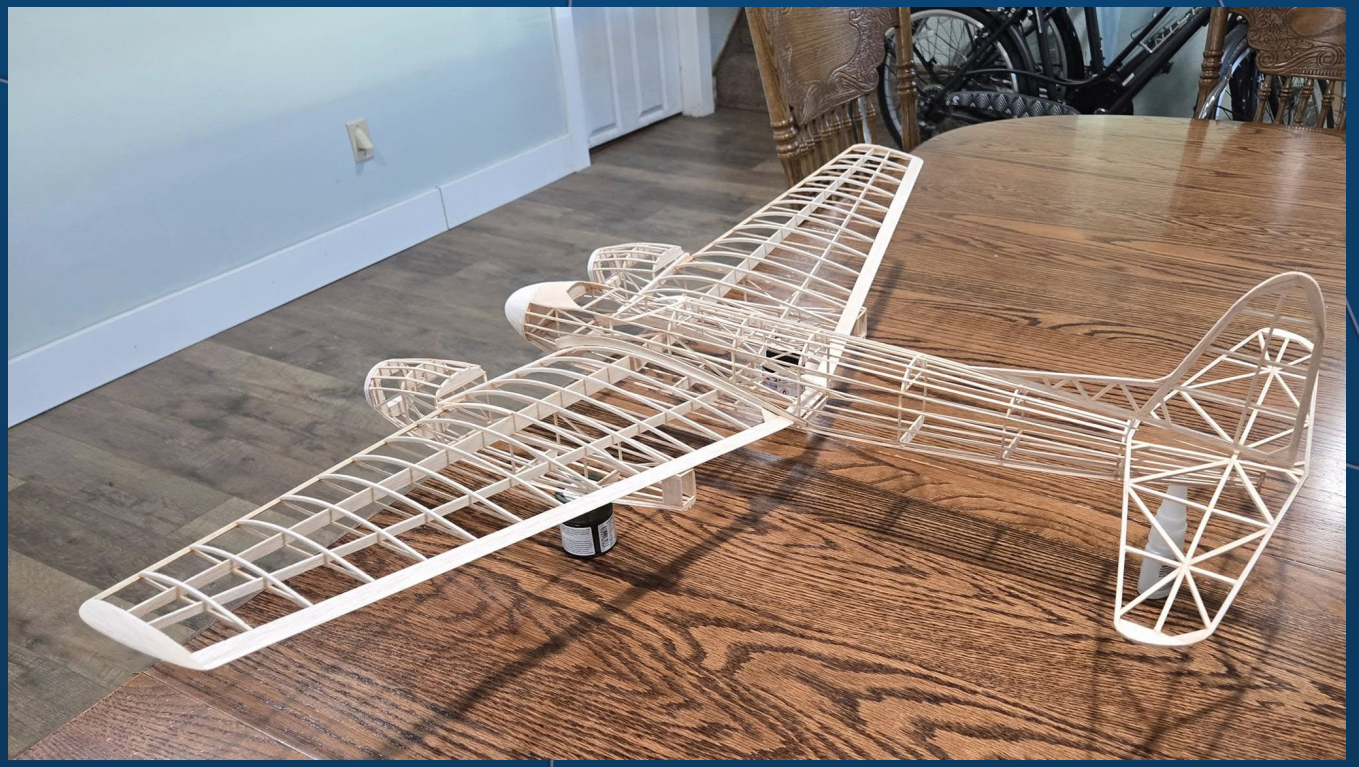


Chuperosa RC-HLG





De Havilland Sea Hornet



Covering

- Aerodynamic
- Structural

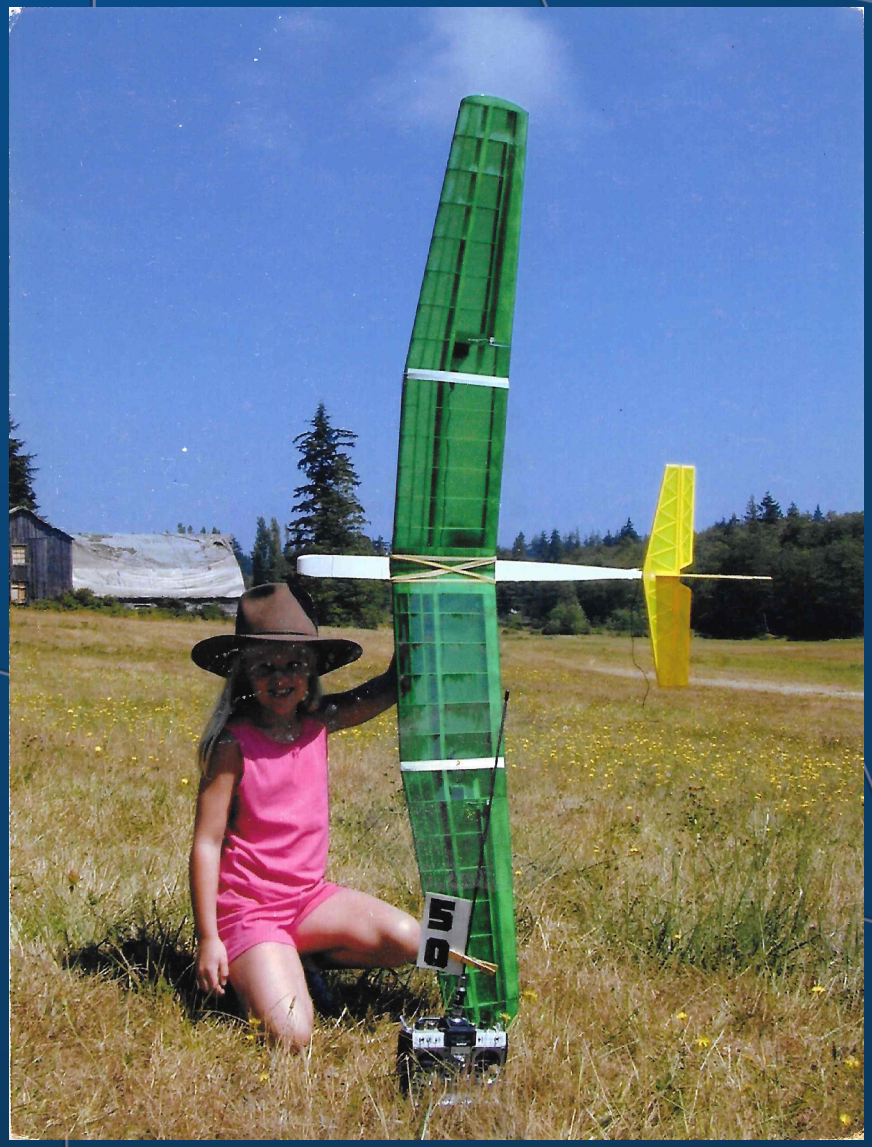
- Tissue
- Fabric
- Heat-shrink film
- Thin plywood
- Composite skin







Dave Jones (California) R-2



House of Balsa 2x4

Section 5

Composite model aircraft construction

Advantages of composites

- High stiffness
- High strength
- Excellent aerodynamic surfaces
- Integral skins and spars
- Complex shapes
- Excellent torsional stiffness

Fabrics

Fiberglass

- Variety of weights and weaves
- Inexpensive
- Good impact resistance

Carbon

- Variety of weights and weaves
- High stiffness
- High strength

Aramid/Kevlar

- Excellent in tension
- Excellent impact resistance
- Difficult to cut and machine

