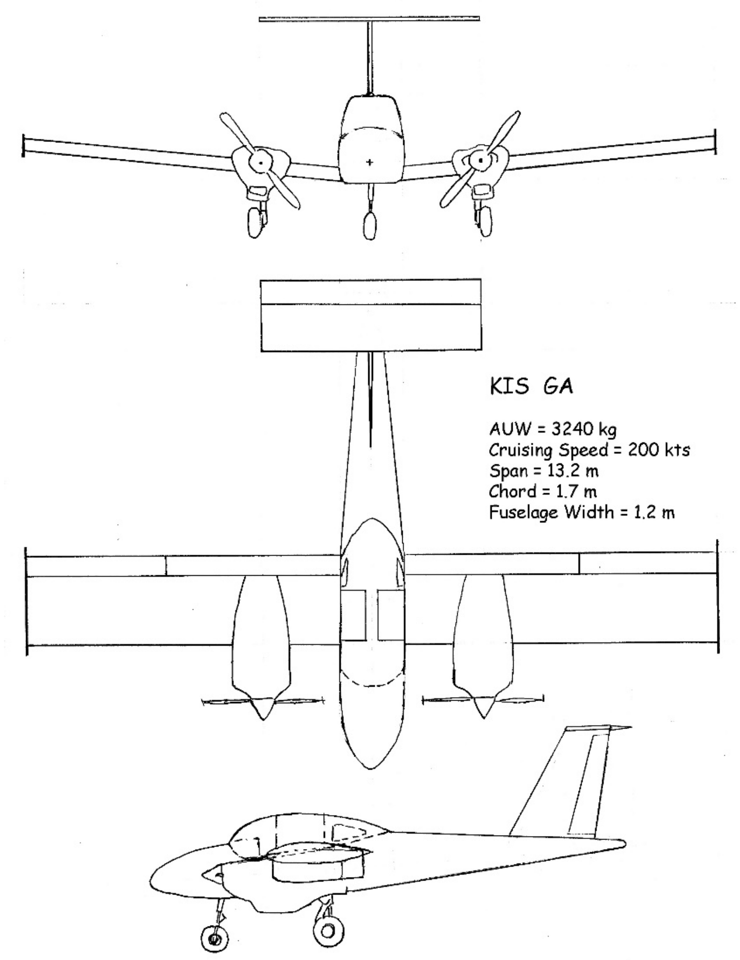
STRUCTURAL AIRWORTHINESS

by

Danny Heaton

AIRCRAFT GA


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

Introduction

What are LOADS or LOADING ACTIONS?

STRUCTURAL LOADS are the RESULTANT FORCES acting on the AIRCRAFT during TAKE-OFF, FLIGHT and LANDING and are mainly a FUNCTION of AERODYNAMIC and MASS (WEIGHT) EFFECTS

The STRUCTURAL LOADS are the RESULT of INTERPRETATING the REGULATIONS defined in CS/FAR and include

- PILOT INDUCED EFFECTS
- ATMOSPHERE (GUST) EFFECTS
- CHANGE FROM AIRBORNE TO NON-AIRBORNE (LANDING)
- EMERGENCY CONDITIONS (CRASH/DITCHING)
- BIRD STRIKE/HAIL IMPACT

STATIC, FATIGUE, OPERATING and FAILURE (INCLUDING JAMMING CONDITIONS) are INVESTIGATED

Design Cases for the Structure

The DESIGN CASES for the STRUCTURE result from the APPLICATION and INTERPRETATION of the AIRWORTHINESS REGULATIONS issued by the AIRWORTHINESS AUTHORITIES (EASA and FAA)

In Europe these regulations are known as CS's and in America FAR's

EASA (which issues Certification Specifications (CS)) has replaced the JAA which issued JAR's.

CS's and FAR's are very similar in wording, application and interpretation.

See web sites for further information

EASA https://www.easa.europa.eu/document-library/certification-specifications

FAR http://www.ecfr.gov/cgi-bin/text-idx?SID=e8dfe8f3a0baf95ea114fdafbaaf018b&mc=true&tpl=/ecfrbrowse/Title14/14cfrv1_02.tpl#0

Certification Specifications (CSs) http://easa.europa.eu/document-library/certification-specifications

Initial Airworthiness

AMC-20	General Acceptable Means of Compliance for Airworthiness of Products, Parts and Appliances
CS-22	Sailplanes and Powered Sailplanes
CS-23	Normal, Utility, Aerobatic and Commuter Aeroplanes
CS-25	Large Aeroplanes
CS-27	Small Rotorcraft
CS-29	Large Rotorcraft
CS-31GB	Gas Balloons
CS-31HB	Hot Air Balloons
CS-31TGB	Tethered Gas Balloons
CS-34	Aircraft Engine Emissions and Fuel Venting
CS-36	Aircraft Noise
CS-APU	Auxiliary Power Units
CS-E	Engines
CS-ETSO	European Technical Standard Orders
CS-LSA	Light Sport Aeroplanes
CS-P	Propellers
CS-SIMD	Simulator Data
CS-STAN	Standard Changes and Standard Repairs
CS-VLA	Very Light Aeroplanes
CS-VLR	Very Light Rotorcraft
CS-CCD	Cabin Crew Data
CS-FCD	Flight Crew Data

CS-AWO	All Weather Operations
CS-Definitions	Definitions and Abbreviations

Certification Specifications (CSs)

Additional airworthiness specifications

CS-26	Additional airworthiness specifications for operations

ADR - Aerodromes

CS-ADR-DSN	Aerodromes Design

Air Operations

CS-FSTD(A)	Aeroplane Flight Simulation Training Devices
CS-FSTD(H)	Helicopter Flight Simulation Training Devices
CS-FTL.1	Commercial Air Transport by Aeroplane - Scheduled and Charter Operations
CS-MMEL	Master Minimum Equipment List
CS-GEN-MMEL	Generic Master Minimum Equipment List

Aircrew

CS-FSTD(A)	Aeroplane Flight Simulation Training Devices
CS-FSTD(H)	Helicopter Flight Simulation Training Devices
CS-CCD	Cabin Crew Data
CS-FCD	Flight Crew Data

ATM/ANS - Air Traffic Management/Air Navigation Services

CS-ACNS	Airborne Communications, Navigation and Surveillance

CS–25

LARGE AEROPLANES

BOOK 1 – AIRWORTHINESS CODE

SUBPART A – GENERAL
SUBPART B – FLIGHT
SUBPART C – STRUCTURE
SUBPART D – DESIGN AND CONSTRUCTION
SUBPART E – POWERPLANT
SUBPART F – EQUIPMENT
SUBPART G – OPERATING LIMITATIONS AND INFORMATION
SUBPART H -- ELECTRICAL WIRING INTERCONNECTION SYSTEMS
SUBPART J – GAS TURBINE AUXILIARY POWER UNIT INSTALLATION
APPENDIX A
APPENDIX C
APPENDIX D
APPENDIX F
APPENDIX H – INSTRUCTIONS FOR CONTINUED AIRWORTHINESS
APPENDIX I – AUTOMATIC TAKEOFF THRUST CONTROL SYSTEM (ATTCS)
APPENDIX J – EMERGENCY DEMONSTRATION
APPENDIX K

BOOK 2 – ACCEPTABLE MEANS OF COMPLIANCE(AMC):

INTRODUCTION
SUBPART B – FLIGHT
SUBPART C – STRUCTURE
SUBPART D – DESIGN AND CONSTRUCTION
SUBPART E – POWERPLANT
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AMC APPENDIX F
GENERAL AMCs

AIRWORTHINESS

- All manned Aircraft have to satisfy a specific set of Airworthiness Regulations during design, manufacture and testing before they can be awarded a Type Certificate of Airworthiness.
- The Aircraft also have to meet the Specification laid down by the customer.
- In UK, airworthiness requirements are regulated by two authorities:
  Civil Aviation Authority (CAA) for private and public transport aircraft;
  Ministry of Defence via QinetiQ for military aircraft.
- The main civil regulations are Certification Specifications (CS) issued by EASA.EUROPA (EASA) in Europe and Federal Airworthiness Regulations (FAR) issued by the Federal Aviation Administration (FAA) in the USA.
- For military aircraft, the UK issues Def Stan 00-970 and the USA Mil Specs. These are for general requirements as the specification and detailed requirements are usually in another (secret) document.
- For civil aircraft, the C of A is awarded when it satisfies the appropriate regulations. It must not be used for reward or hire without this certificate.

AIRWORTHINESS

- The regulations cover all aspects of aircraft design and operation.
- Conformance with the regulations is by calculation, analysis and testing (rig and flight).
- All drawings and calculations must be available for inspection by the Airworthiness Authority
- Inspection (quality control) maintain close control to ensure that all parts and assemblies are manufactured according to the drawings.

