STRUCTURAL AIRWORTHINESS

Load Calculation for KIS

by

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Load Calculation

What do we need?

Aircraft Weights

Geometry

Design Speeds

V-n Data

Aerodynamic Data

Mass Data

Engine Thrust or Power

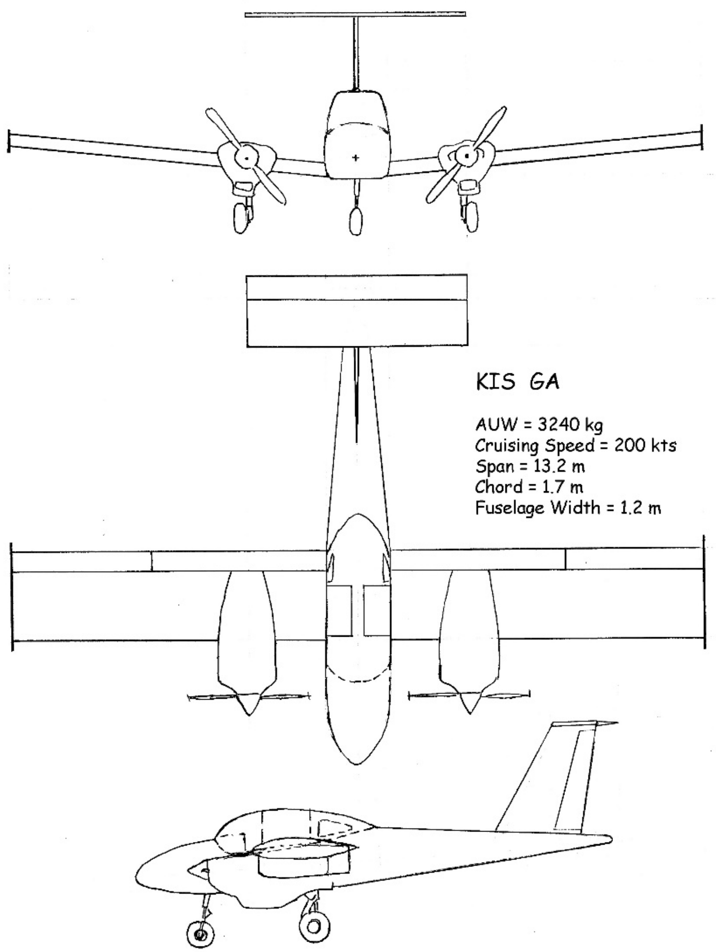
Systems Data (Fuel, EFCS etc)

Also we need to know the Airworthiness Regulation

the aircraft is to be certified to.

This exercise will use a mixture of CS23 and 25

AIRCRAFT GA


KIS GA
AUW = 3240 kg
Cruising Speed = 200 kts
Span = 13.2 m
Chord = 1.7 m
Fuselage Width = 1.2 m

Load Calculation

The worked example is going to evaluate the shear force, bending moment and torque at the wing root (body side) for 3 flight conditions and 2 ground conditions