Composite wing load path

Air =>

Skin =>

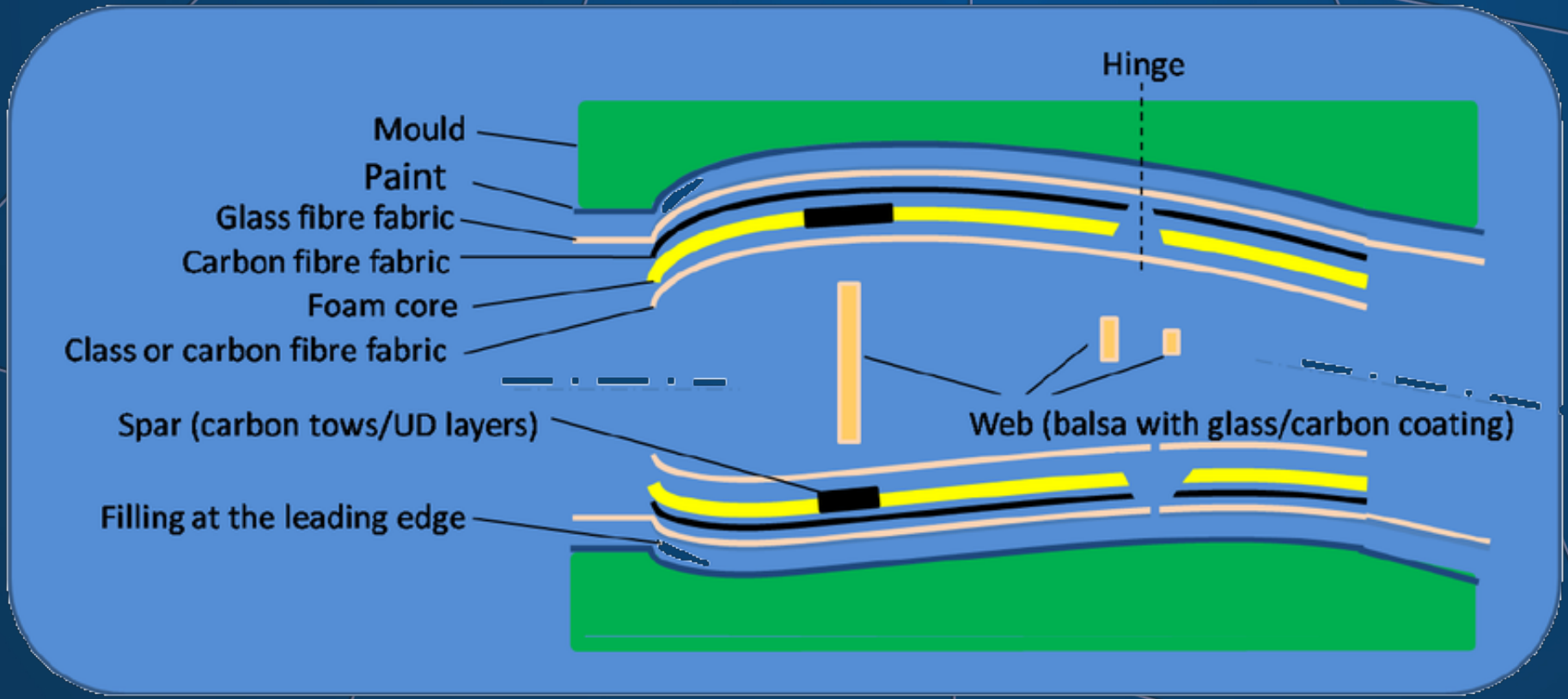
Spar caps =>

Shear web =>

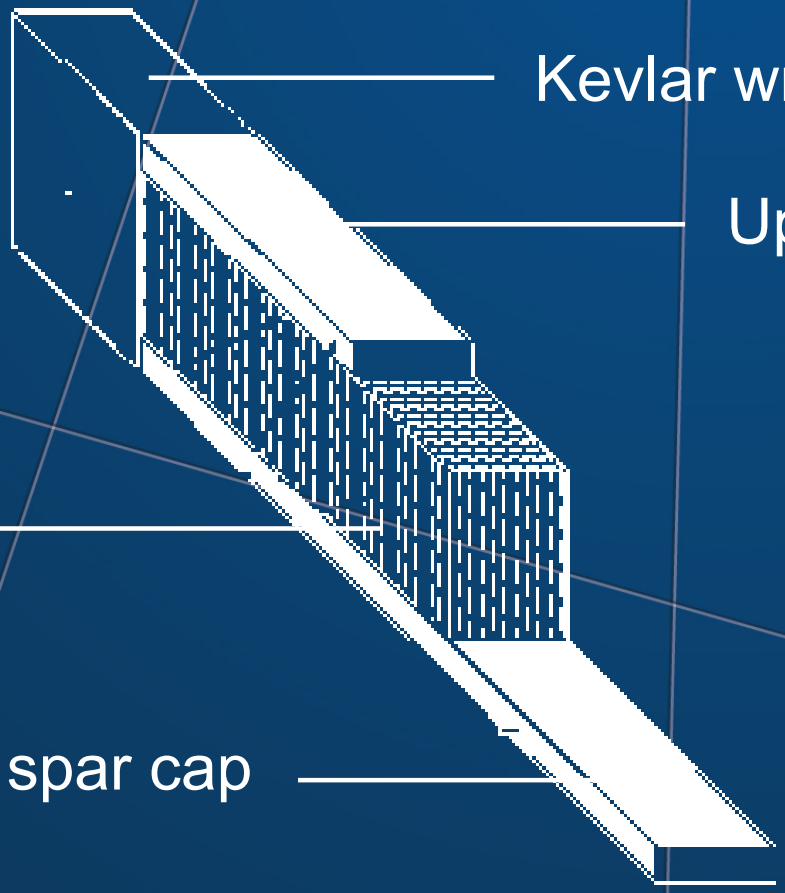
Joiner =>

Fuselage

* Bonds between each element


Hinge
Mould
Paint
Glass fibre fabric
Carbon fibre fabric
Foam core
Class or carbon fibre fabric
Spar (carbon tows/UD layers)
Web (balsa with glass/carbon coating)
Filling at the leading edge

Modern composite spar



Wing joiner construction

Joiner

- Plywood blade
- Aluminum extrusion
- Steel blade
- Drill rod
- Molded carbon fiber