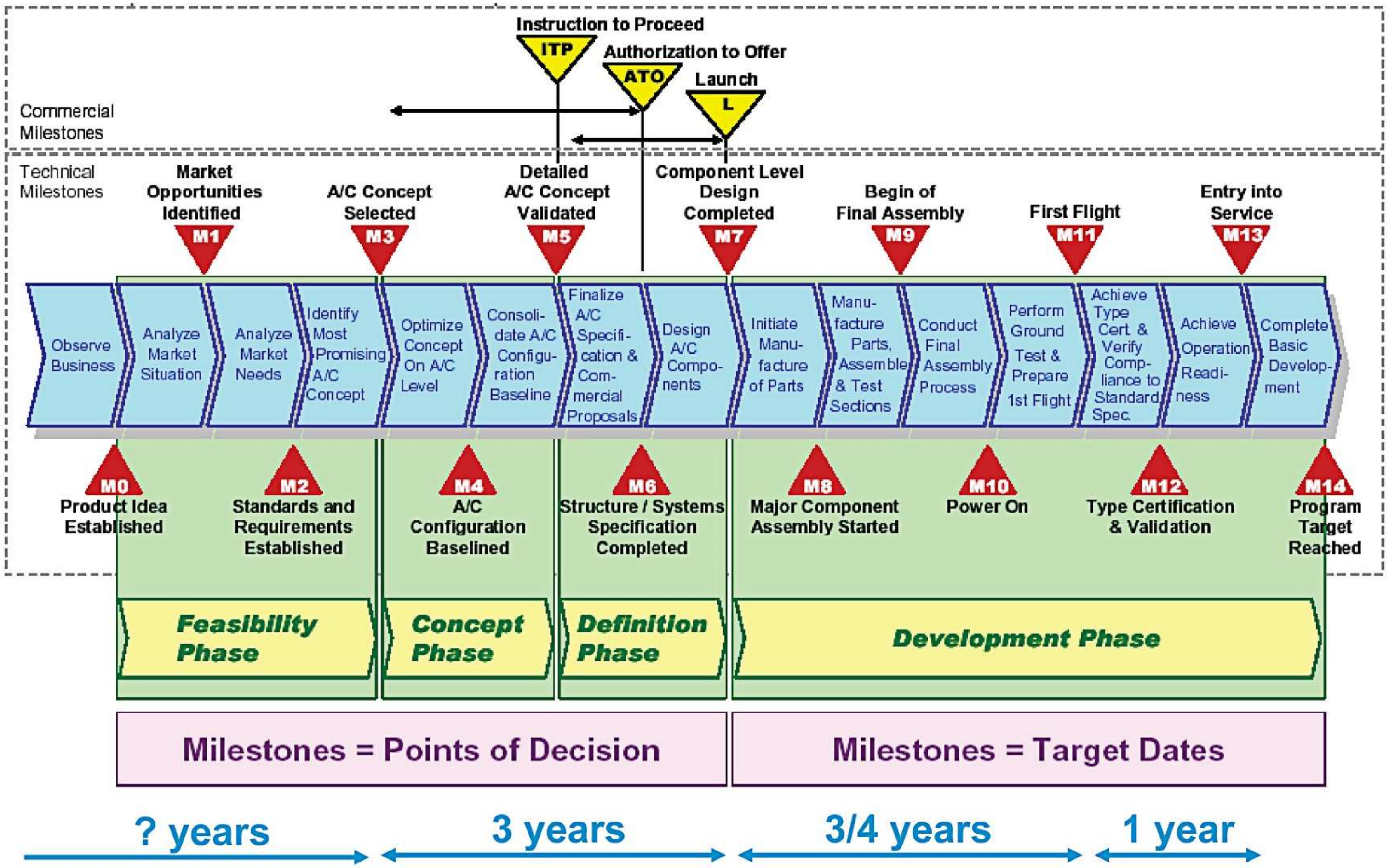
Certification of a Large Aircraft

Concept Phase

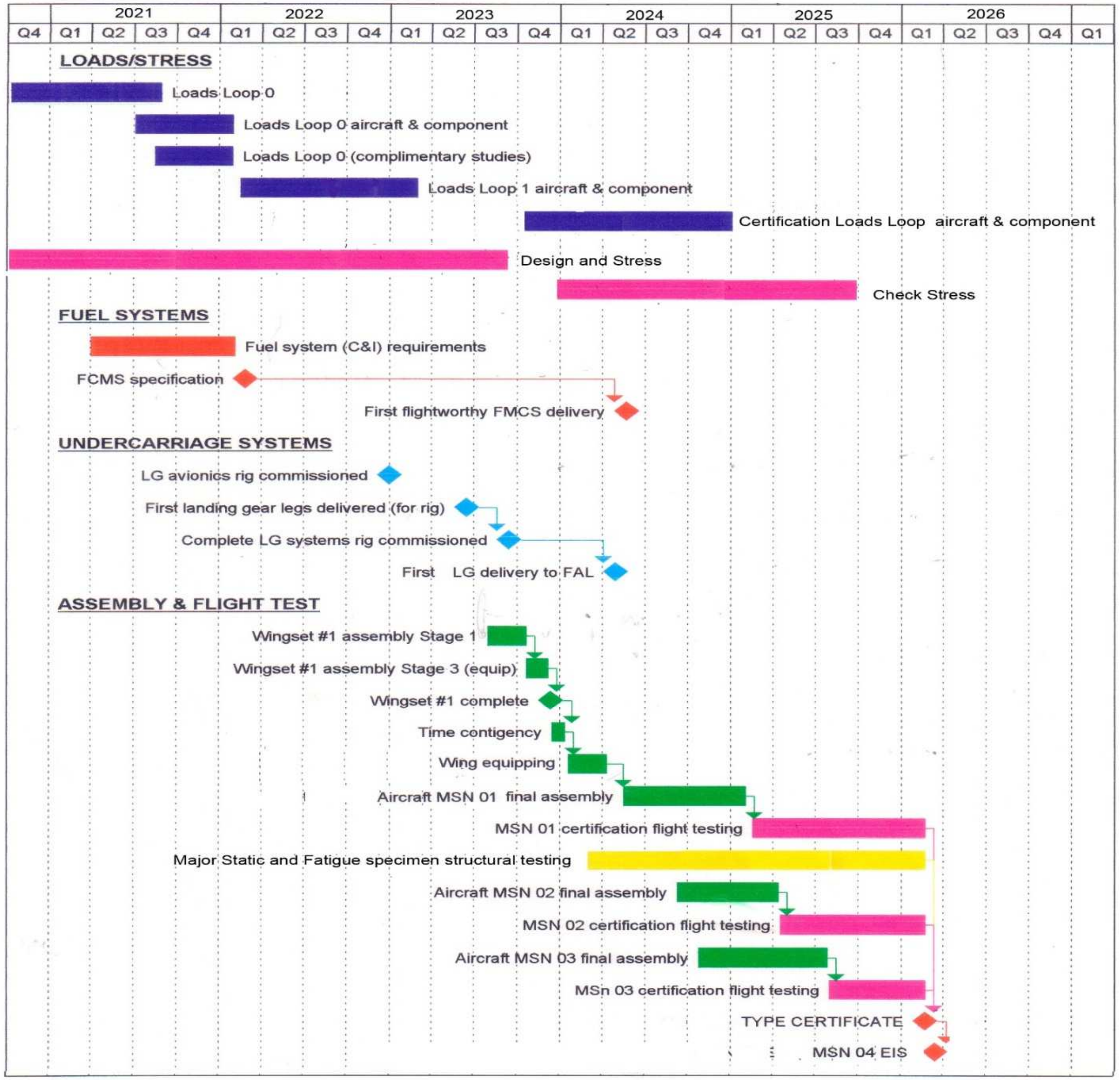
Design Development & Manufacture Phase

- **Establish requirements** to be met and likely Certification basis
  - Design - CS/FAR 25
  - Operational - EU OPS/FAR 91,121
- **Apply for Type Certificate** (application date sets 'revision' standard)
- **Presentation of Aircraft Design** to Airworthiness Authorities
- **Additional Military Requirements**
- **Determination of Certification Basis**
  - Latest issue requirement standard
  - Regulations in pipeline
  - Special conditions for novel features
- **Establish means of Compliance**
  (Analysis, Test, Flight Test, Simulation etc)
- **Demonstrate means of Compliance** through Development and Test Programme and Specialists meetings
- **Type Board Meeting** with Airworthiness Authorities
- **Grant Type Certificate** and individual Certificate of Airworthiness

Typical Design Process



Top Level Programme



Types of Loading

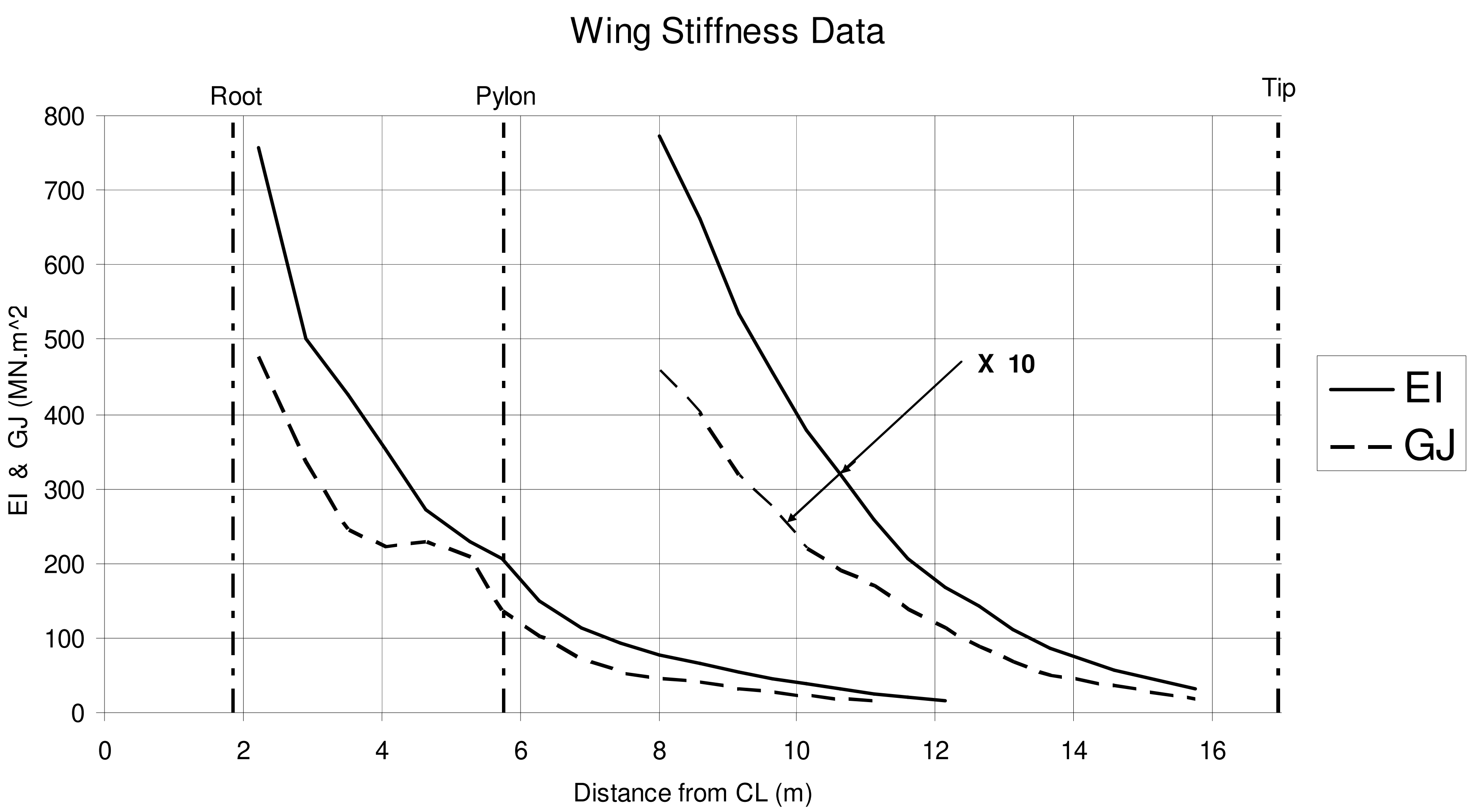
STATIC LOADING	The ONE big load that the Structure is Designed to withstand (=Limit Load)
FATIGUE LOADING	The repeated or cyclic loading that the Structure should withstand for a given number of hours and/or flights
OPERATING LOADS	Anything that moves (like slats and flaps)
RIGID/FLEXIBLE CONDITIONS	Most, if not all structures are flexible in that they distort/deform under load. However some structures are more flexible than others

