Structural Analysis of a World War One Biplane

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SAWE Western Regional Conference

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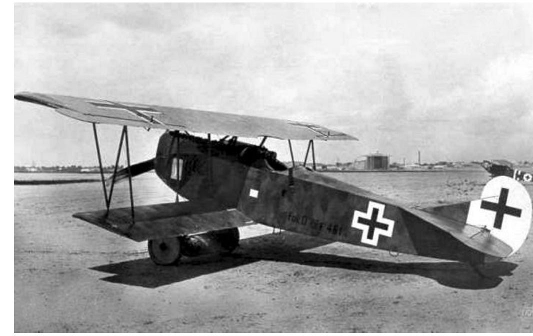
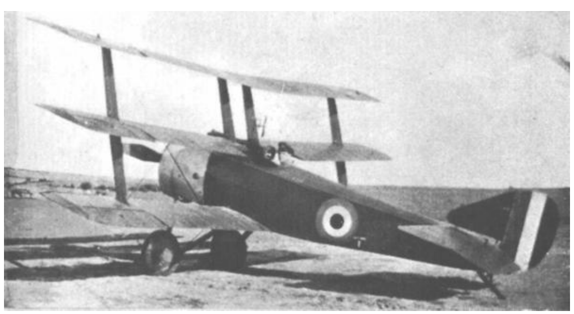
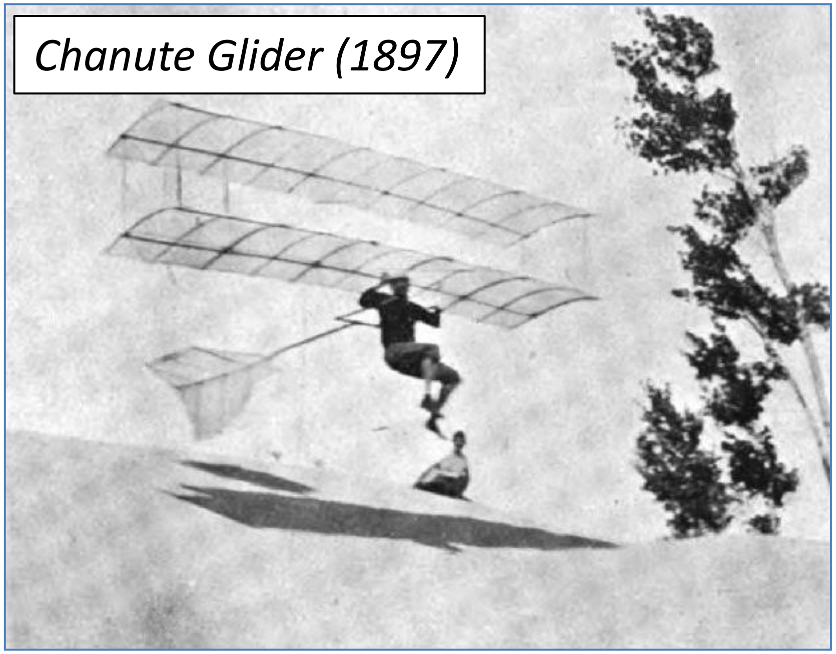
World War One Fighters