Receptacle

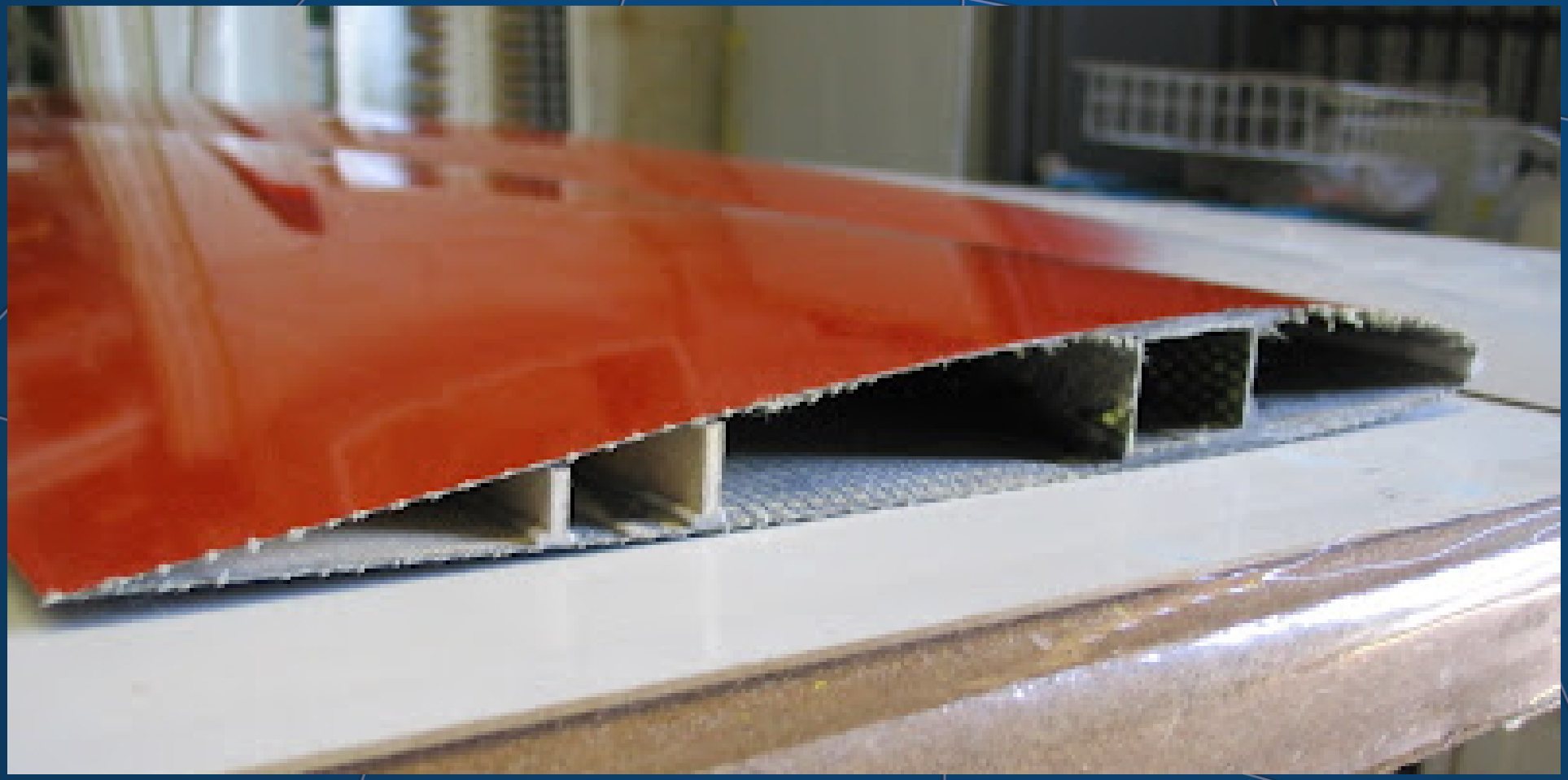
- Plywood box
- Aluminum extrusion
- Brass extrusion
- Carbon fiber box











Cross-section of Shongololo wing



Sine wave spar web

Section 6

Scale sailplanes

Types of scale

- Outline scale
- Dimensional scale
- Construction scale
- Detail scale
- Performance scale

Wood construction differences

Full size

- Wood spars
- Trussed ribs
- Light plywood skin
- Fabric covering

Scale model

- Spruce spars
- (Solid) balsa ribs
- Thin balsa skin
- Plastic covering



Detail Sclae
¼ scale Pioneer 2D

Composite construction differences

Full size

- Composite spars
- Hollow core
- Fiberglass skin
- No covering

Scale model

- Composite spars
- Hollow core
- Fiberglass skin
- No covering

Necessary compromiseses

- Spar depth
- Spar cap thickness
- Web composition
- Materials
- Load factors
- Manufacturing constraints