Flexibility affects loading in two ways

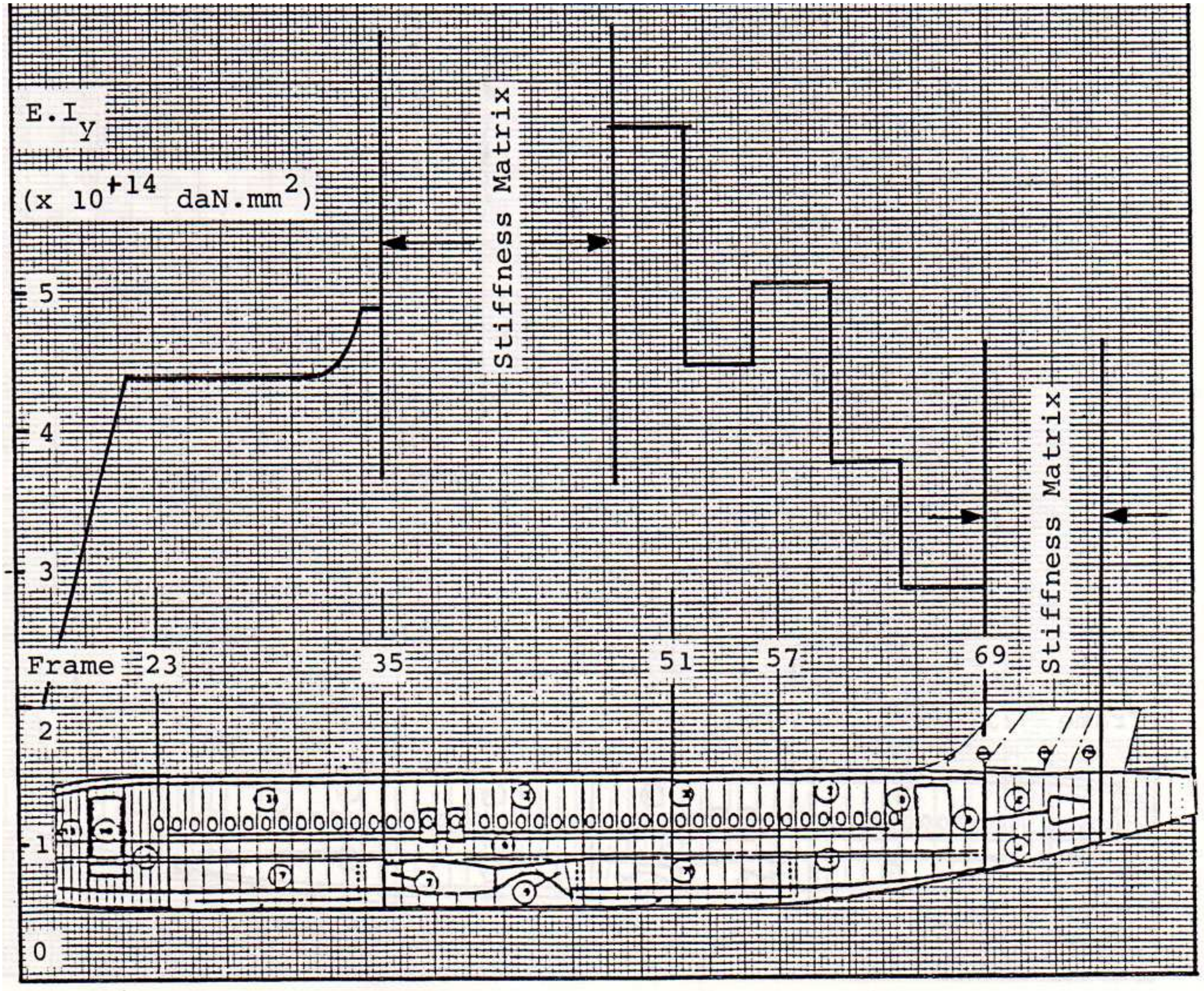
- -Slowly applied loads like the bending of a wing in manoeuvre cases which in turn affects the aerodynamic loading
- -Rapidly applied loads like gusts or landing which give rise to dynamic effects (usually a function of the natural frequency of the aircraft or component)

Wing Bending Frequencies

Aircraft	Wing Area (m2)	Weight (Tonnes)	Frequency(Hz)
125	33	9-10	5.0
1-11	91	40-47	3.5
Trident	135	64-70	3.0
A320	122	66-77	2.3
A310	219	132-164	1.9
A300	260	137-171	1.7
A330/A340	361	208-275	1.3
A380	845	540-590	0.9


Wing Stiffness Data
Root
Pylon
Tip
X 10
EI
GJ
EI & GJ (MN.m^2
Distance from CL (m)
0
100
200
300
400
500
600
700
800
0
2
4
6
8
10
12
14
16

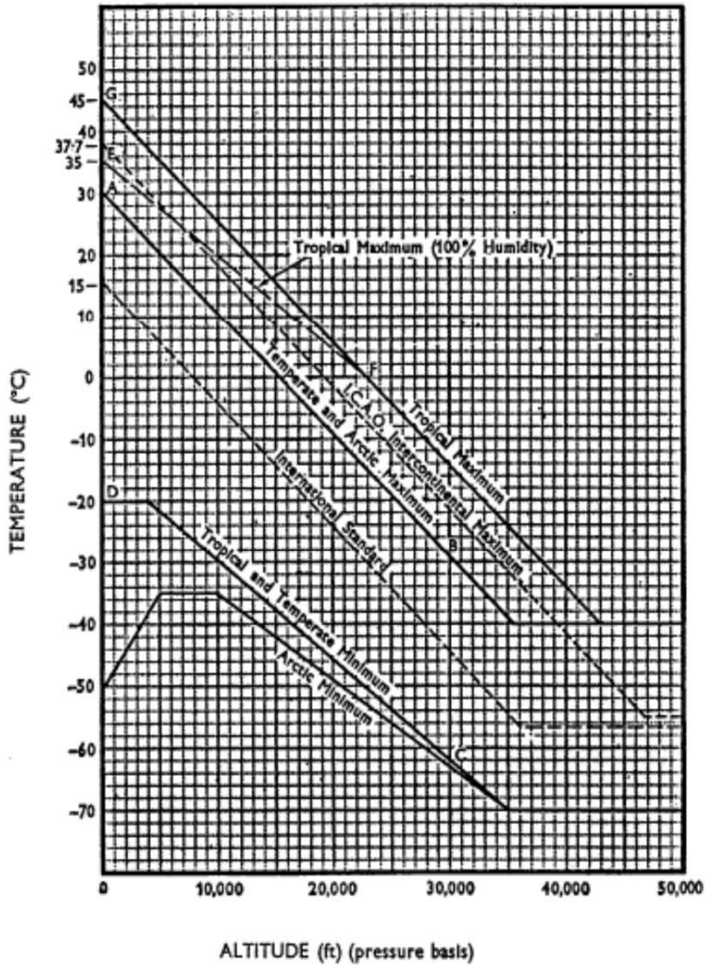
Fuselage Stiffness Data



FACTORS of SAFETY

(or limit/proof/ultimate loads)