The 3 flight conditions being

1g level flight

3.5g Manoeuvre

-1.4g Manoeuvre

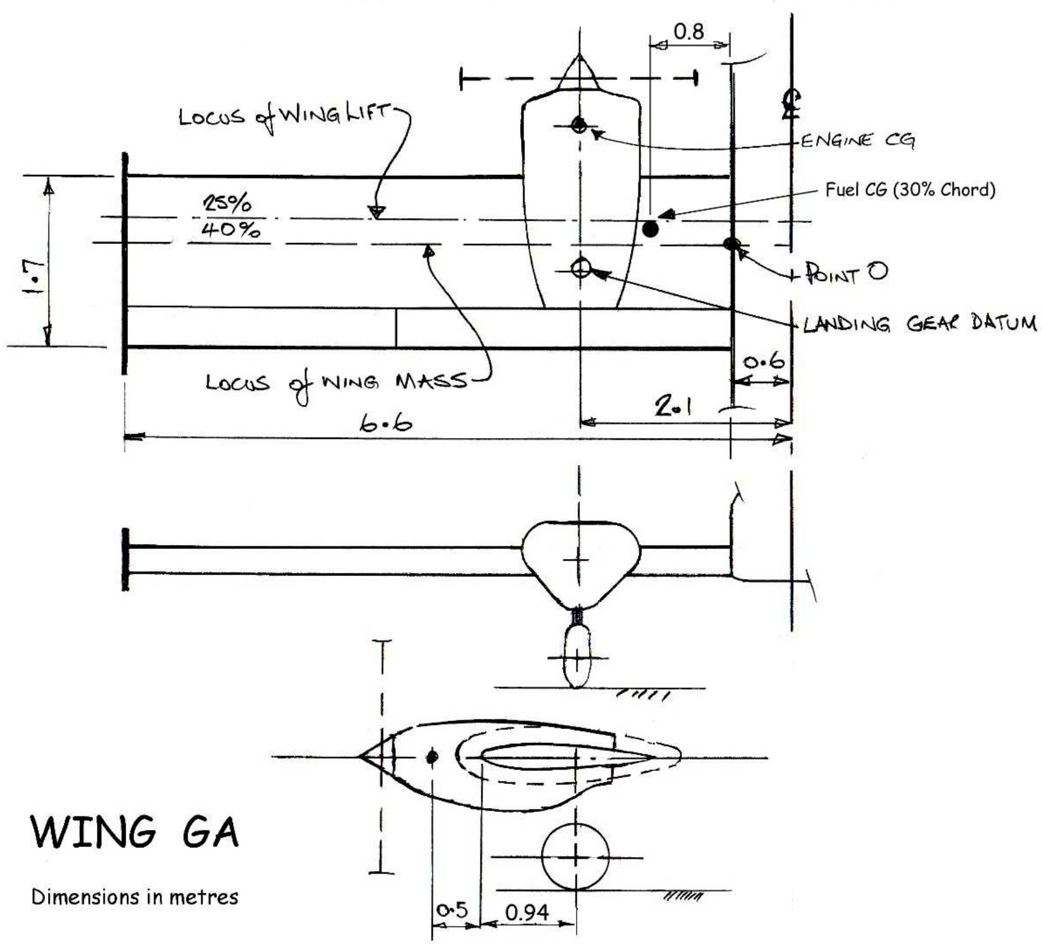
The ground cases being

2.2g bump on take-off (no airload)

Landing case with a reaction factor of 2.0

The aerodynamic loading and the mass loading will be derived separately and then summed for relevant case.

WING GA



WING GA

Dimensions in metres

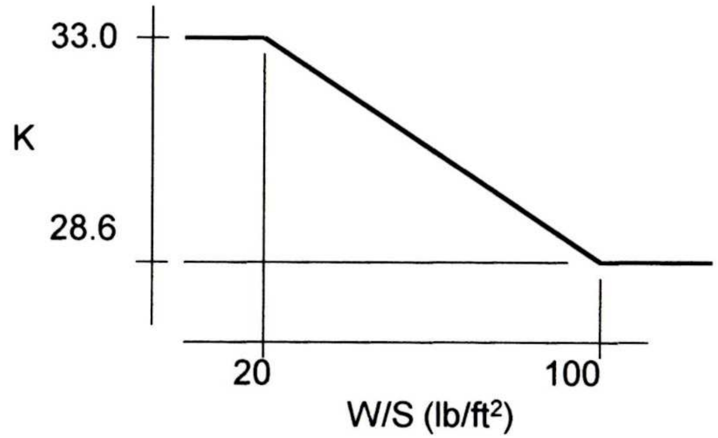
Load Calculation

Design Speeds

V_C

Given V_C =200 kts but need to check

$$V_{CMIN}\ (\text{kts}) = K \times \sqrt{\frac{W}{S}}$$



W/S = 3240 x 9.80665/22.44 = 1415.9 N/m2 (29.57 lb/ft^2)

By interpolation K = 32.47

V_{CMIN} (kts) = 176.6 kts (90.8 m/s)

For W/S in N/m^2 and V in kts	
33 - 20	4.769 - 957.6
28.6 - 100	4.133 - 4788

V_D

$V_D = 1.4\ V_{CMIN}$ or $1.25\ V_C$

= 247 or 250 kts (128.6 m/s)

Load Calculation

V_S

Using C_{LMAX} = 1.35

$$V_S = \sqrt{\frac{2Wg}{\rho_0 C_{LMAX} S}} = \sqrt{\frac{2 \times 3240 \times 9.80665}{1.225 \times 1.35 \times 22.44}} = 41.38\, m/s\,(80.44kts)$$