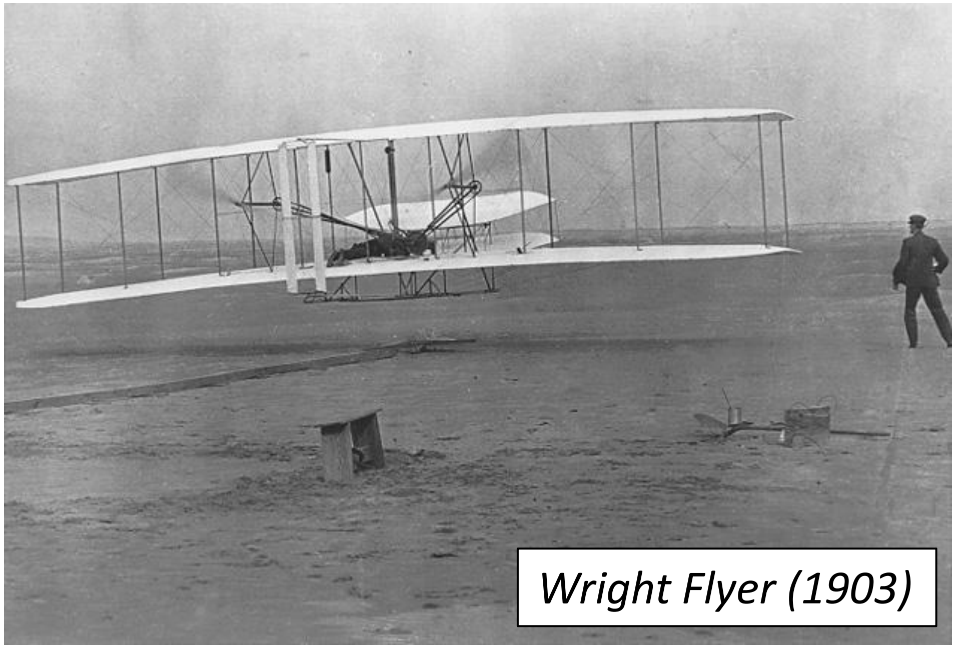




In the Beginning…

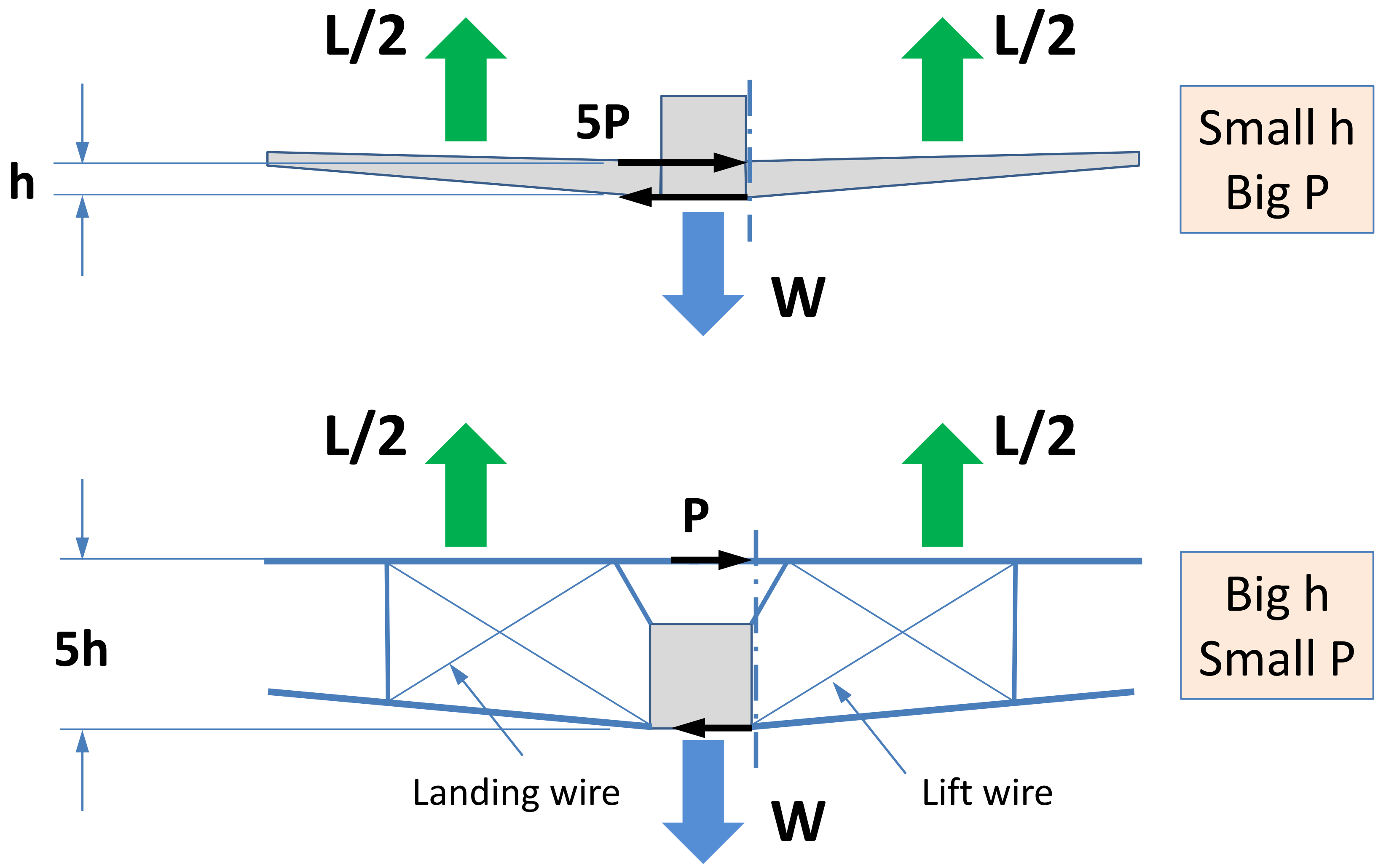


Chanute Glider (1897)

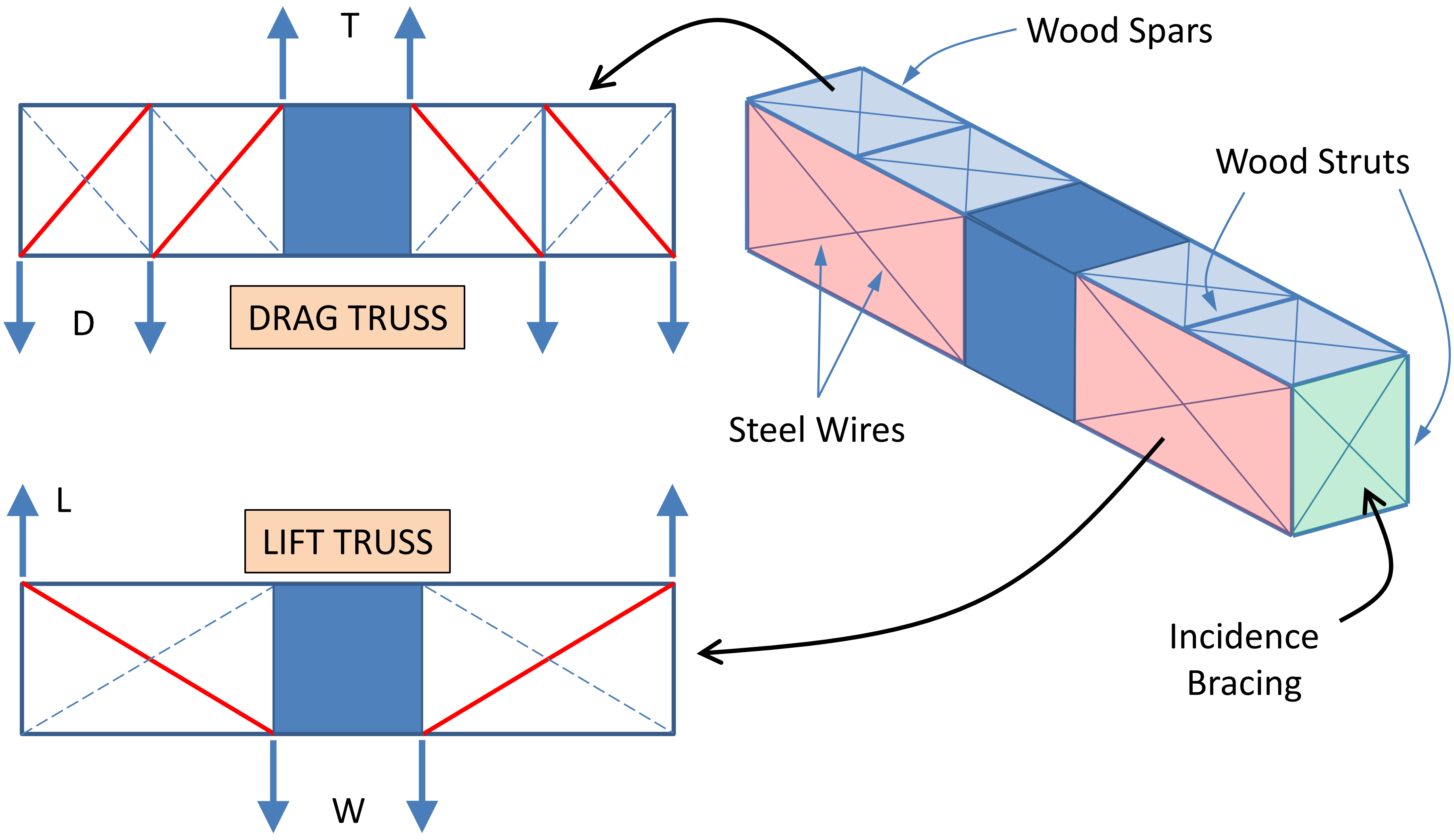


Wright Flyer (1903)

Structural Comparison



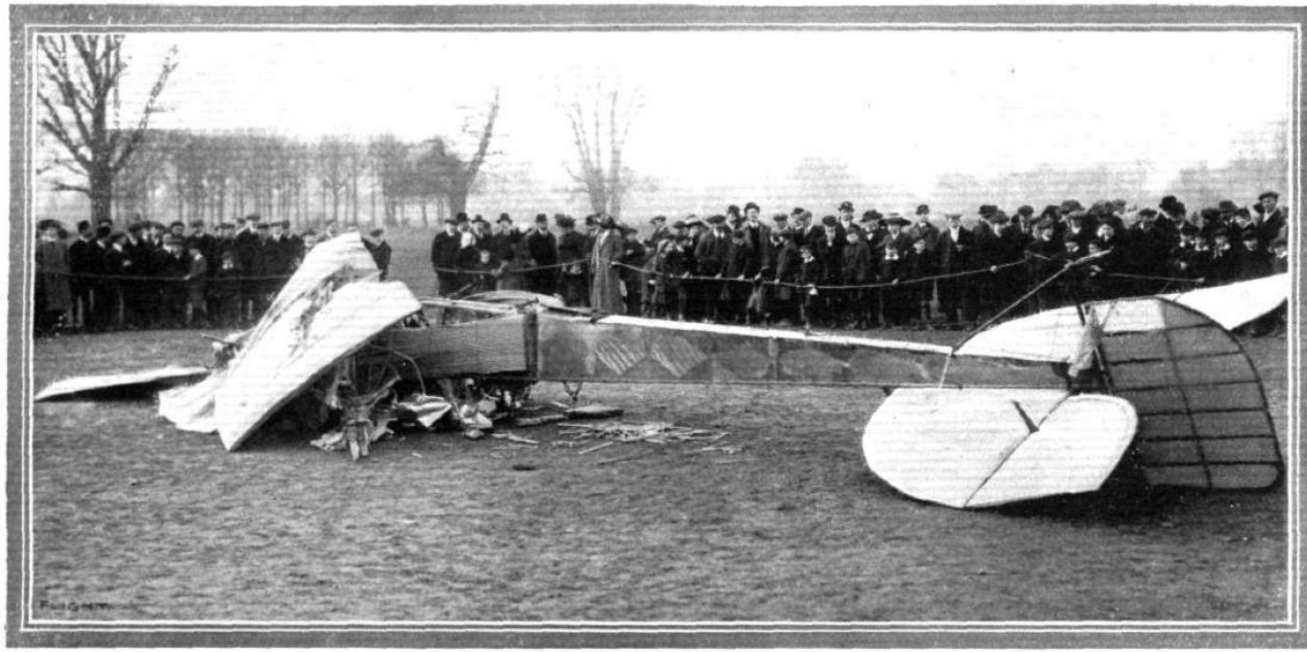
Truss Action



British Monoplane Ban

THE COLLAPSE OF MONOPLANE WINGS.