LET 1/3.75 scale DG-1000



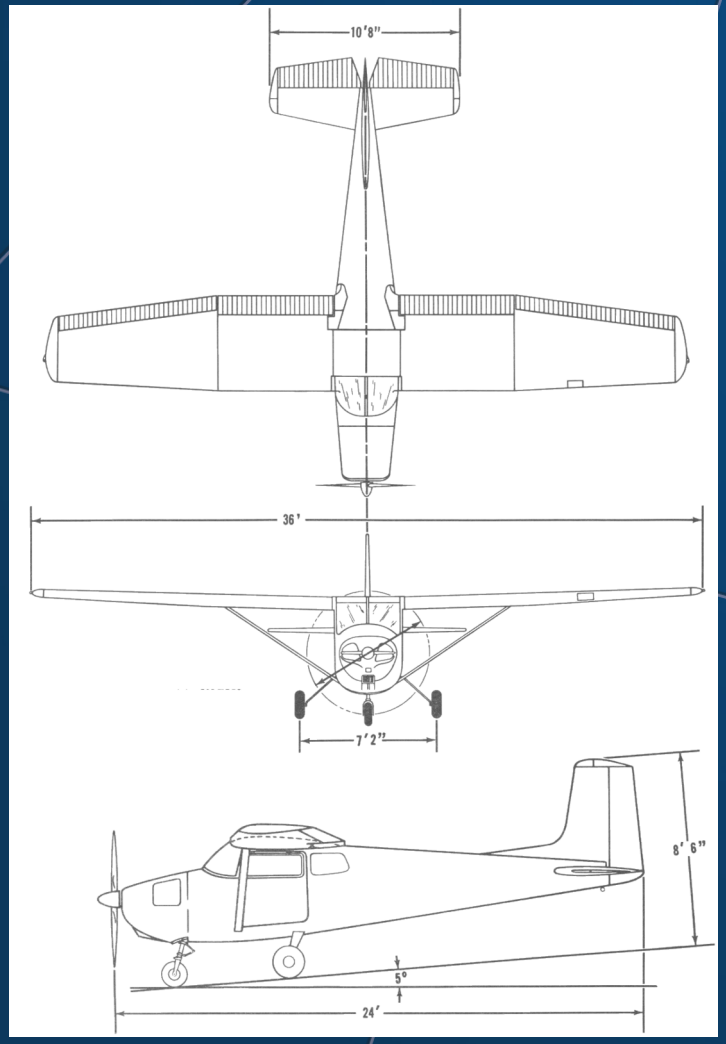




Dynamic scaling

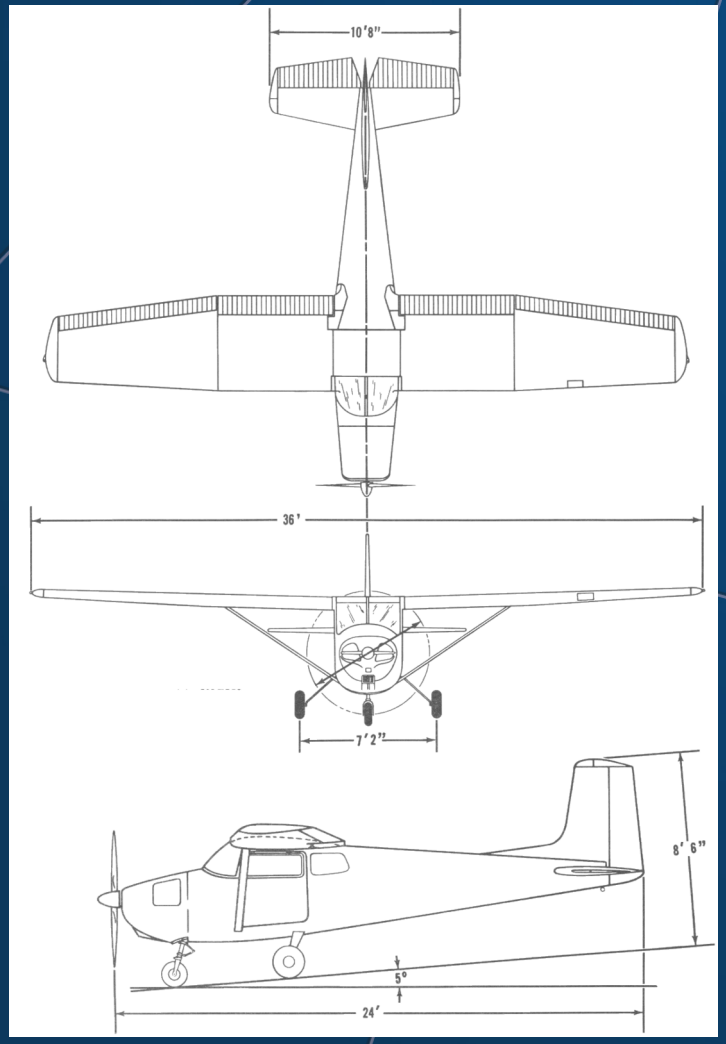
The flight path and angular displacements of the model and vehicle will be geometrically identical.

Scale Cessna 172

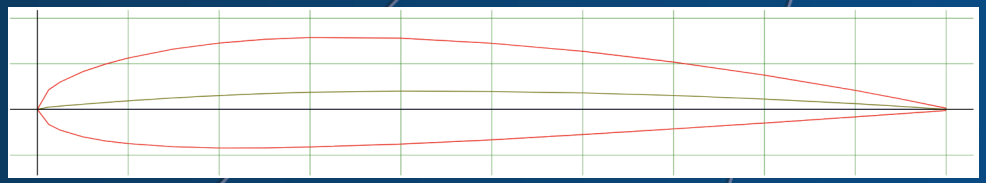


	1:1	1:4
Span	36’	9’
Area	175 ft^2	10.9 ft^2
Av. chord	4.9’	1.2’
Length	25’	6.25’
Height	8.5’	2.125’
Weight	2200 lbs	34.4 lbs 8.6 lbs
Wing loading	12.6 lbs/ft^2	3.1 lbs/ft^2 0.78 lbs/ft^2
Flying speed	108 kts	54 kts 27 kts