V_A

$V_A = V_S \times \sqrt{n}$ but what is the value of n

$n = 2.1 + \dfrac{24000}{W + 10000}$ with W in lb $n = 2.1 + \dfrac{106757}{W + 44482}$ with W in Newtons

with n not greater than 3.8 and not less than 2.5 for normal category aircraft

n = 3.5g   Negative value is usually 40% of positive value = -1.4g

$$V_A = 80.44 \times \sqrt{3.5} = 150.5kts(77.4m/s)$$

Load Calculation

V_B

V_{BMIN} is the lesser of the intersection of n due to C_{LMAX} with n due to gust

or $V_B = V_S \times \sqrt{n_{gust V_C}}$

Intersection comes from $$n = \frac{C_{L\,max}\rho_0 V^2 S}{2W} = 1 + \frac{KaUV\rho_0 S}{2W}$$

Solving for speed gives $$V = \frac{KaU}{2C_{LMAX}} + \sqrt{\left(\frac{KaU}{2C_{LMAX}}\right)^2 + \left(\frac{2W}{\rho_o C_{LMAX} S}\right)}$$

Load Calculation

Data required to derive n_{gust} and Results

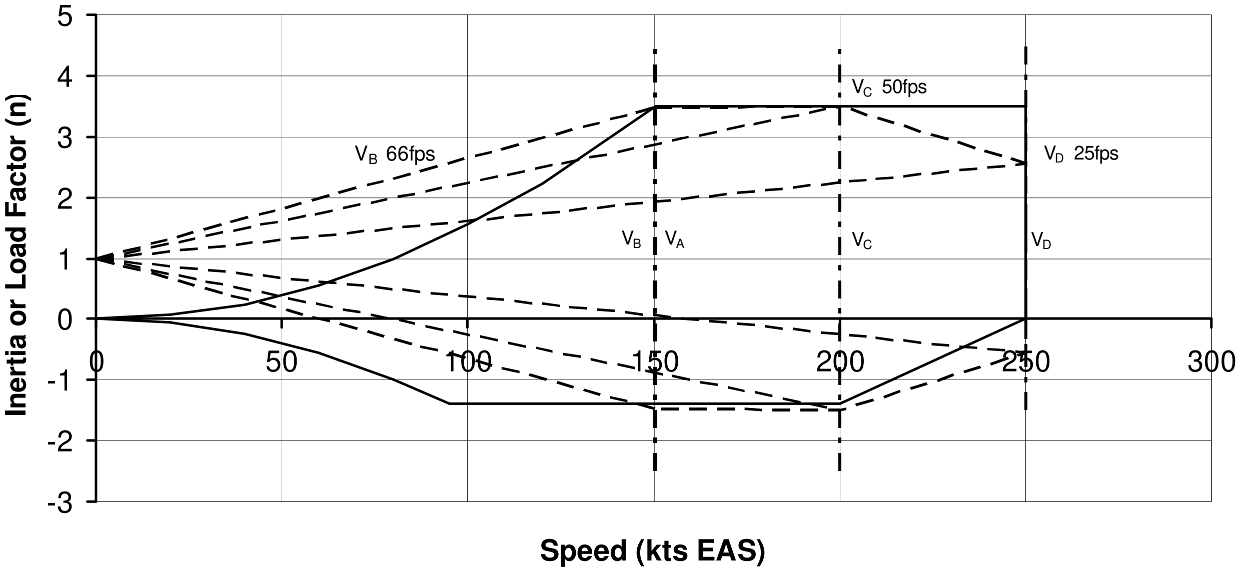
W	3240	kg			
S	22.44	m^2			
c	1.7	m			
ρ_o	1.225	kg/m^3			
a	5				
C_{Lmax}	1.35				
V_S	41.38	m/s			
V_S	80.44	kts			
V_A	150.5	kts			
		VB(Cl)	VB(vc)	VC	VD
V	kts	150.11	150.60	200	250
V	m/s	77.22	77.48	102.89	128.61
U	ft/sec	66	66	50	25
U	m/s	20.1168	20.1168	15.24	7.62
ρ	kg/m^3	1.225	1.225	1.225	1.225
μ		27.7330	27.7330	27.7330	27.7330
K		0.7388	0.7388	0.7388	0.7388
Δn		2.48	2.49	2.51	1.57
n pos	$1+\Delta n$	3.48	3.49	3.51	2.57
n neg	$1-\Delta n$	-1.48	-1.49	-1.51	-0.57