Royal Flying Corps bans monoplanes Oct 1912 – Feb 1913

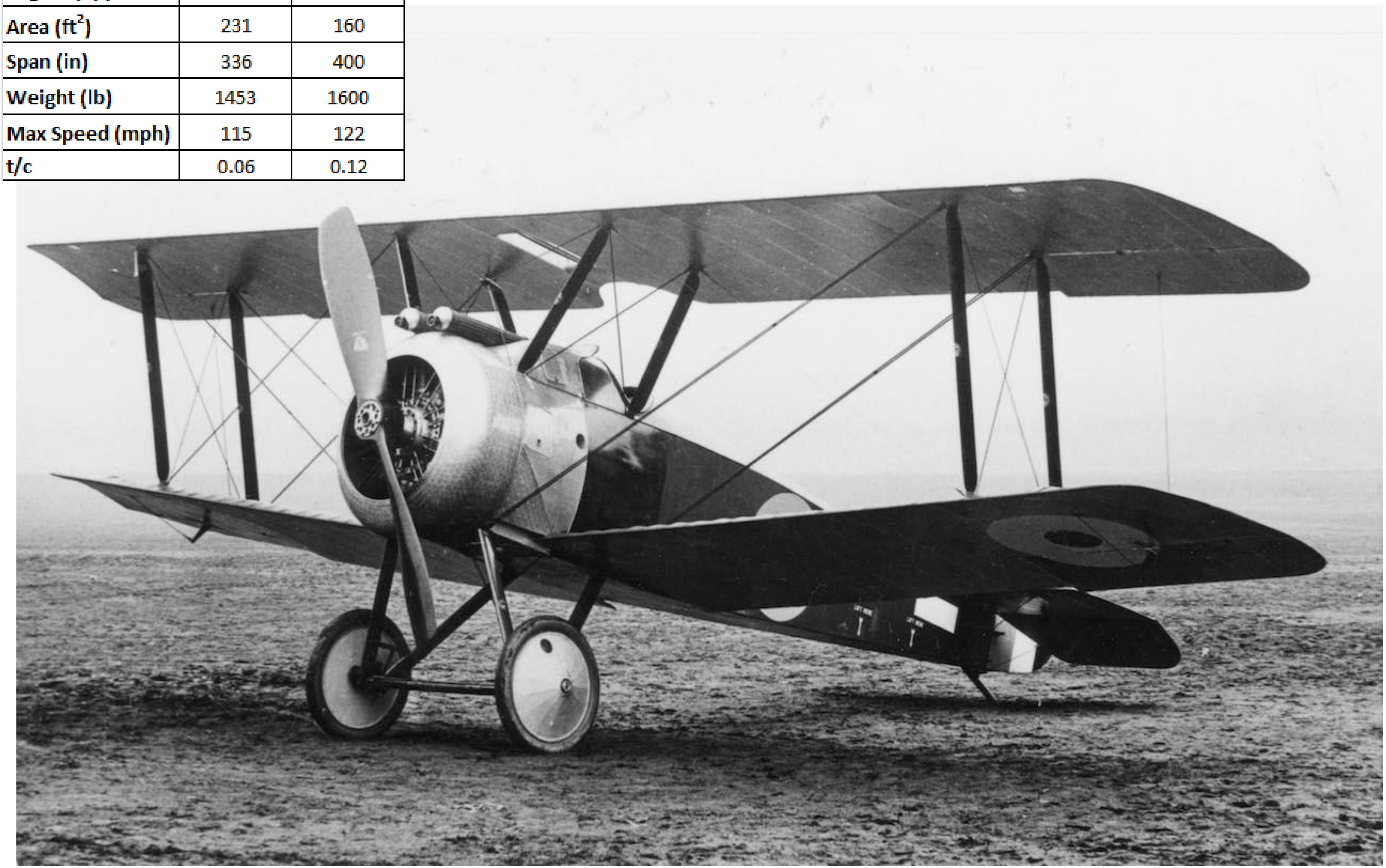


MR. GRAHAM GILMOUR'S FATAL ACCIDENT.—General view of the monoplane after the disaster.

REPORT OF THE GOVERNMENT COMMITTEE ON MONOPLANE ACCIDENTS

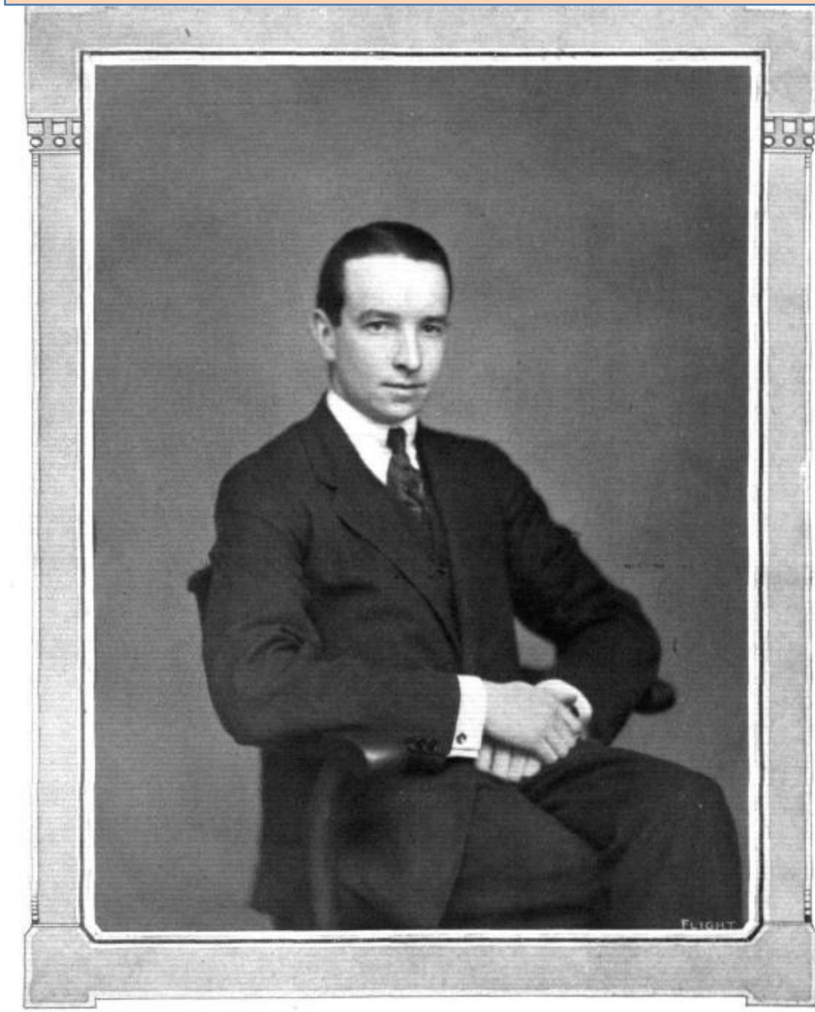
Sopwith Camel (1917)

	Camel	Cessna 150
Engine (hp)	130	100
Area (ft^2)	231	160
Span (in)	336	400
Weight (lb)	1453	1600
Max Speed (mph)	115	122
t/c	0.06	0.12