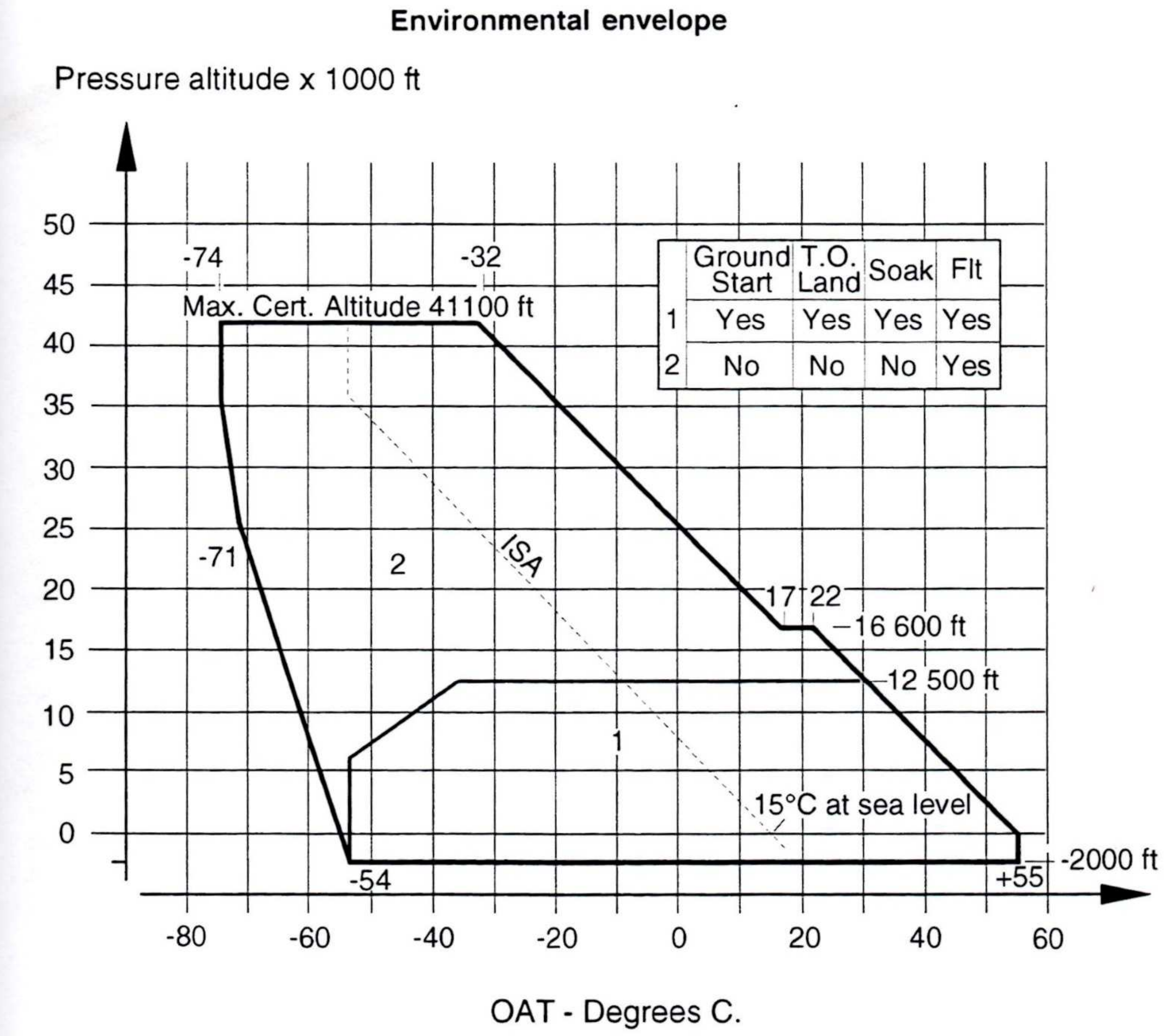
LIMIT LOAD	(or UNFACTORED LOAD) - This is the largest load likely to occur during operations
PROOF LOAD	Determined by multiplying the LIMIT load by the PROOF factor which varies from 1.0 to 1.5 depending on the case - the STRUCTURE must withstand the PROOF load without distortion (no buckling or permanent deformation)
ULTIMATE LOAD	Determined by multiplying the LIMIT load by the ULTIMATE factor which varies from 1.5 to 2.0 depending on the case (Note that some failure/crash cases can have an ULTIMATE factor as low as 1.0, See CS-25.302) - The STRUCTURE must withstand ULTIMATE load without failure.
RESERVE FACTOR	This is the ratio of the PERMISSIBLE LOAD (STRESS) divided by the APPLIED LOAD (STRESS)



STANDARD CLIMATES – NON S.I. UNITS
Figure 1b

This diagram gives envelope conditions for design purposes; it does not constitute an accurate representation of any particular climate.

The line BC has no significance other than as illustrating the text.


Environmental envelope
Pressure altitude x 1000 ft
50
45
40
35
30
25
20
15
10
5
0
-74
-32
Max. Cert. Altitude 41100 ft
-71
2
ISA
17
22
16 600 ft
12 500 ft
1
15°C at sea level
-54
+55
-2000 ft
-80
-60
-40
-20
0
20
40
60
OAT - Degrees C.
Ground Start
T.O. Land
Soak
Flt
1
Yes
Yes
Yes
Yes
2
No
No
No
Yes

Perspective on Probability

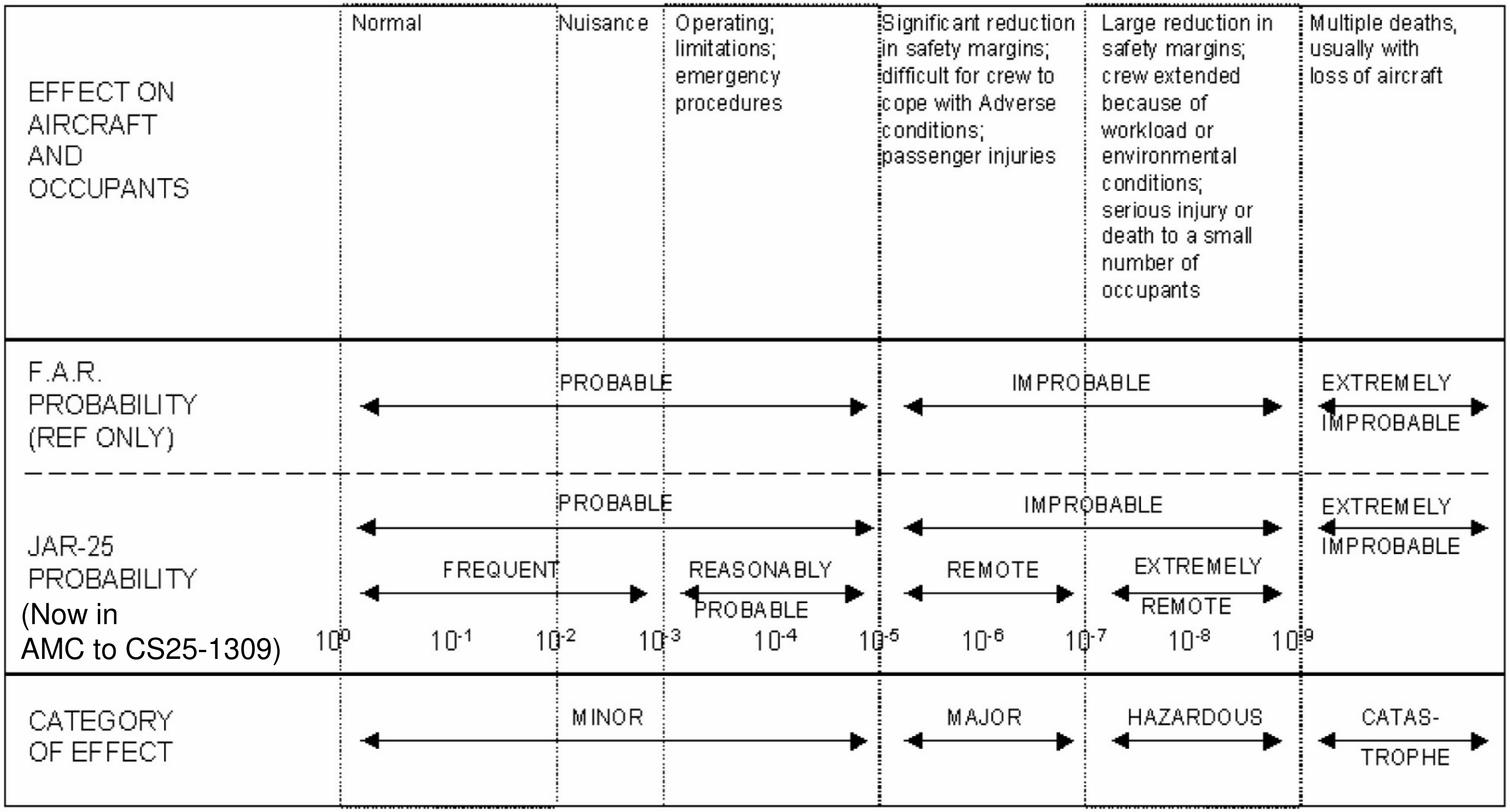
1 x 10-9	1 in a billion hours Catastrophic event once in a fleet of 10,000 Enhanced A340s (100,000 flt Hrs System Life) i.e. 1 in 1,000,000,000 Flying hours
1 x 10-7	1 in ten million hours Hazardous event once in a fleet of 100 Enhanced A340s (100,000 flt Hrs System Life) i.e. 1 in 10,000,000 Flying hours
1 x 10-5	1 in 100,000 hours Major Event once in life of Enhanced A340 (100,000 flight Hrs System Life) i.e. 1 in 100,000 Flying hours
1 x 10-4	1 in 10,000 hours Minor Event at 1e-4 would occur 10 times in the life of a single enhanced A340 (100,000 flight Hrs System Life) i.e. 10 in 100,000 Flying hours

Lottery Jackpot Win
1 in 14 million

Person Killed by Lightning in UK
1 in 10 million (2000 Stats)

Rolling '6' on a die 5 times consecutively
1 in 7,776

Failure Categories



TYPICAL DESIGN LOADING CONDITIONS

OVERALL AIRCRAFT CONDITIONS - FLIGHT CASES

VERTICAL MANOEUVRES	- Trimmed steady - ng - Pitching Manoeuvre
VERTICAL GUSTS	- Discrete Gust - Continuous Turbulence
LATERAL MANOEUVRES	- Pilot Initiated Rudder Action
LATERAL GUSTS	- as for Vertical Gusts
ENGINE FAILURE	- Engine Thrust Decay resulting in aircraft response in Yaw/Roll/Pitch - Pilot Corrective action included
ROLLING MANOEUVRES	- Pilot Initiated Roll Action (by ailerons and/or spoilers)

TYPICAL DESIGN LOADING CONDITIONS

OVERALL AIRCRAFT CONDITIONS - GROUND CASES (also for LANDING GEAR)