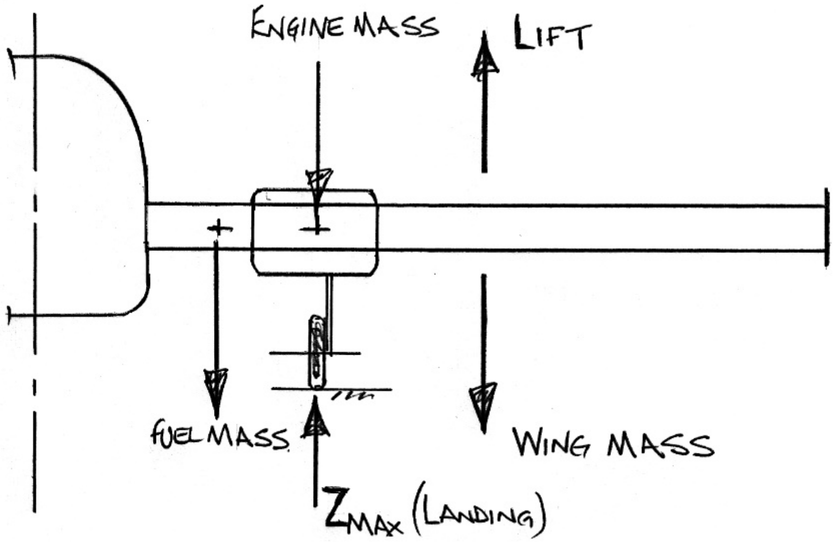
Value Required

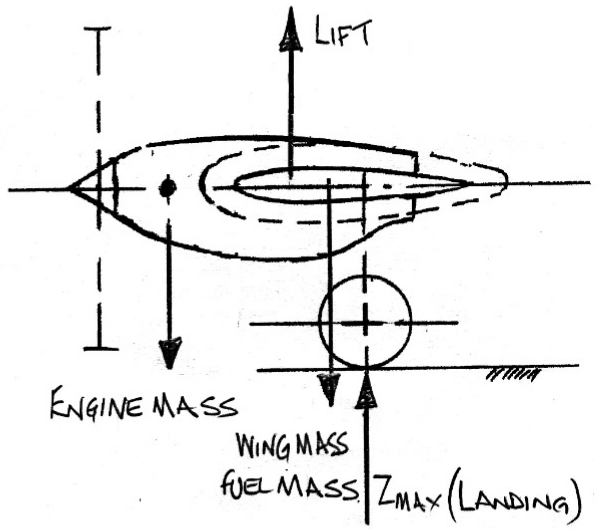
Load Calculation

Design Speeds, Manoeuvre and Gust Envelope

VS	80.4 kts
VA	150.5 kts
VB	150.1 kts
VC	200 kts
VD	250 kts




ENGINE MASS
LIFT
FUEL MASS
WING MASS
ZMAX (LANDING)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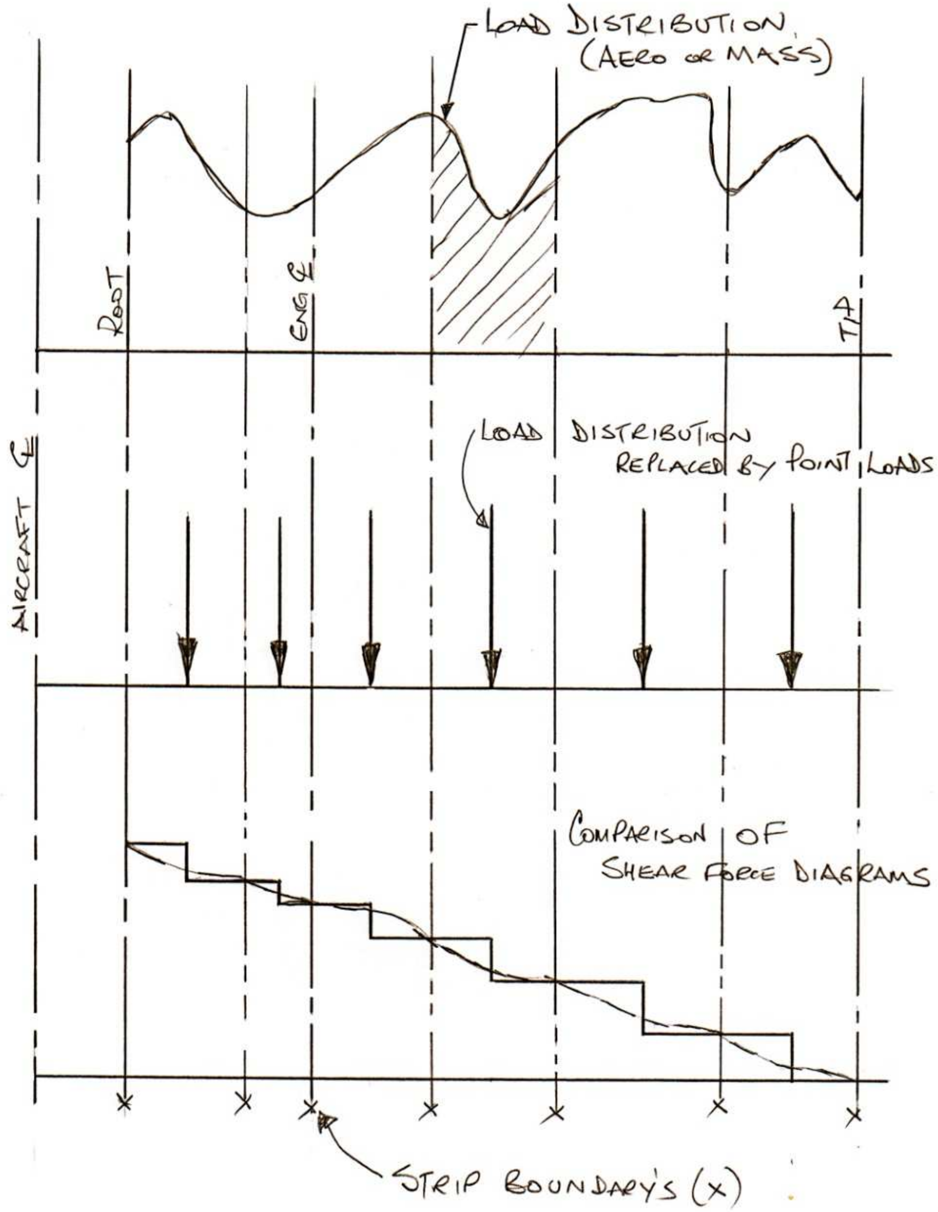

LOAD DISTRIBUTION (AERO OR MASS)
ROOT
ENG ℄
TIP
AIRCRAFT ℄
LOAD DISTRIBUTION REPLACED BY POINT LOADS
COMPARISON OF SHEAR FORCE DIAGRAMS
STRIP BOUNDARY'S (X)

Load Calculation

The Lift on the complete aircraft comes from its separate components and its distribution depends on Weight, inertia factor, CG, and Speed.

Typical $L = L_W + L_F + L_T$ where the suffixes W, F and T represent the Wing , Fuselage and Tailplane

L_T depends on n, CG and Speed, and for trim on a conventional aircraft acts downwards. The distribution between L_W and L_F depends largely on their relative sizes and shapes as they are usually rigidly connected.

L_T can vary from 0 to 20% of aircraft weight and acts downwards.

Taking $L_W + L_F = 100$, then typically $L_W = 84$ and $L_F = 16$

Assuming that the lift on the fuselage equals the down load on the tail, then

the lift on the exposed wing outboard of the root equals the weight of the aircraft times the inertia factor