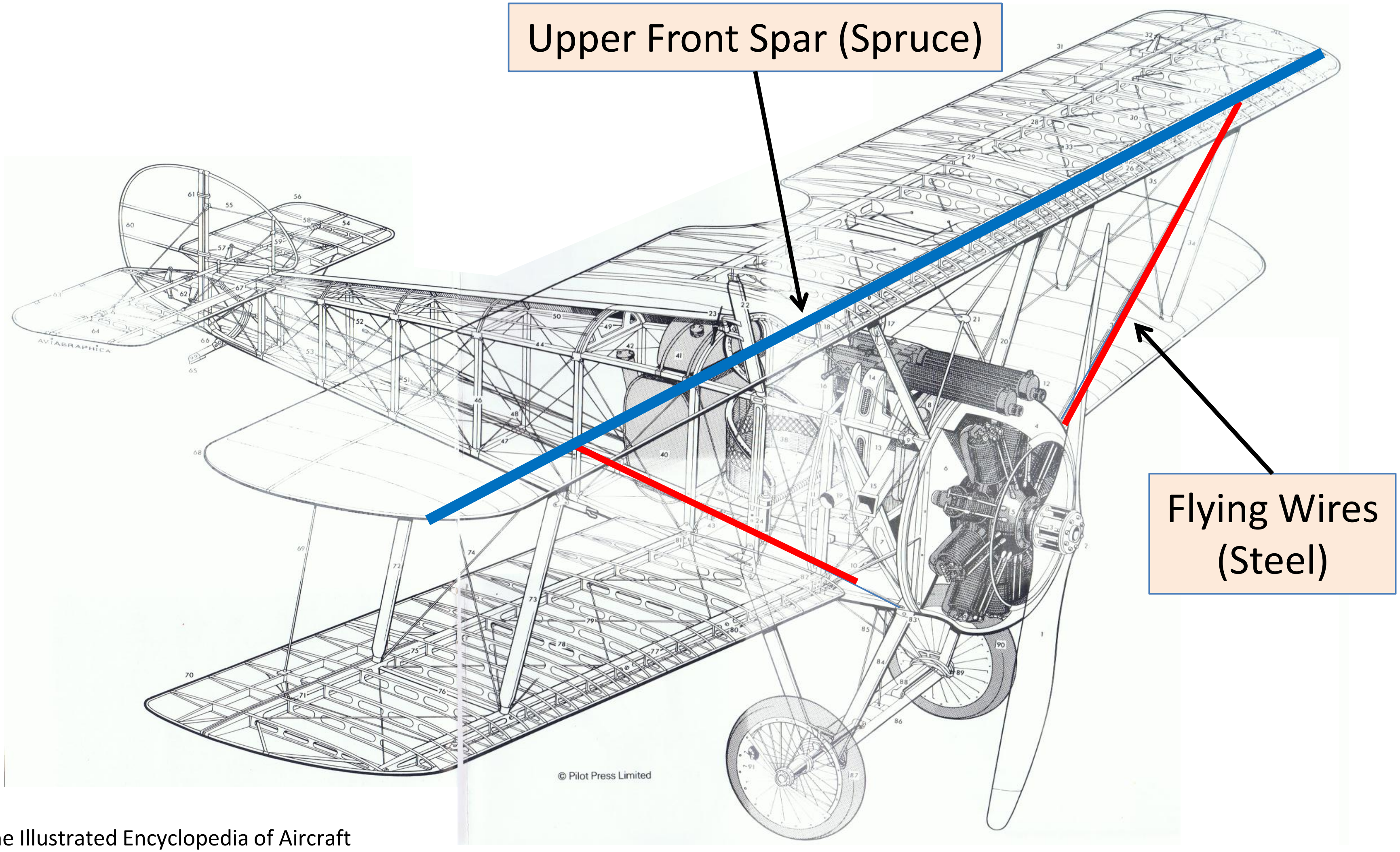
Mr. T.O.M. Sopwith (1888-1989)

1910 Royal Aero Club Aviators’ Certificate No. 31
1913 Founded Sopwith Aviation Company



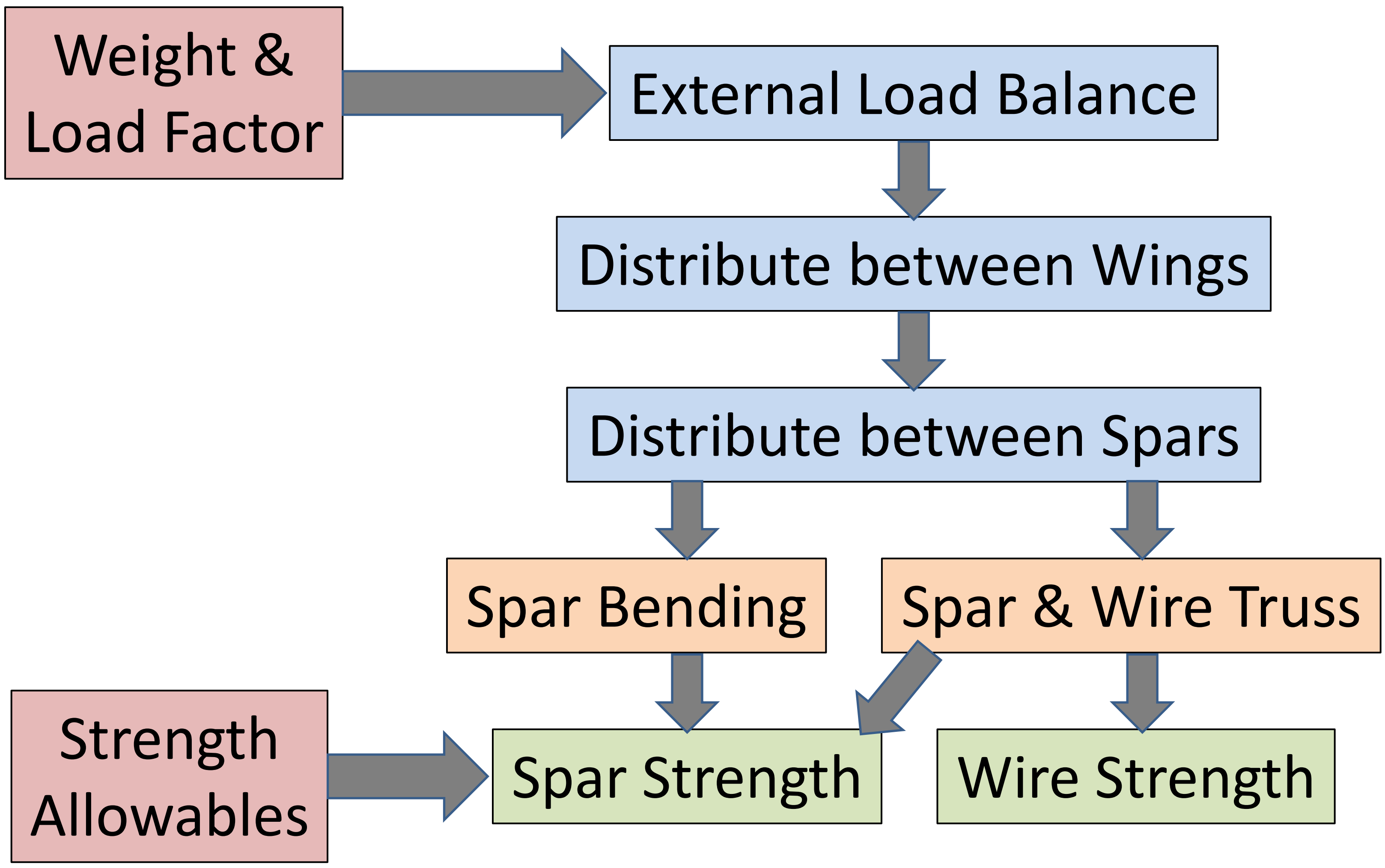
Sopwith Tabloid
1914 Schneider Cup Winner