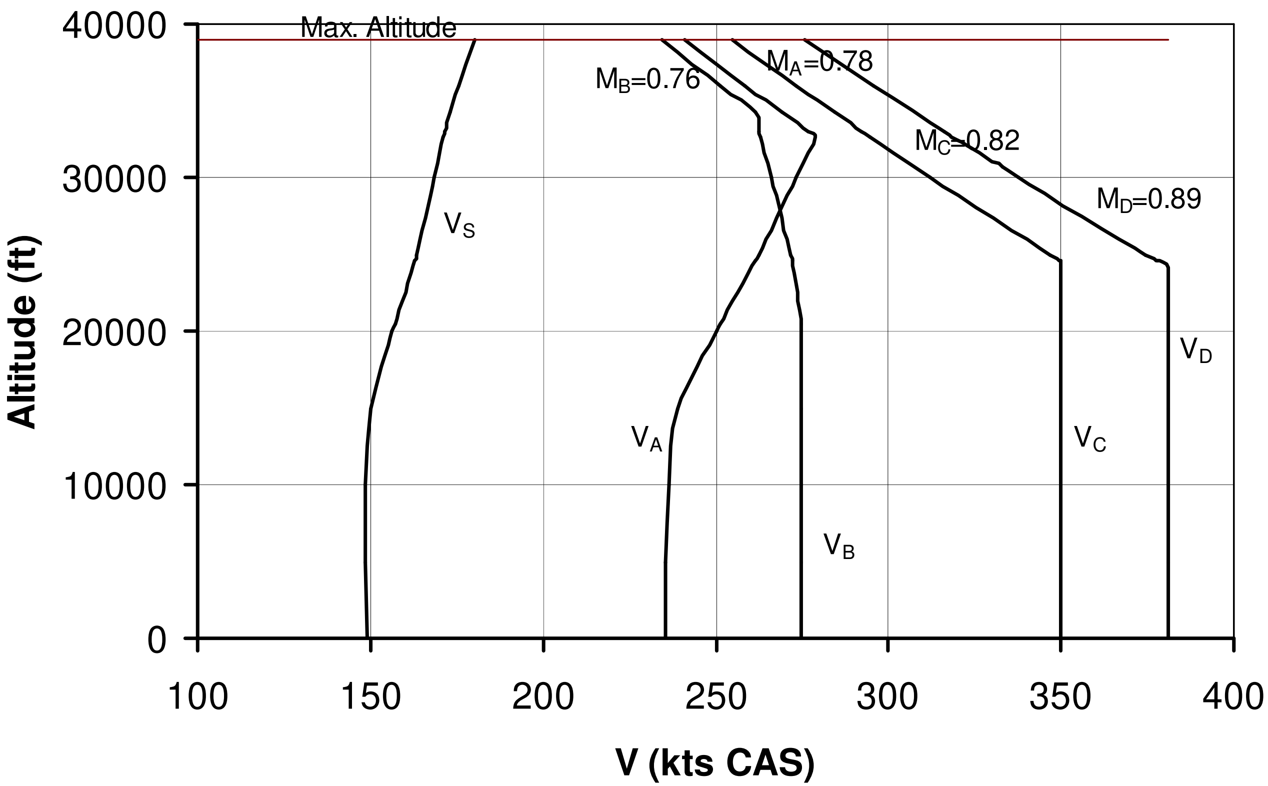
DYNAMIC CONDITIONS	- These are the result of a fully flexible dynamic response calculation		
	LANDING	- Limit Drop Velocity - 10ft/sec	
	TAKE-OFF	- Over a given Runway Profile	
	BRAKING	- Response to Brake System inputs	
RIGID CONDITIONS	- Rigid Aircraft Loads associated with Landing Gear inputs (often known as 'BOOK' cases)		
	TAKE-OFF(BUMP)	TURNING	PIVOTING
	LANDING with DRIFT	BRAKING	TOWING
JACKING	- Aircraft or Landing Gear (High Ultimate Factors)		
CRASH/DITCHING	- Emergency Alighting Conditions - includes Wheels Up Landings and 9g forward		

TYPICAL DESIGN LOADING CONDITIONS

LOCAL LOADING on ‘MINOR’ COMPONENTS

- SLATS and FLAPS
- CONTROL SURFACES (Aileron, Spoiler, Airbrakes, Rudder, Elevator)
- LANDING GEAR DOORS
- RETRACTION JACKS and ACTUATORS
- WHEELS, TYRES and BRAKES
- FLOOR LOADING
  - Running Load (kg/m)
  - Distributed Load (kg/m^2)
  - Local Heel Loads or Crate Cornering
- PRESSURISATION
  - Cabin Pressure Differential (approx 600mb to -70mb)
  - Fuel Tank - Flight, Refuelling and Crash
  - Duct Failure Conditions
- BIRD STRIKE
- JAM CASES
- THERMAL EFFECTS
  - Solar, Kinetic, De-icing, Duct Burst
- FAILURES
  - Mechanical or Electrical, Detected or Undetected

Design Speeds



DESIGN SPEEDS

V_C (Design Cruising Speed) - M_C is the Mach Number equivalent at altitude.

This is the Structural Design Cruising Speed and it usually gives a margin over the normal cruising (or operating) speed of about 4 or 5%.

CS 23 specifies a V_{Cmin} which is a function of wing loading.
CS 25 specifies V_{Cmin} as V_{Bmin}+43kts, where VB is determined from the Gust Envelope.

In normal operation the aircraft should not exceed V_C

V_D (Design Diving Speed) - M_D is the Mach Number equivalent at altitude.

The maximum speed for a given aircraft design is usually limited by aeroelastic characteristics (e.g. control reversal, flutter or divergence).

Typically $V_D = 1.25\ V_C$ unless an analysis of a 20 sec. dive at 7.5 degrees followed by a 1.5 g pullout shows the maximum speed to be less.
Taking V_C as 360kts, then V_D is 1.25 * 360 = 450kts (no rational analysis)
With rational analysis then V_D = 360 + 60 = 420kts (approximately) and for an aircraft with High Speed (FBW) Protection Devices (like A320), then V_D = 360 + 30 =390kts (approx).

In Mach Number terms $M_D = M_C + 0.07$ (Conventional)
$M_D = M_C + 0.03$ (FBW with full envelope protection)

DESIGN SPEEDS

V_S (Stalling Speed – Flaps up)

This is the speed at which the Lift equals the Weight at the maximum lift coefficient

$$L = W = C_{L\,max} \times \tfrac{1}{2}\rho_0 V_S{}^2 S$$

As the aircraft climbs its weight reduces due to fuel burn which tends to decrease the stalling speed. Also as the aircraft climbs at constant speed, Mach No. increases. The maximum lift coefficient reduces with increasing Mach No. thereby increasing the stalling speed.

V_A (Design Manoeuvring Speed) - M_A is the Mach Number equivalent at altitude.

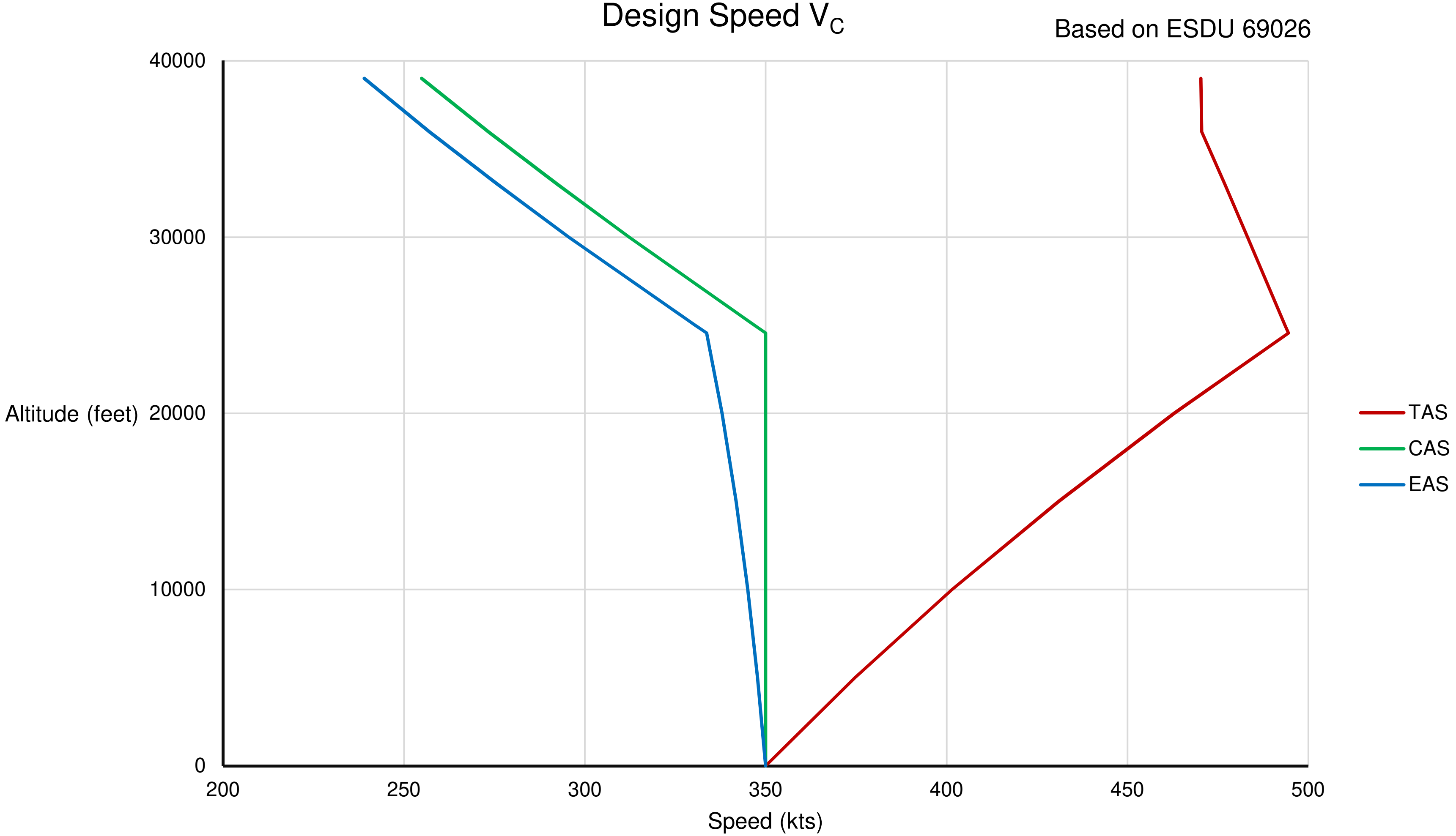
This is the minimum speed at which the positive manoeuvring load factor can be achieved and is related to stalling speed by

$$V_A = V_S\sqrt{n} \qquad \text{which comes from} \qquad L = nW = C_{L\,max} \times \tfrac{1}{2}\rho_0 V^2 S$$

V_B (Maximum Gust Velocity Speed) - M_B is the Mach Number equivalent at altitude.