$$L = nW$$

Load Calculation - Aerodynamic

The wing lift is uniformly distributed from root to trip

The reference point will be at the wing root at 40% chord

SF at root = Lift/2 = nW/2

For **1g Flight** SF = 1 x 3240 x 9.80665/2 = **15887** N (upwards)

BM at root = Lift/2 x distance of centre of lift from root (reference point)

= SF root x 6/2 =15887 x 3 = **47661** Nm (tip up)

Torque = Pitching Moment + Lift/2 x distance of centre of lift forward of reference point
+ Engine Thrust x vertical distance to reference point

= M_o + SF root x xac + Thrust x z_t

ignoring Mo and taking thrust as zero

= 15887 x 1.7(0.4 -0.25) = **4051** Nm (nose up)

Load Calculation - Mass

Wing Mass will be taken as 220 kg/side outboard of root
and is uniformly distributed from root to trip

Engine Mass will be taken as 300 kg/engine and Fuel Mass as 50 kg/side

SF_{root} = n x (wing mass + engine mass + fuel mass)

For **1g Flight** SF = 1 x 9.80665 x (220 + 300 + 50) = **5590** N (downwards)

BM at root = Wing Mass x distance of centre of gravity from root (reference point)
+ Engine Mass x distance of centre of gravity from root (reference point)
+ Fuel Mass x distance of centre of gravity from root (reference point)