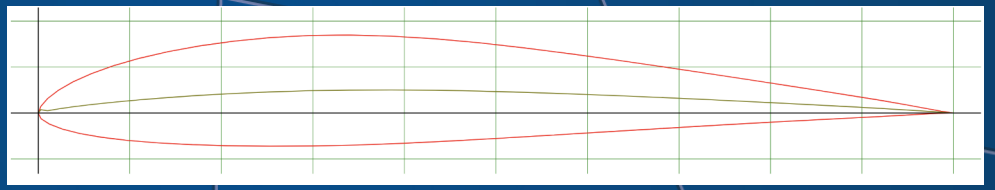
Scale Cessna 172



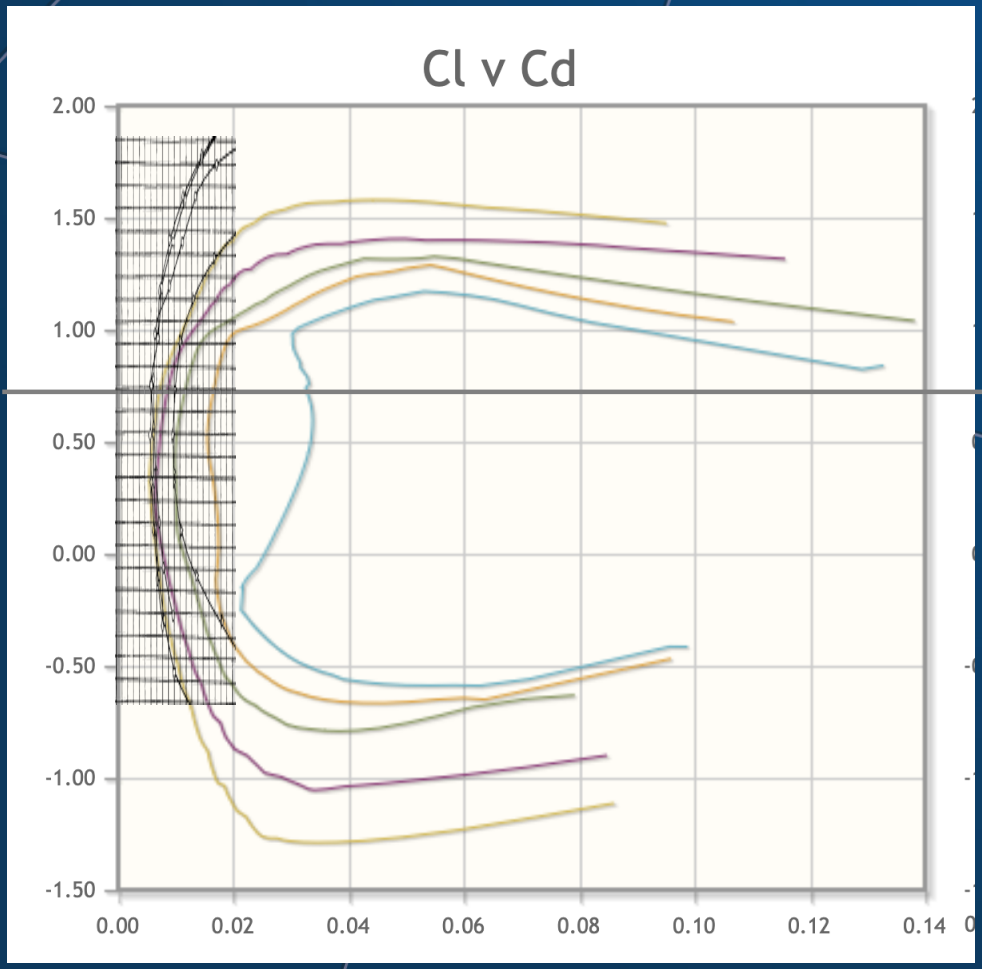
	1:1	1:4
Weight	2200 lbs	8.6 lbs
Wing loading	12.6 lbs/ft^2	0.78 lbs/ft^2
Cruise speed	108 kts	27 kts
Reynolds number	6200k	390k
Stall speed	43 kts	10.8 kts
Reynolds number	2500k	155k