Camel Structure



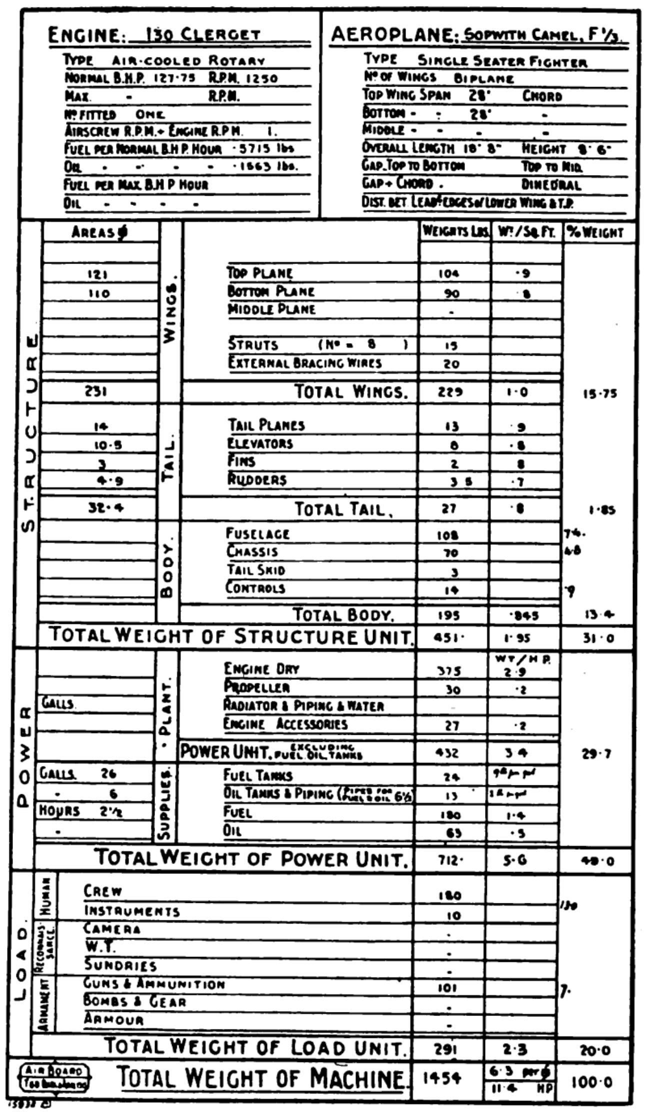
The Illustrated Encyclopedia of Aircraft
Volume 9, Issue 102
Orbis Publishing, 1983

Structural Analysis Steps



Weight Breakdown

	Weight	% TOTAL
	lb	
STRUCTURE		
Top Plane	104	
Bottom Plane	90	
Struts	15	
External Bracing Wires	20	
TOTAL WINGS	229	16%
Tail Planes	13	
Elevators	8	
Fins	2	
Rudders	3.5	
TOTAL TAIL	27	1.8%
Fuselage	108	
Chassis	70	
Tail Skid	3	
Controls	14	
TOTAL BODY	195	13%
TOTAL STRUCTURE	451	31%
POWER		
Engine Dry	375	
Propeller	30	
Engine Accessories	27	
Fuel Tanks	24	
Oil Tanks & Piping	13	32%
Fuel	180	
Oil	63	17%
TOTAL POWER	712	49%
LOAD		
Crew	180	
Instruments	10	
Guns & Ammunition	101	
TOTAL LOAD	291	20%
TOTAL WEIGHT OF MACHINE	1454	100%



ENGINE: 130 CLERGET
Type Air-cooled Rotary
Normal B.H.P. 127·75 R.P.M. 1250
Max. - R.P.M.
No. fitted One
Airscrew R.P.M. ÷ Engine R.P.M. 1.
Fuel per Normal B.H.P. Hour ·5715 lbs
Oil - - - - ·1563 lbs.
Fuel per Max. B.H.P. Hour
Oil - - - -

AEROPLANE: Sopwith Camel, F 1/3.
Type Single Seater Fighter
No. of Wings Biplane
Top Wing Span 28' Chord
Bottom - - 28' -
Middle - - - -
Overall Length 18' 8" Height 8' 6"
Gap, Top to Bottom Top to Mid.
Gap ÷ Chord . Dihedral
Dist. bet. Lead. Edges of Lower Wing & T.P.

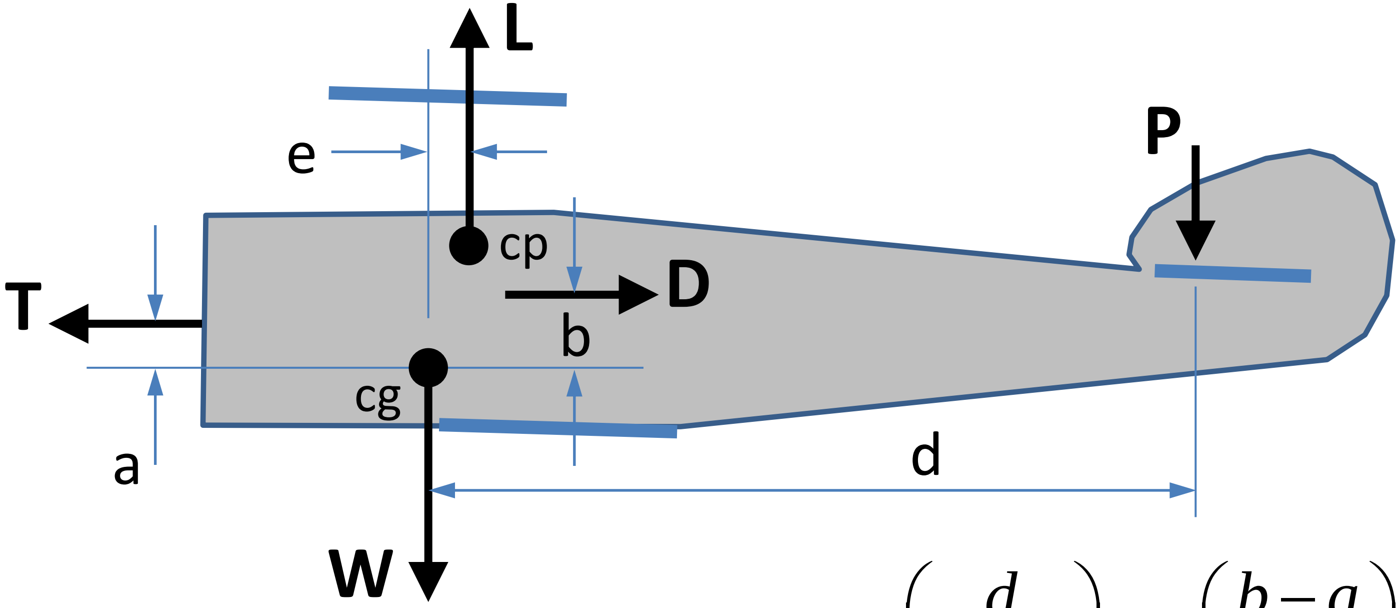
	Areas ⌀			Weights Lbs.	Wt./Sq. Ft.	% Weight
Structure	121	Wings	Top Plane	104	·9	
	110		Bottom Plane	90	·8	
			Middle Plane	-		
			Struts (No. = 8)	15		
			External Bracing Wires	20		
	231		Total Wings.	229	1·0	15·75
	14	Tail	Tail Planes	13	·9	
	10·5		Elevators	8	·8	
	3		Fins	2	·8	
	4·9		Rudders	3 5	·7	
	32·4		Total Tail.	27	·8	1·85
		Body	Fuselage	108		74.
			Chassis	70		4·8
			Tail Skid	3		
			Controls	14		·9
			Total Body.	195	·845	13·4
			Total Weight of Structure Unit.	451·	1·95	31·0
Power		Plant	Engine Dry	375	Wt./H.P. 2·9	
			Propeller	30	·2	
	Galls.		Radiator & Piping & Water	-		
			Engine Accessories	27	·2	
			Power Unit, excluding fuel, oil, tanks	432	3·4	29·7
	Galls. 26	Supplies	Fuel Tanks	24	[illegible]	
	- 6		Oil Tanks & Piping (Pipes for fuel & oil 6½)	13	[illegible]	
	Hours 2½		Fuel	180	1·4	
	-		Oil	63	·5	
			Total Weight of Power Unit.	712·	5·6	49·0
Load		Human	Crew	180		13·0
			Instruments	10		
		Reconnaissance	Camera	-		
			W.T.	-		
			Sundries	-		
		Armament	Guns & Ammunition	101		7·
			Bombs & Gear	-		
			Armour	-		
			Total Weight of Load Unit.	291	2·3	20·0
Air Board			Total Weight of Machine.	1454	6·3 per ⌀ / 11·4 HP	100·0

Fig. 5. Analysis of Weight. Sopwith–Camel.