This is sometimes referred to as the rough air speed.

Design Speed V_C



FLAP and SLAT

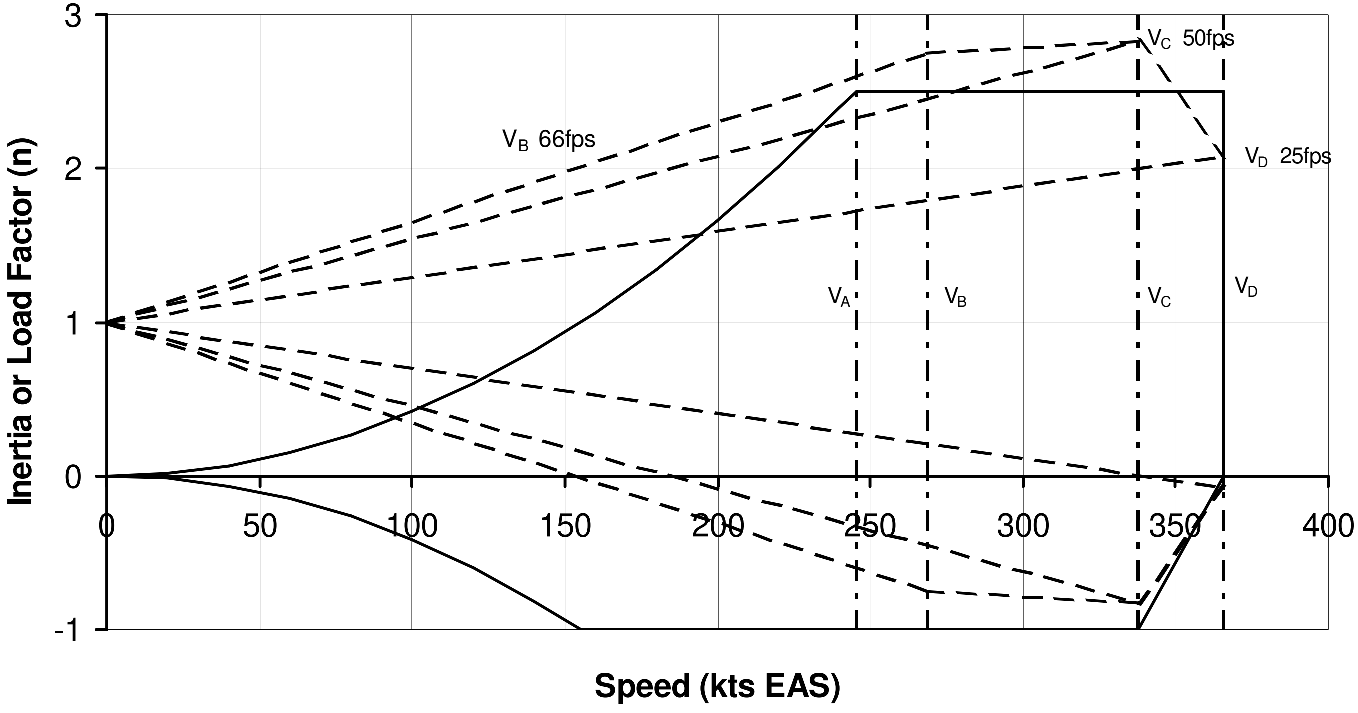
DESIGN SPEEDS

CONFIG	CONDITION	NOMINAL SLATS	NOMINAL FLAPS	Vs1	Vf	Vext	Vret	Vf+g $
1	take-off	18	0	139.3	245	230	245	259.8
1+F		18	10	128.3	225	215	225	239.8
2		22	17	119.8	215	200	215	229.8
3		27	25	117.5	202	190	202	216.8
2	approach	22	17	112.9	215	200	215	229.8
3		27	25	110.7	202	190	202	216.8
FULL	ldg	27	35	107.5	195	180	204 *	209.8

Note: * denotes Vret landing = Vf + 9 kts
$ denotes Vf+g = Vf + head on gust of 25 ft/sec (14.8 kts)

V - n Diagram

Manoeuvre - full line,   Gust - dotted line



DESIGN WEIGHT TERMINOLOGY

Maximum Taxi Weight (MTW) [Also known as Maximum Ramp Weight (MRW)]

The maximum taxi weight shall be the maximum weight of the aircraft for manoeuvring on the ground

Maximum Take-Off Weight (MTOW)

The maximum take-off weight shall be the maximum permissible weight of the aircraft when the brakes are released for take-off, or at the start of the take-off roll (also used for aircraft Performance).

Maximum Landing Weight (MLW)

The maximum landing weight shall be the maximum weight at which the aircraft meets the appropriate landing certification regulations. It will include adequate fuel reserves (also used for aircraft Performance).

Maximum Zero Fuel Weight (MZFW)

The maximum zero fuel weight shall be the maximum weight of the aircraft less all usable fuel, which is equivalent to OWE plus maximum Payload

Operators Weight Empty (OWE)

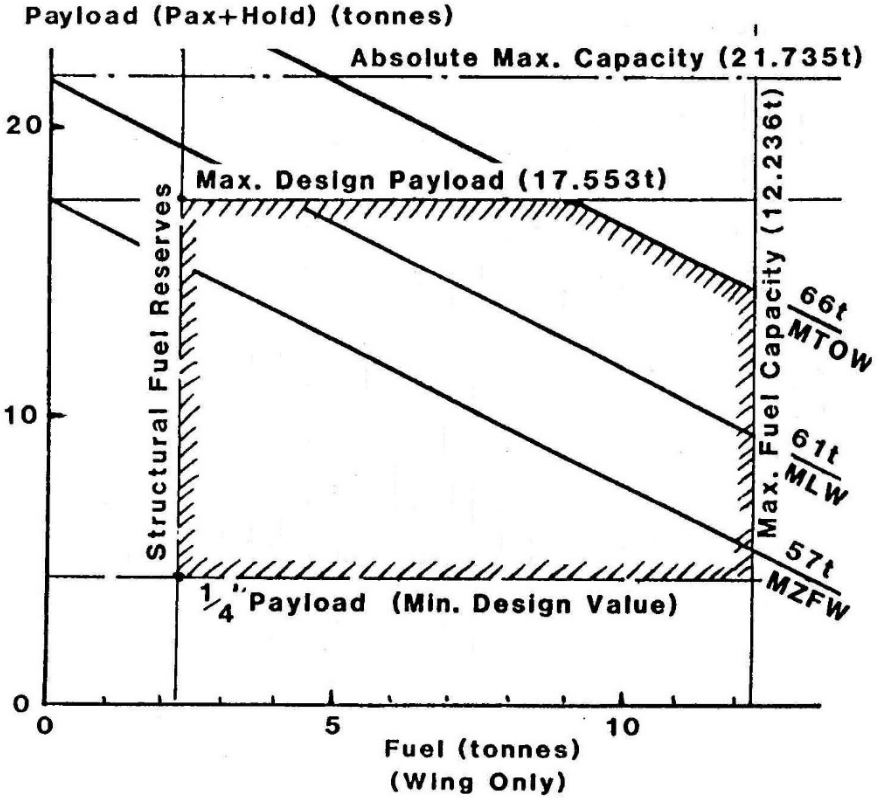
The operating weight empty shall be the manufacturers weight empty plus the operator's items. The operator's items shall be the flight and cabin crew and their baggage, unusable fuel, engine oil, emergency equipment, toilet chemicals and fluids, galley structure, catering equipment, seats, documents etc

Manufacturers Weight Empty (MWE)

The manufacturer's weight empty shall be the weight of the structure, power plant, furnishings, systems and other items of equipment that are considered an integral part of the aircraft. It is essentially a 'dry' weight, including only those fluids contained in closed systems (e.g. hydraulic fluid).

For light aircraft often the All-up Weight (AUW) which is equivalent to MTOW, is used for most if not all loads calculations.