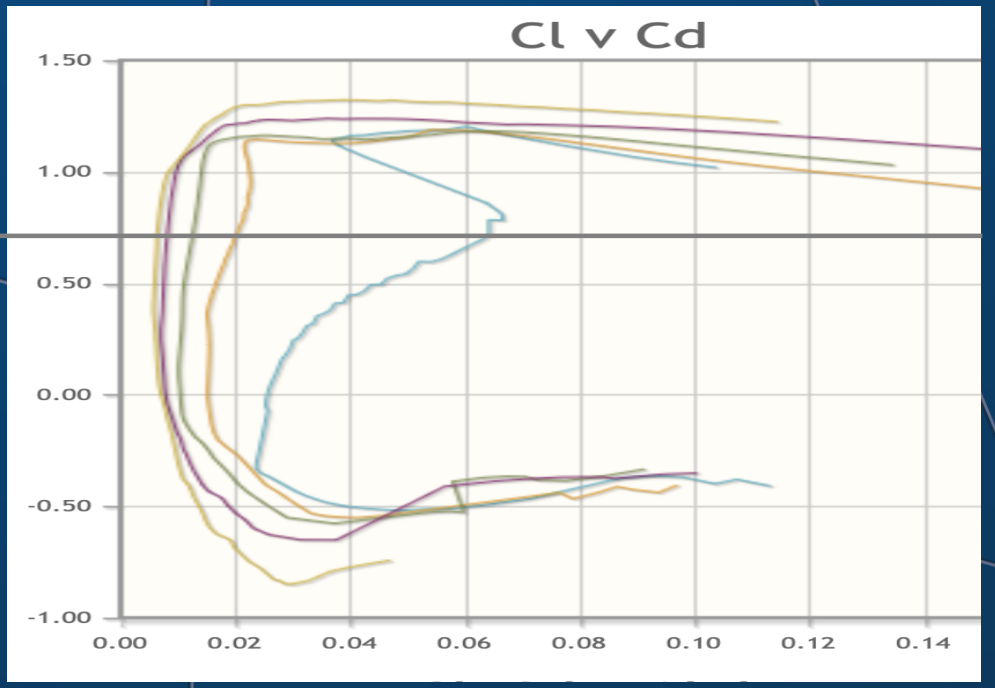


NACA 2412
Re = 50k -1,000k

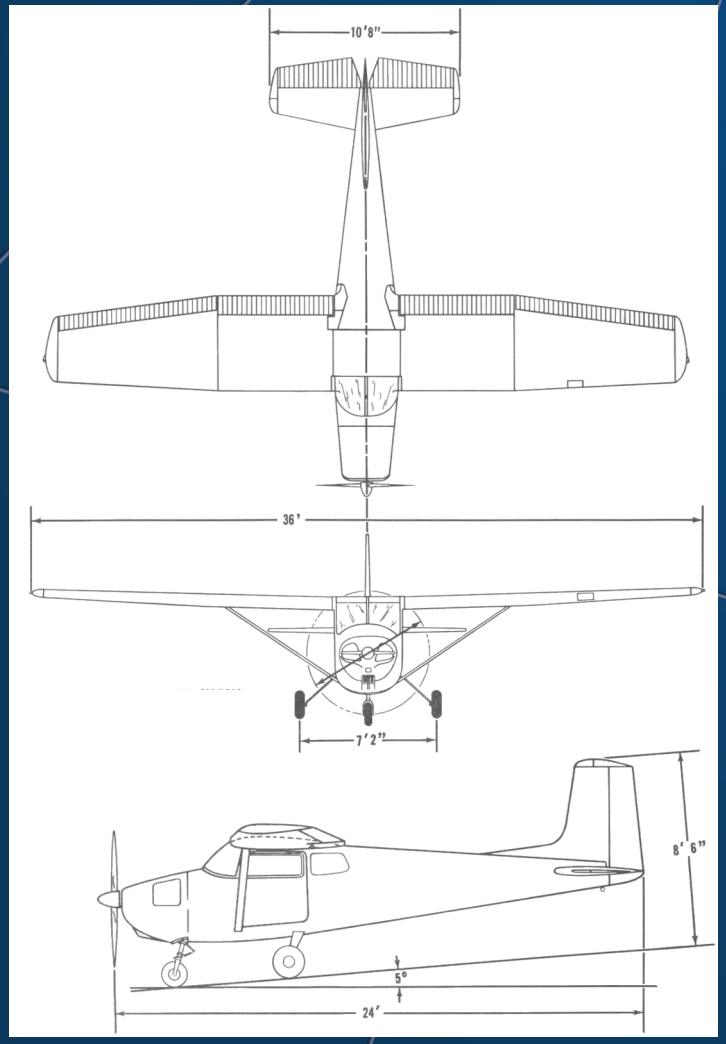


Eppler 207
Re = 50k -1,000k;





Scale Cessna 172



	1:1	1:4
Span	36’	9’
Area	175 ft^2	10.9 ft^2
Av. chord	4.9’	1.2’
Length	25’	6.25’
Height	8.5’	2.125’
Weight	2200 lbs	34.4 lbs 8.6 lbs
Wing loading	12.6 lbs/ft^2	3.1 lbs/ft^2 0.78 lbs/ft^2
Flying speed	108 kts	54 kts 27 kts

Section 7

Non-scale high performance models

General structural requirements

- Aerodynamic performance
- Mass
- Stiffness
- Strength
- Manufacturability

Specific FAI class requirements

- F3B Multi-task: Winch launch; duration (max C_{Lmax}), speed (C_{Dmin}), distance (max C_L/C_D)