$= W_{WING} \times 6/2 + W_{ENG} \times 1.5 + W_{FUEL} \times 0.8$

$= 220 \times 9.80665 \times 3 + 300 \times 9.80665 \times 1.5 + 50 \times 9.80665 \times 0.8$

= 6472 + 4413 + 392 = **11277** Nm (tip down)

Torque = Wing Mass x distance of centre of gravity forward of reference point
+ Engine Mass x distance of centre of gravity forward of reference point
+ Fuel Mass x distance of centre of gravity forward of reference point

$= W_{WING} \times 1.7(0.4 - 0.4) + W_{ENG} \times ((1.7 \times 0.4) + 0.5) + W_{FUEL} \times 1.7(0.4 - 0.3)$

$= 220 \times 9.80665 \times 0.0 + 300 \times 9.80665 \times 1.18 + 50 \times 9.80665 \times 0.17$

= 0 + 3472 + 83 = **3555** Nm (nose down)

Load Calculation - Total (LIMIT)

Flight Conditions

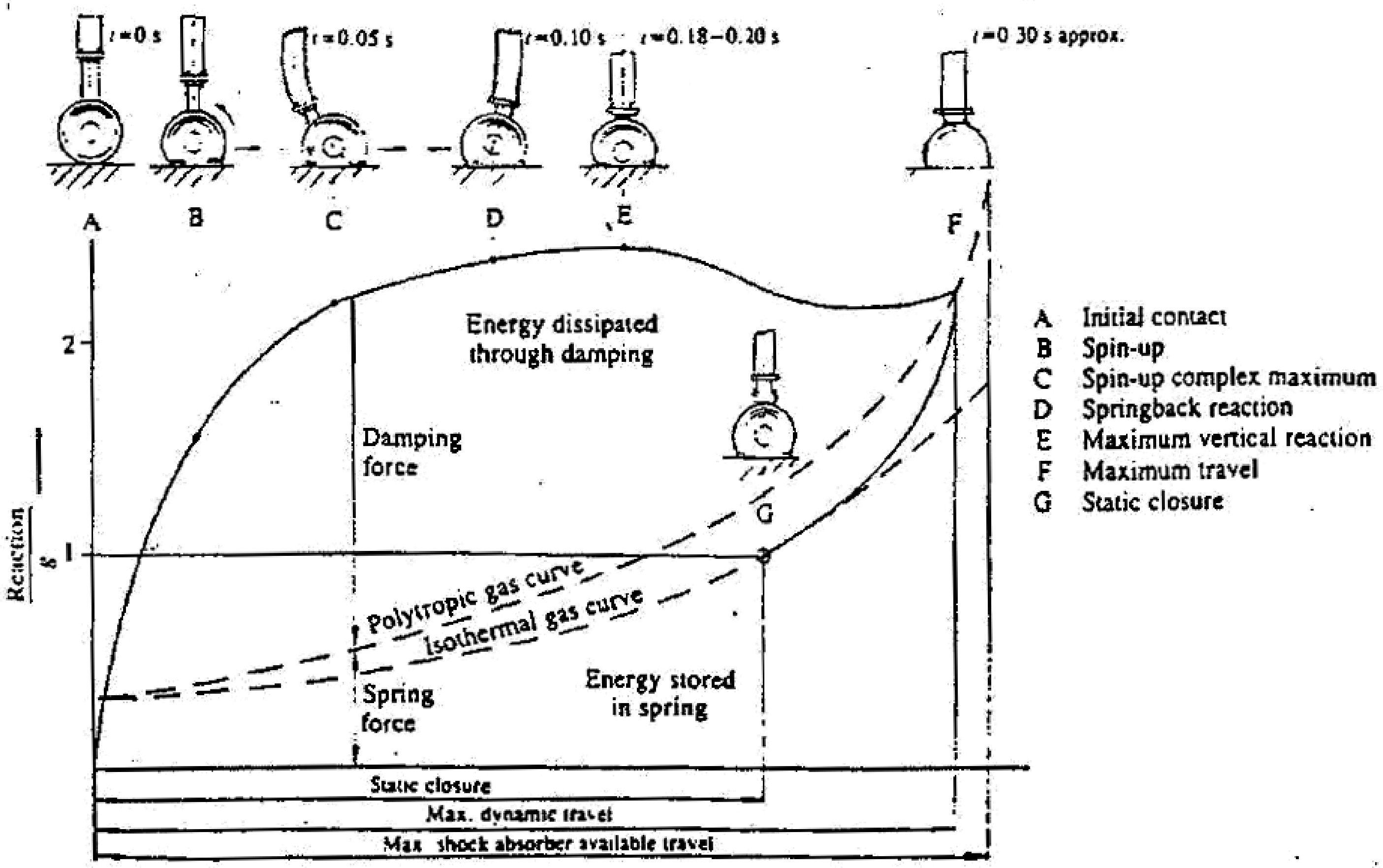
1g	SF =	15887 - 5590	= 10297 N (+ve upwards)
	BM =	47661 - 11277	= 36384 Nm (+ve tip up)
	T =	4051 - 3555	= 496 Nm (+ve nose up)
3.5g	SF =	10297 x 3.5	= 36040 N (+ve upwards)
	BM =	36384 x 3.5	= 127344 Nm (+ve tip up)
	T =	496 x 3.5	= 1736 Nm (+ve nose up)
-1.4g	SF =	10297 x -1.4	= -14416 N (+ve upwards)
	BM =	36384 x -1.4	= -50938 Nm (+ve tip up)
	T =	496 x -1.4	= -694 Nm (+ve nose up)