Structure	31%
Powerplant	32%
Fuel	17%
Load	20%
	100%

Load Factor ~5-7

Loads Balance



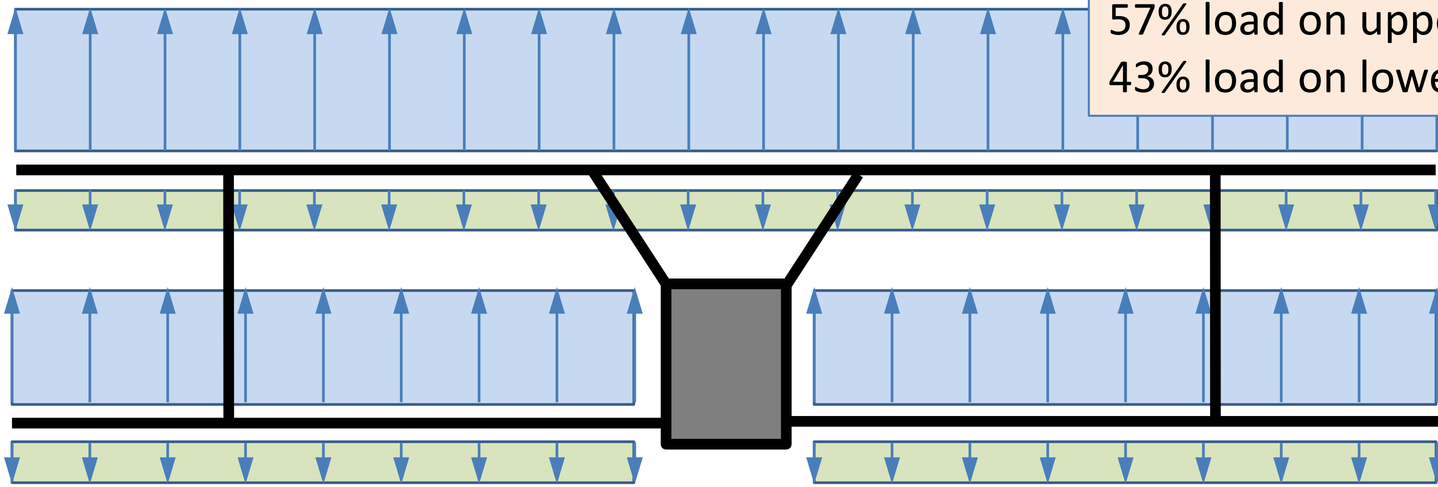
$$L = W\left(\frac{d}{d-e}\right) - T\left(\frac{b-a}{d-e}\right) \approx W\left(\frac{d}{d-e}\right)$$

$$P = L - W$$

Condition	W (lb)	e (in)	d (in)	L (lb)	P (lb)
cp fwd	1455	-5.9	147	1399	-56
cp aft	1455	4.9	147	1505	50

Load Factor = 1

Wing Load Distribution



57% load on upper wing
43% load on lower wing

L = total air load
w = wing weight
A_T = upper wing area
A_B = lower wing area

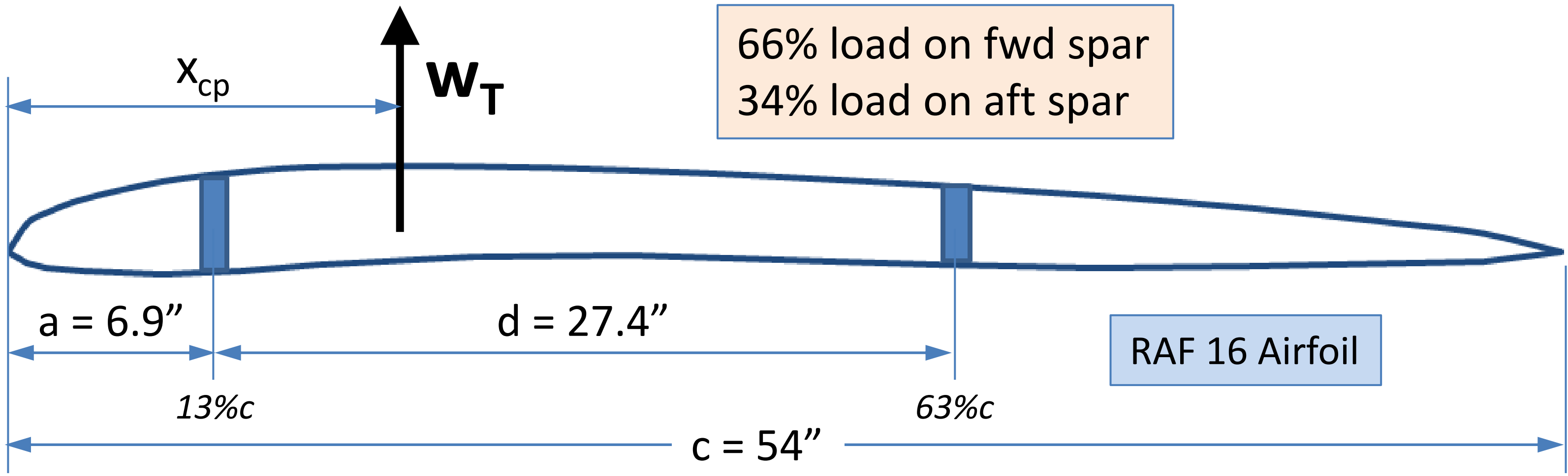
$$\text{Load on Upper Wing} = (L - w)\frac{1.2A_T}{1.2A_T + A_B}$$

$$\text{Load on Lower Wing} = (L - w)\frac{A_B}{1.2A_T + A_B}$$

L (lb)	w (lb)	L-w (lb)	A_T (ft^2)	A_B (ft^2)	L_T (lb)	L_B (lb)
1399	220	1179	125	115	667	512

Load Factor = 1

Spar Load Distribution



w_T = running load (per length of span)
a = distance from LE to front spar
b = distance from front spar to aft spar
x_{cp} = distance from LE to cp for load condition

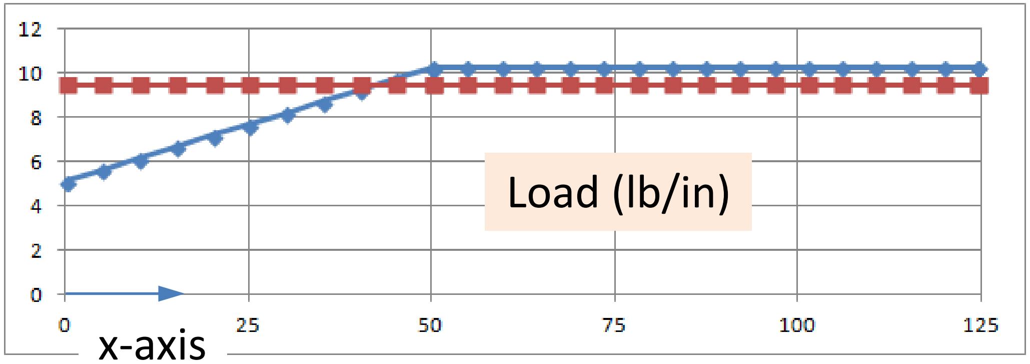
$$\text{Load on Front Spar} = \left(\frac{a+d-x_{cp}}{d}\right)w_T$$