- F3J Duration within window: 2-person hand tow; thermal duration (C_{lmax})

- F3F Slope racing: Speed (C_{dmin}) over closed course with tight turns (intermittant C_{Lmax})

Section 8

Model aircraft special structural problems

Special structural problems

- High bending moments with low structural depth, as with high aspect ratio wings
- Torsion loads with control surface deflection can lead to aileron reversal
- Bending, torsion and mass distribution can lead to flutter of the wing and/or control surfaces



Bruce Tebo, Transonic DP, April 2 2026, Bird Spring Pass, 567mph

Transonic DP at 567 mph

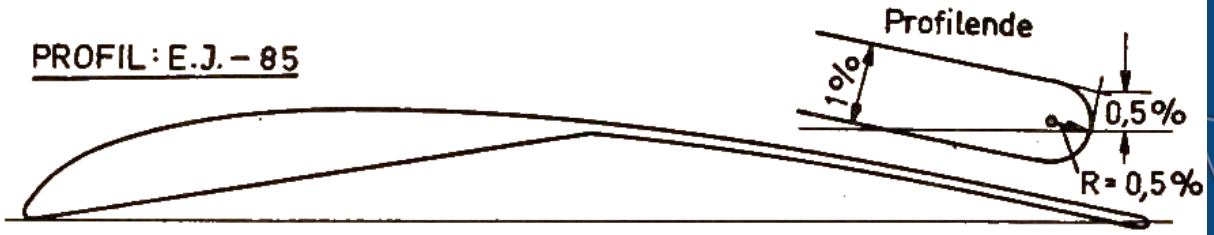
Weight	20.3 lbs, 325 oz
Span	3.3m, 130”
Area	0.484 m2, 5.2 ft2, 750 in2
Aspect ratio	22.5:1
Average chord	0.147 m, 5.8”
Reynolds number	~2.5 million
Wing loading, static	20.3 lbs/ft2, 325 oz/5.2 ft2, 62 oz/ft2
Estimated g-load	90g+
Wing loading at 90g	1827 lbs/5.2ft2, 351 lbs.ft2
Computed C_L	0.5

Flutter

Caused by...

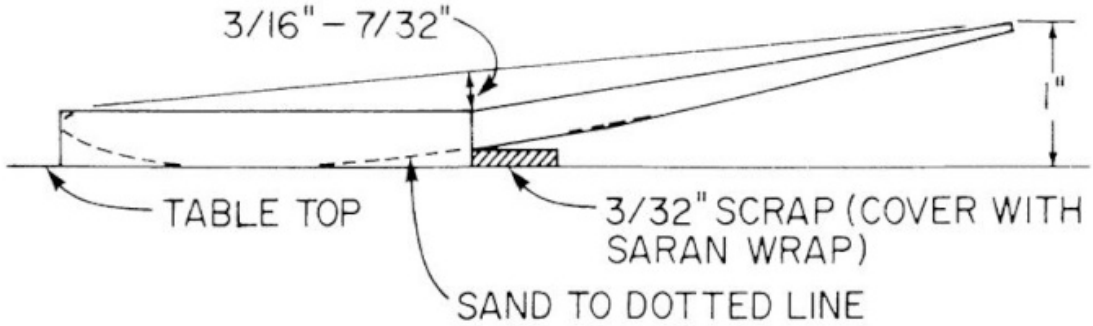
- Low mass
- Mass distribution
- Thin surfaces
- Flexible pushrods
- Loose linkages
- Worn servo gears
- Flexible skins

PROFIL : E.J. – 85



X	0	1,25	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Yo	0,5	3	4,3	6	7,2	8	9,2	9,5	10	9,8	9	8	6,5	4,8	2,8	1,7	0
Yu	0,5	0,1	0,5	1	1,3	1,8	2,7	3,3	5	6,5	8	7	5,5	3,8	1,8	0,7	0

WING CONSTRUCTION



Jedelsky wing



Jedelsky wing structure failure

Adhesives become structure

- Cyanoacrylite
- Epoxy and polyester resins
- Aliphatic resins
- Polyurethane
- Contact adhesives
- Structural film adhesives

Hardware becomes structure

- Screws
- Blind nuts
- Bolts
- Clevices
- Ball links
- Control horns
- Servo mounts
- Wing hold-downs

Section 9

Conclusions

Part 1 Concept	Model Aircraft Equivalent
Wing bending (compression & tension)	Spar caps
Shear	Spar web
Torsion	D-box/skin
Buckling	Too thin spar cap or skin
Stressed skin	Composite shell
Sandwich	Foam/honeycomb wing
Load path	Joiner-fuselage integration
Joint design	Bond lines & wing bolts
Flutter	Flying surface/control surface design

Central Themes

An aircraft is designed and constructed as an integrated load-management system.

The same structural principles apply to model aircraft, but scale does not reproduce those principles, it adapts them.

End of Part 2