PAYLOAD - FUEL LOADING



NOTES

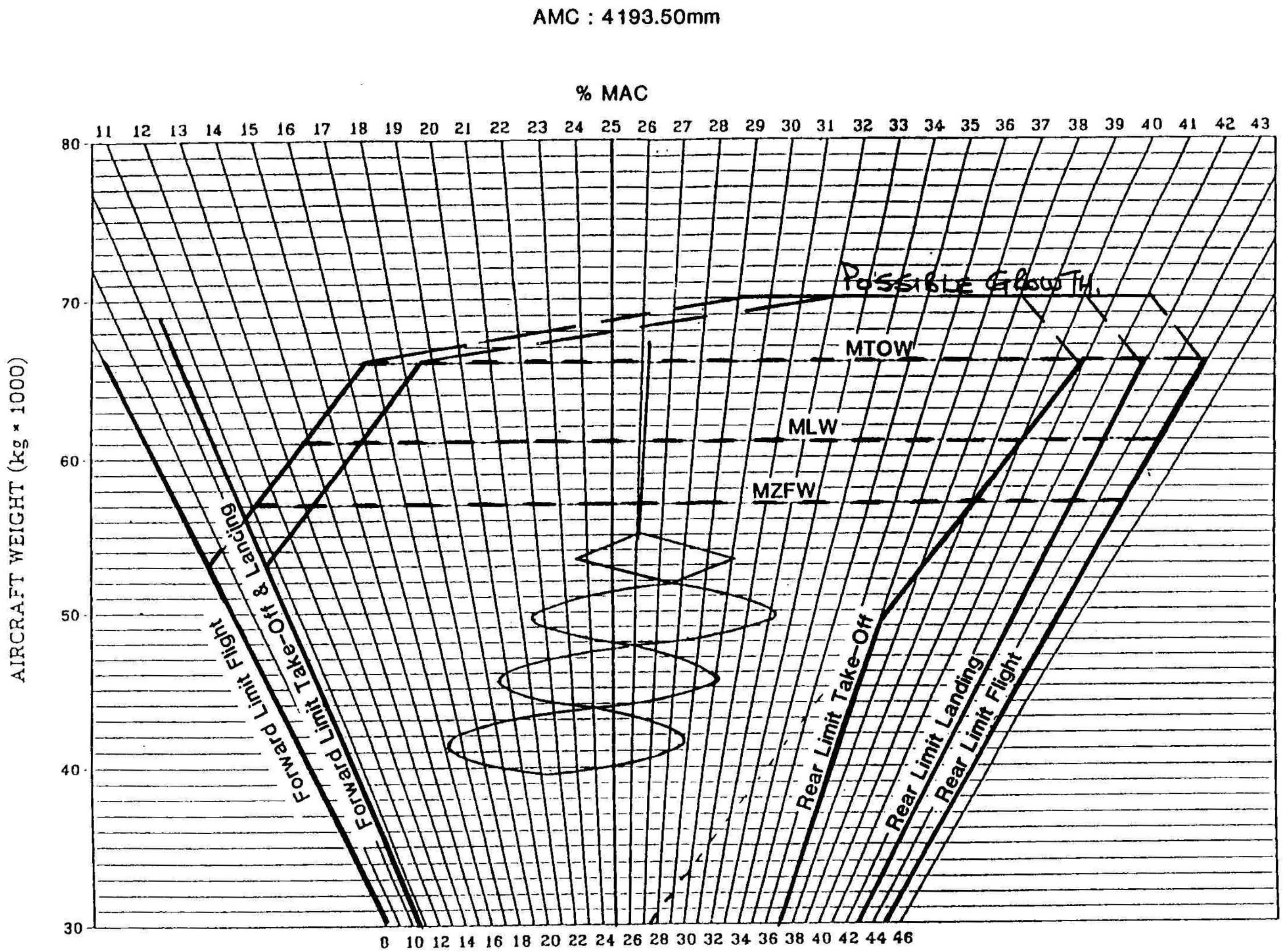
- Passengers (75kg) and Baggage (15kg)

  165 X (75 + 15) = 14850 kg

  Max Hold Capacity = 9435 kg

- Structural Fuel Reserves - Fuel required to climb to 10000 ft and then cruise at speed appropriate to that for maximum range for 45 mins
- Payload loaded from front or back to give CG range
- Payload for Fatigue Mission is between 65% and 80% of maximum Design Payload

WEIGHT - CG DIAGRAM



MISSION COMPARISON

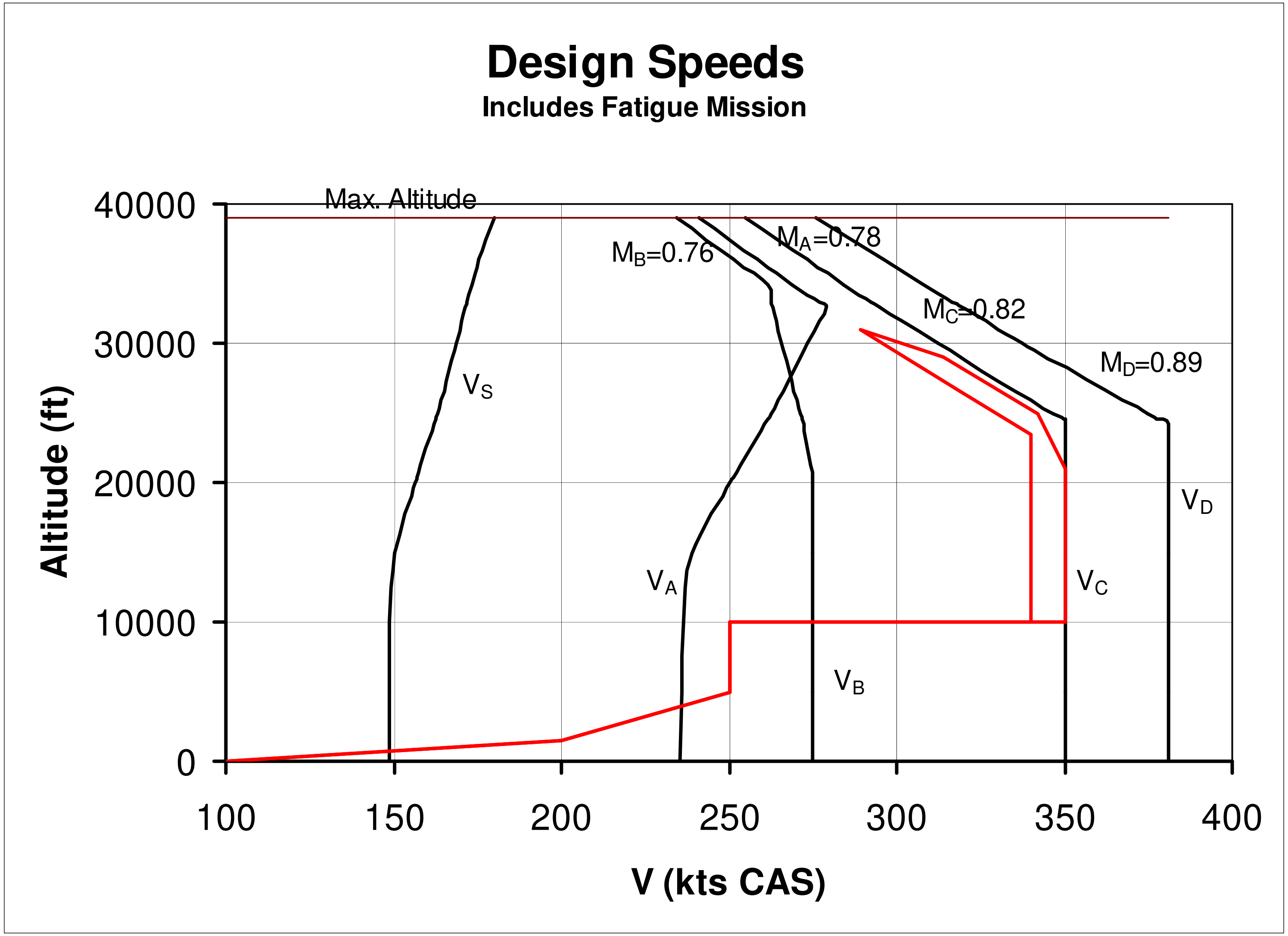
	MAXIMUM DESIGN WEIGHTS	DESIGN MISSION	FATIGUE MISSION
OWE (kg)	39447	39447	39447
Payload (kg)	17553	15580	11410
ZFW (kg)	57000	55027	50857
Fuel (reserve) (kg)	4000	3109	2543
Landing Weight (kg)	61000	58136	53400
Fuel (block) (kg)	5000	7864	2600
TOW (kg)	66000	66000	56000
Fuel (max) (kg)	12200		
Range (nm)		1500	370
Cruise Altitude (ft)		35000	31000
Cruise Mach No		0.76	0.78
Flight Time (mins)		219	60
Block Time (mins)		233	74

Typical Fatigue Mission

Flight Stage		ALTITUDE [ft]	VCAS [kt]	VTAS [kt]	DYN. PRESS. [daN/m2]	MACH	GROSS WEIGHT [kg]	DISTANCE [nm]	TIME [min]	NET THRUST One ENG. [daN]	DIFF. CABIN PRESS [mb]	MASS REPR. STAGE	FLAP ANGLE [deg]	SLAT ANGLE [deg]	A/B L/D ANGLE [deg]
1	PREFLIGHT TAXI	0					55952	(2.0)	7.0	500	0	1	0	0	0
2	TAKE OFF/ROTATION	0	140	140	317.7	0.212	55895	(0.5)	0.35	8995	7	2	20	22	0
3 A	INITIAL CLIMB	500	160	161.2	414.9	0.244	55851	1.2	0.45	8483	22	3	20	22	0
3 B	TO 1500 ft	1250	190	193.4	584.7	0.294	55786	1.3	0.40	6700	44	3	0	22	0
4	CLIMB 1500 ft TO	3250	225	235.7	817.8	0.360	55727	3.0	0.76	6041	104	4,5	0	0	0
5	10000 FT; 250 kt	7500	250	278.3	1002.2	0.432	55616	7.1	1.54	5475	222	4,5	0	0	0
6	ACCELER. TO 340 kt	10000	295	339.7	1381.7	0.532	55512	4.5	0.79	4871	275	6-12	0	0	0
7		12000	340	401.5	1811.8	0.634	55427	9.8	1.46	4509	310	6-12	0	0	0
8	CLIMB 10000 ft	16000	340	425.1	1784.4	0.681	55306	12.2	1.72	4213	382	6-12	0	0	0
9	TO 31000 ft	20000	340	450.3	1752.8	0.733	55157	16.5	2.20	3850	435	6-12	0	0	0
10	340 kt/ 0.78 Ma	23500	339	472.5	1710.9	0.780	55009	13.5	1.71	3486	471	6-12	0	0	0
11		26500	319	466.6	1501.5	0.780	54886	12.0	1.54	3178	496	6-12	0	0	0
12		29500	299	460.7	1313.4	0.780	54764	13.1	1.71	2864	515	6-12	0	0	0
13	CRUISE 0.78 Ma 31000 ft	31000	289	457.8	1222.9	0.780	54238	181.3	23.80	1801	545	13	0	0	0