Load Calculation - Total (ULTIMATE)

Flight Conditions

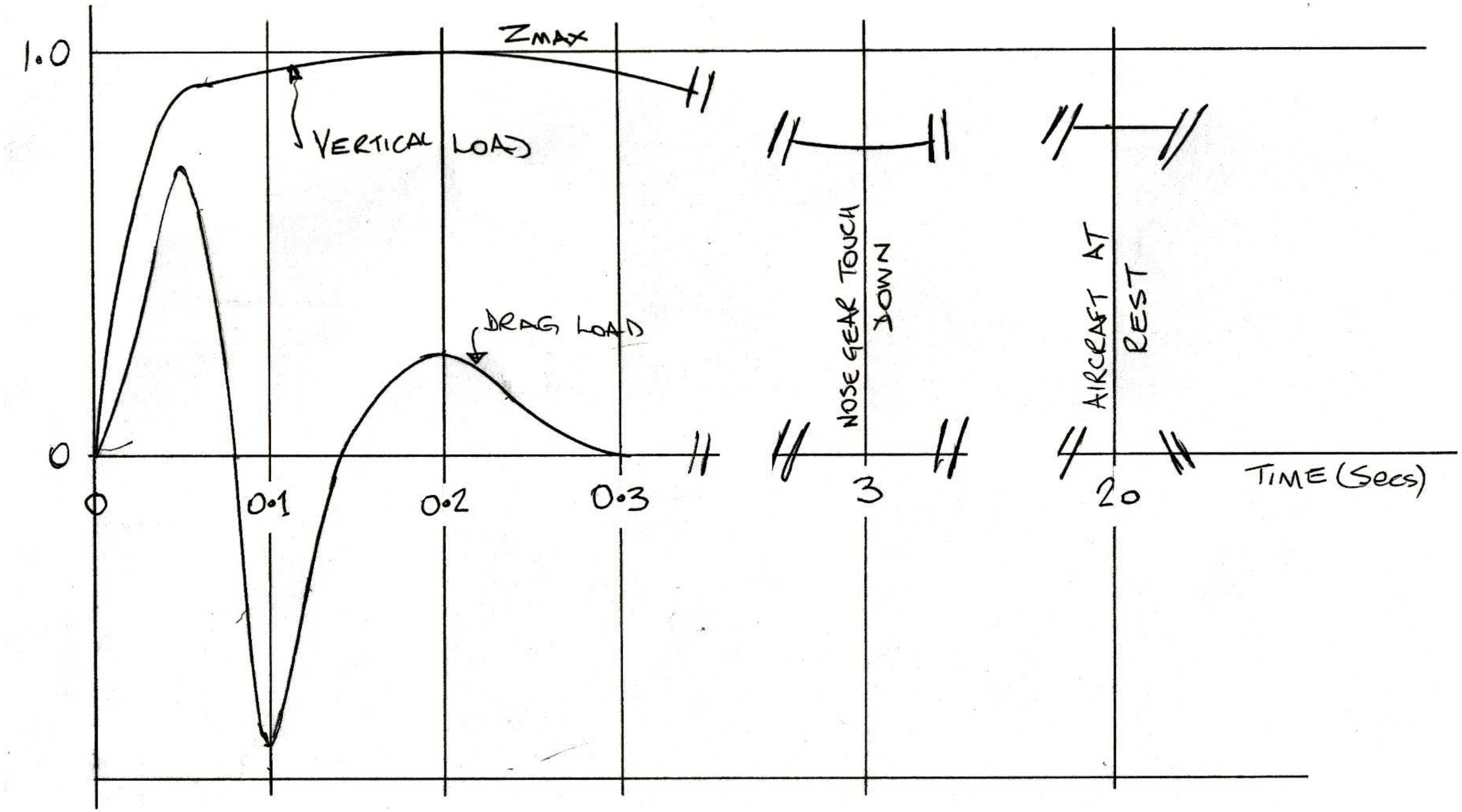
1g	SF = 10297 x 1.5 = 15446 N (+ve upwards)	
	BM = 36384 x 1.5 = 54576 Nm (+ve tip up)	
	T = 496 x 1.5 = 744 Nm (+ve nose up)	
3.5g	SF = 36040 x 1.5 = 54060 N (+ve upwards)	
	BM = 127344 x 1.5 = 191016 Nm (+ve tip up)	
	T = 1736 x 1.5 = 2604 Nm (+ve nose up)	
-1.4g	SF = -14416 x 1.5 = -21624 N (+ve upwards)	
	BM = -50934 x 1.5 = -76407 Nm (+ve tip up)	
	T = -694 x 1.5 = -1041 Nm (+ve nose up)	