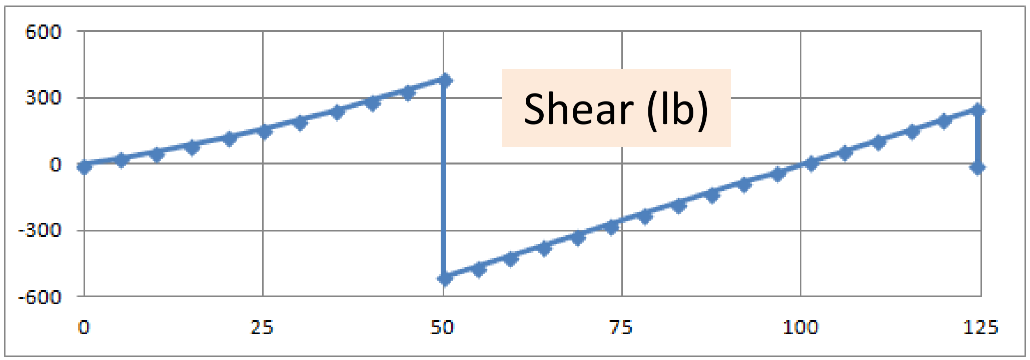
$$\text{Load on Aft Spar} = \left(\frac{x_{cp}-a}{d}\right)w_T$$

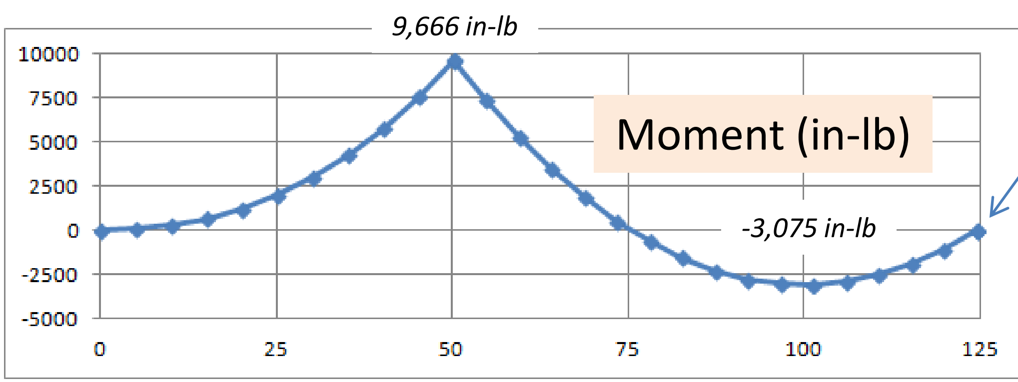
Load Factor = 1

Condition	w_T (lb/in)	x_{cp} (in)	a (in)	d (in)	Front Spar Load (lb/in)	Aft Spar Load (lb/in)
cp fwd (0.3c)	2.00	16.2	6.9	27.4	1.32	0.68
cp aft (0.5c)	2.14	27	6.9	27.4	0.57	1.57