Landing Gear Load Sequence



Significant events during the landing cycle

Landing Gear Time History



Load Calculation - Landing Impact (Ground Loads)

The Reaction Factor (λ) is the ratio of the Peak Vertical Load (on all gears) during the landing impact to the Landing Weight, for this aircraft it will be taken as 2.0

Fore and Aft Loads are ignored

Peak Vertical Ground Load (Z_{max}) = 3240 x 9.80665 x 2.0/2 =31774 N (per leg)

ΔSF = **31774** N (upwards)

ΔBM at root = Z_{max} x distance of landing gear datum from root (reference point)

= 31774 x 1.5 = **47661** Nm (tip up)

ΔTorque = Z_{max} x distance of landing gear datum from reference point

= Z_{max} x ((1.7 x 0.4) - 0.94) = 31774 x -0.26

= **8261** Nm (nose down)

The values for Take-Off bump case are obtained in a similar way giving:

Take-Off bump Vertical Ground Load = 3240 x 9.80665 x 2.2/2 =34951 N (per leg)

ΔSF = **34951** N (upwards)

ΔBM at root = 34951 x 1.5 = **52427** Nm (tip up)

ΔTorque = 34951 x -0.26 = **9087** Nm (nose down)

Load Calculation - Total (LIMIT)

Ground Conditions

Landing Case (Bump Increment - (λ x Mass) + 1g Level Flight)

SF = 31774 – (2 x 5590) + 10297 = 30891 N (+ve upwards)

BM = 47661 – (2 x 11277) + 36384 = 61491 Nm (+ve tip up)

T = -8261 – (2 x 3555) + 496 = -14875 Nm (+ve nose up)

2.2g Take-Off bump (Bump Increment - (2.2 x Mass))

SF = 34951 - (2.2 x 5590) = 22653 N (+ve upwards)

BM = 52427 - (2.2 x 11277) = 27618 Nm (+ve tip up)

T = -9087 - (2.2 x 3555) = -16908 Nm (+ve nose up)

Load Calculation - Total (ULTIMATE)

Ground Conditions

Landing Case SF = 30891 x 1.5 = 46337 N (+ve upwards)

BM = 61491 x 1.5 = 92237 Nm (+ve tip up)

T = -14875 x 1.5 = -22312 Nm (+ve nose up)

2.2g Take-Off bump SF = 22653 x 1.5 = 33980 N (+ve upwards)

BM = 27618 x 1.5 = 41427 Nm (+ve tip up)

T = -16908 x 1.5 = -25362 Nm (+ve nose up)

Load Calculation - Summary of ULTIMATE Loads at Wing Root

	Shear	Bending	Torque
	N	Nm	Nm
	+ve up	+ve tip up	+ve nose up
1g level flight	**15446**	**54576**	**744**
3.5g Manoeuvre	**54060**	**191016**	**2604**
-1.4g Manoeuvre	**-21624**	**-76407**	**-1041**
Landing Case	**46337**	**92237**	**-22312**
Take-Off (2.2g bump)	**33980**	**41427**	**-25362**