Front Upper Spar Bending Loads

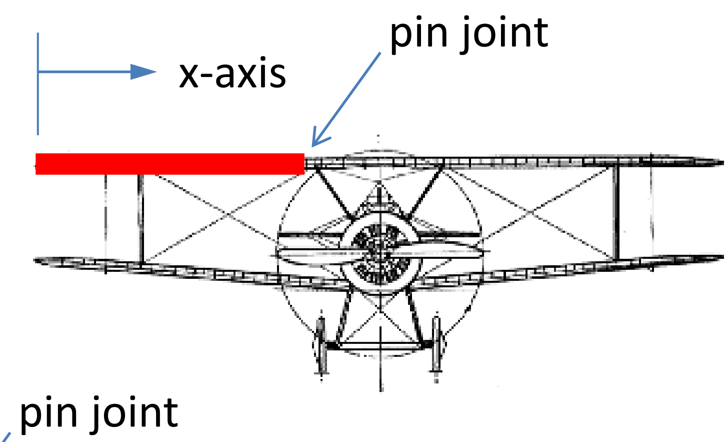






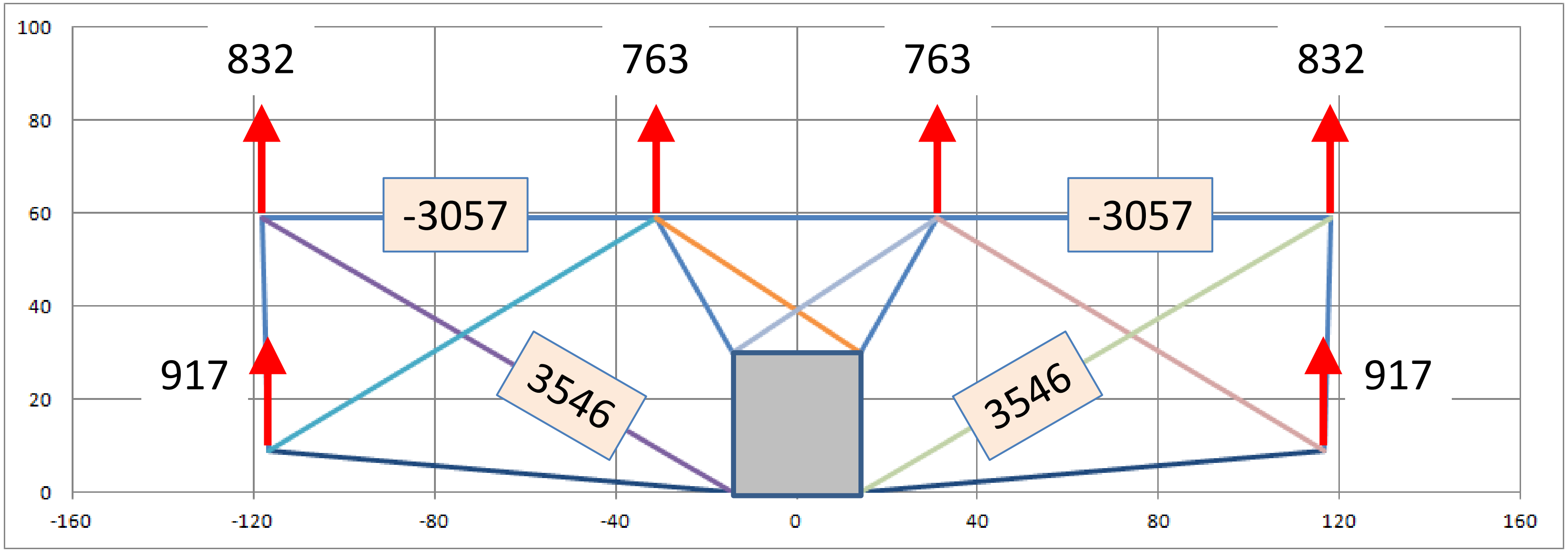
cp Forward Condition

Load Factor = 7



Front Truss Loads

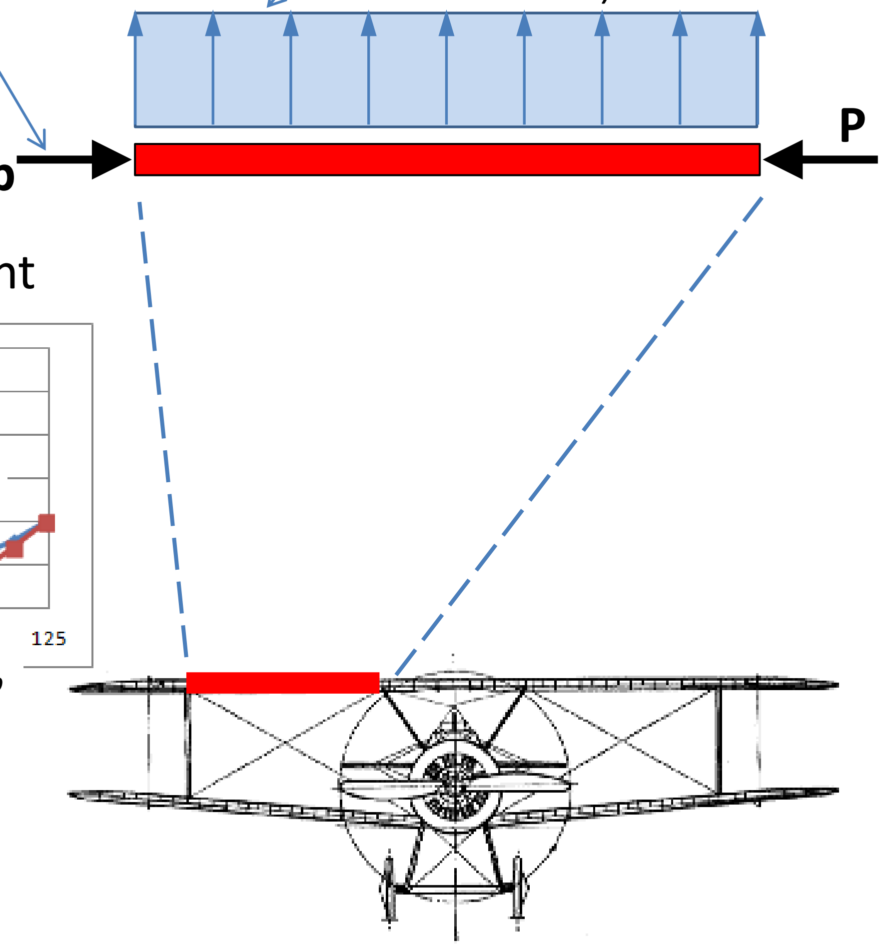
cp Forward Condition
Load Factor = 7

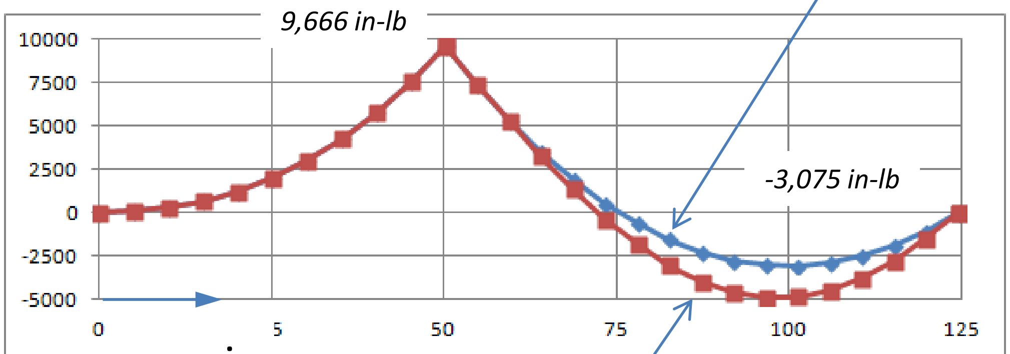


Spar compression load = -3057 lb
Lift wire tension load = 3546 lb

Beam-Column Magnification

cp Forward Condition
Load Factor = 7

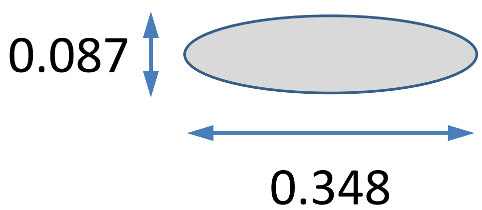




Bending Moment Magnified 59%
due to presence of compression

Flying Wires

Steel Flying Wires
¼" BSF
Strength = 3450 lb

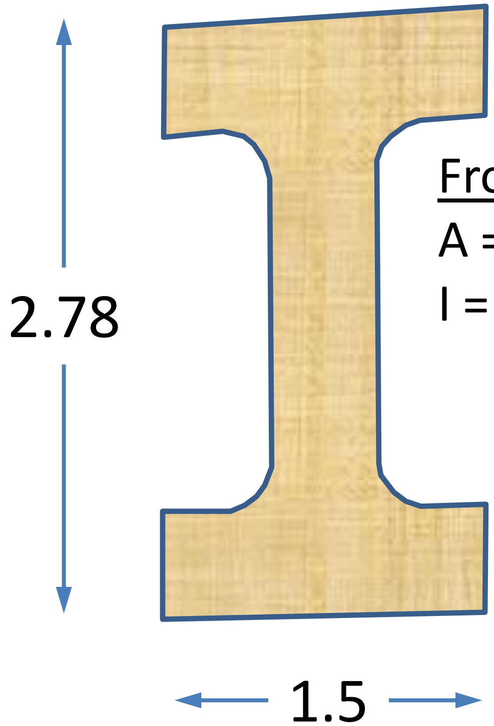


Total Load = 3546 lb
Load per wire = 1773 lb

$$M.S. = \frac{3450}{1773} - 1 = 0.95$$

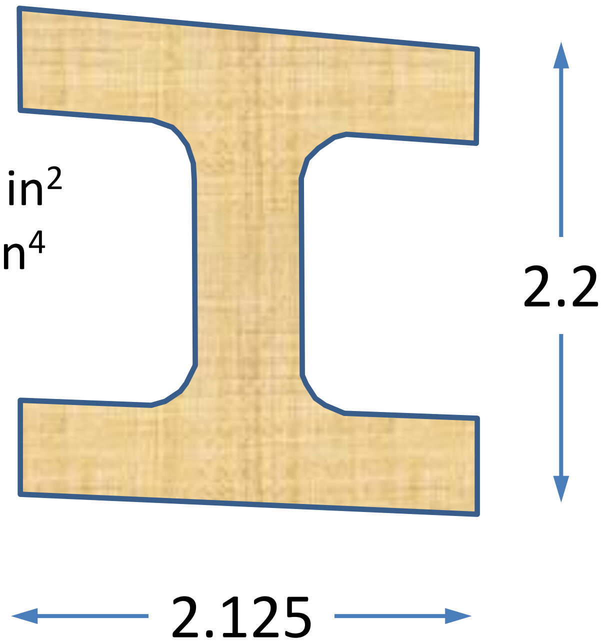
Flying wires were doubled for extra safety

Spar Stresses



Front Spar
$A = 2.445\ in^2$
$I = 2.256\ in^4$

Rear Spar
$A = 2.603\ in^2$
$I = 1.611\ in^4$



Compression		
Load	3057	lb
Stress	1250	psi
Allowable	5000	psi
Ratio	0.25	
Bending		
Load	9666	in-lb
Stress	5955	psi
Allowable	9400	psi
Ratio	0.63	

Spruce
$E = 1.3 \times 10^6$ psi
Fc = 5000 psi
Fb = 9400 psi

$$M.S. = \frac{1}{R_c + R_b} - 1 = \frac{1}{0.25 + 0.63} - 1 = 0.13$$

After the War…

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Summary

- Biplanes are structurally efficient (due to truss action) and were dominant in WW1 & the 1920s
- Monoplanes became more prevalent as engine power and speeds increased in the 1930s, becoming dominant in WW2
- The WW1 era structural analysis process was similar to todays, but we use more complex models, more load conditions, and durability is more important

References

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9. The Performance Paradox: W.W.I Fighter Design, Javier Arango, Society of Experimental Test Pilots, 53rd Symposium, 23-26 September 2009
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Disclaimer: The calculations shown here were made in the interest of historical study only. Due to the unavailability of certain key data, assumptions had to be made which mean that the results presented here cannot be used for a real airplane. Do not use any of the numbers presented here for any purpose.