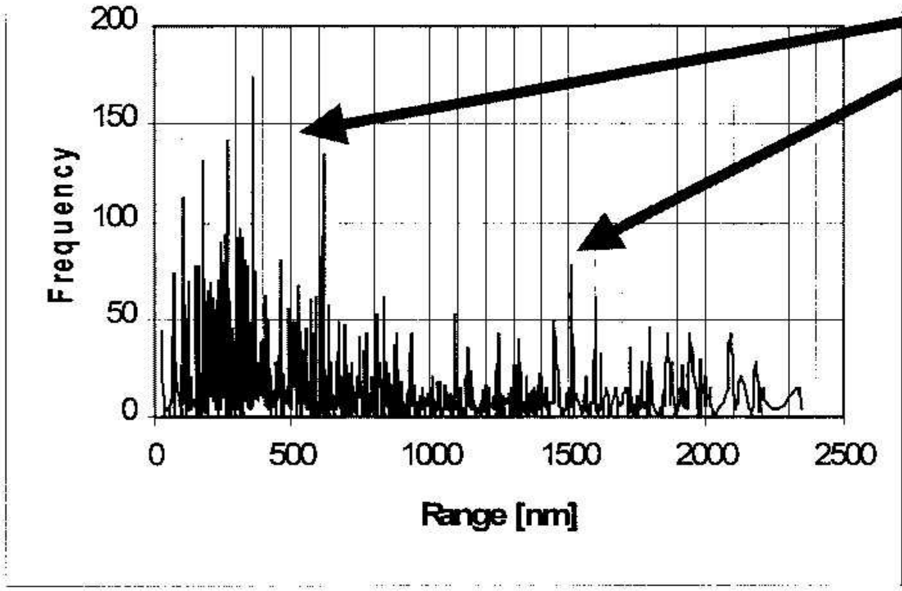
Typical Fatigue Mission

Flight Stage		ALTITUDE [ft]	VCAS [kt]	VTAS [kt]	DYN. PRESS. [daN/m2]	MACH	GROSS WEIGHT [kg]	DISTANCE [nm]	TIME [min]	NET THRUST One ENG. [daN]	DIFF. CABIN PRESS. [mb]	MASS REPR. STAGE	FLAP ANGLE [deg]	SLAT ANGLE [deg]	A/B L/D ANGLE [deg]
14	DESCENT 31000 ft TO 10000 ft 0.82Ma/ 350 kt	29000	314	478.0	1441.5	0.808	53774	4.6	0.58	-241	506	14-18	0	0	0
15		25000	342	487.5	1729.1	0.810	53770	6.3	0.78	-313	455	14-18	0	0	0
16		21000	350	469.5	1841.5	0.767	53764	8.1	1.03	- 371	399	14-18	0	0	0
17		17000	350	443.3	1877.7	0.713	53758	7.8	1.05	- 402	334	14-18	0	0	0
18		12500	350	415.9	1912.9	0.658	53751	9.2	1.33	- 440	248	14-18	0	0	0
19 A	DECELER. TO 250kt	10000	300	345.3	1428.0	0.541	53743	1.7	0.30	- 335	202	19,20	0	0	7
19 B		10000	300	345.3	1428.0	0.541	53743	5.0	0.86	- 335	202	19,20	0	0	0
20	DESCENT TO 5000ft	7500	250	278.3	1002.2	0.432	53727	13.3	2.86	- 216	163	19,20	0	0	0
21	DECELER. TO 210kt	5000	230	247.0	852.5	0.380	53713	2.5	0.60	- 172	109	21-23	0	0	0
22	HOLDING 210 kt	5000	210	225.7	711.4	0.347	53644	16.5	4.40	1464	109	21-23	0	0	0
23	DESCENT TO 1500ft	3250	210	220.0	712.7	0.336	53565	10.3	2.81	- 125	73	21-23	0	0	0
24 A	APPROACH 1500 ft	1500	200	204.3	647.6	0.311	53530	1.7	0.50	518	34	24,25	0	22	30
24 B		1500	200	204.3	647.6	0.311	53530	3.4	1.00	518	34	24,25	0	22	0
24 C		1500	190	194.1	584.5	0.295	53485	4.9	1.50	620	34	24,25	10	22	0
25 A	FINAL AFPROACH	1250	170	173.1	468.1	0.263	53453	1.7	0.60	696	31	24,25	20	22	0
25 B	15000 ft TO SL	500	150	151.1	364.7	0.229	53426	2.8	1.10	1371	17	24,25	40	27	0
26 A	LANDING IMPACT	0	140	140.0	317.7	0.212	53401	(0.5)	0.30	772	7	26	40	27	0
26 B	LANDING RUN	0	140	140.0	317.7	0.212	53401	(0.5)	0.30	-2600	7	26	40	27	50
27	POSTFLIGHT TAXI	0					53356	(2.0)	7.00	500	0	27	0	0	0
							Σ Flight	376.3	60.0						
							Σ Block		74.0						

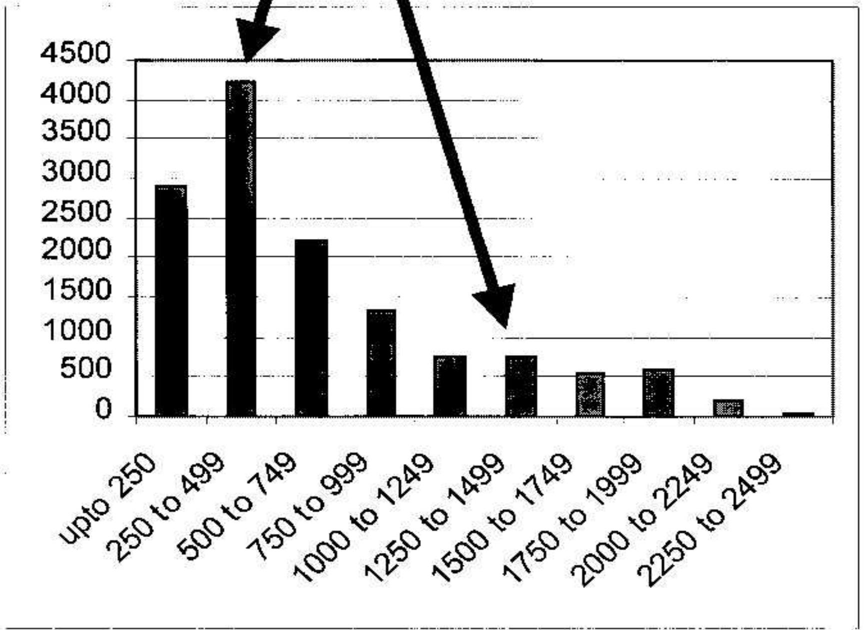


Design Speeds
Includes Fatigue Mission
Max. Altitude
M_B=0.76
M_A=0.78
M_C=0.82
M_D=0.89
V_S
V_A
V_B
V_C
V_D
40000
30000
20000
10000
0
Altitude (ft)
100
150
200
250
300
350
400
V (kts CAS)

Typical Operating Ranges



500 nm is typical + 1500 nm for longer range analysis

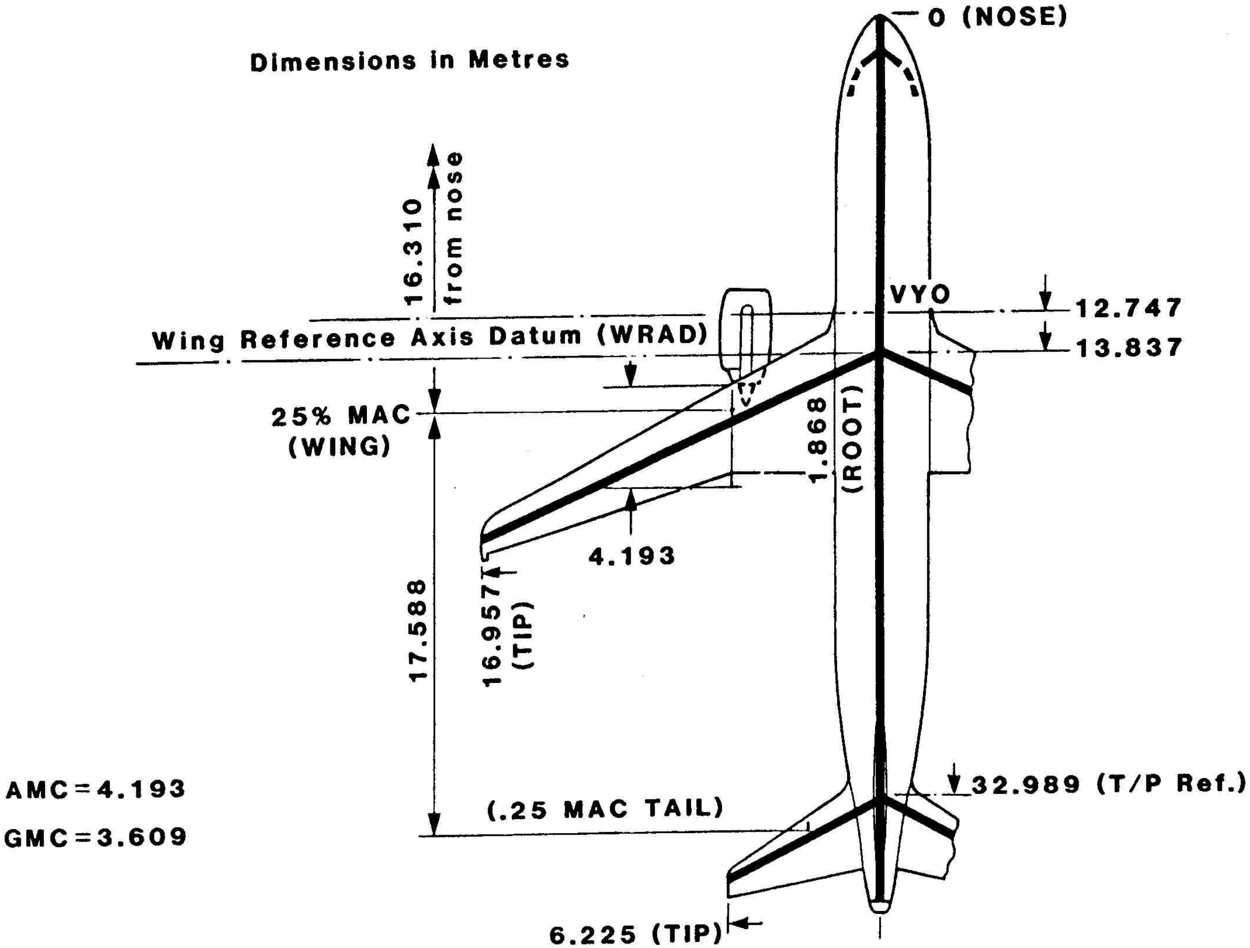


Frequencies are representative of a typical day in September

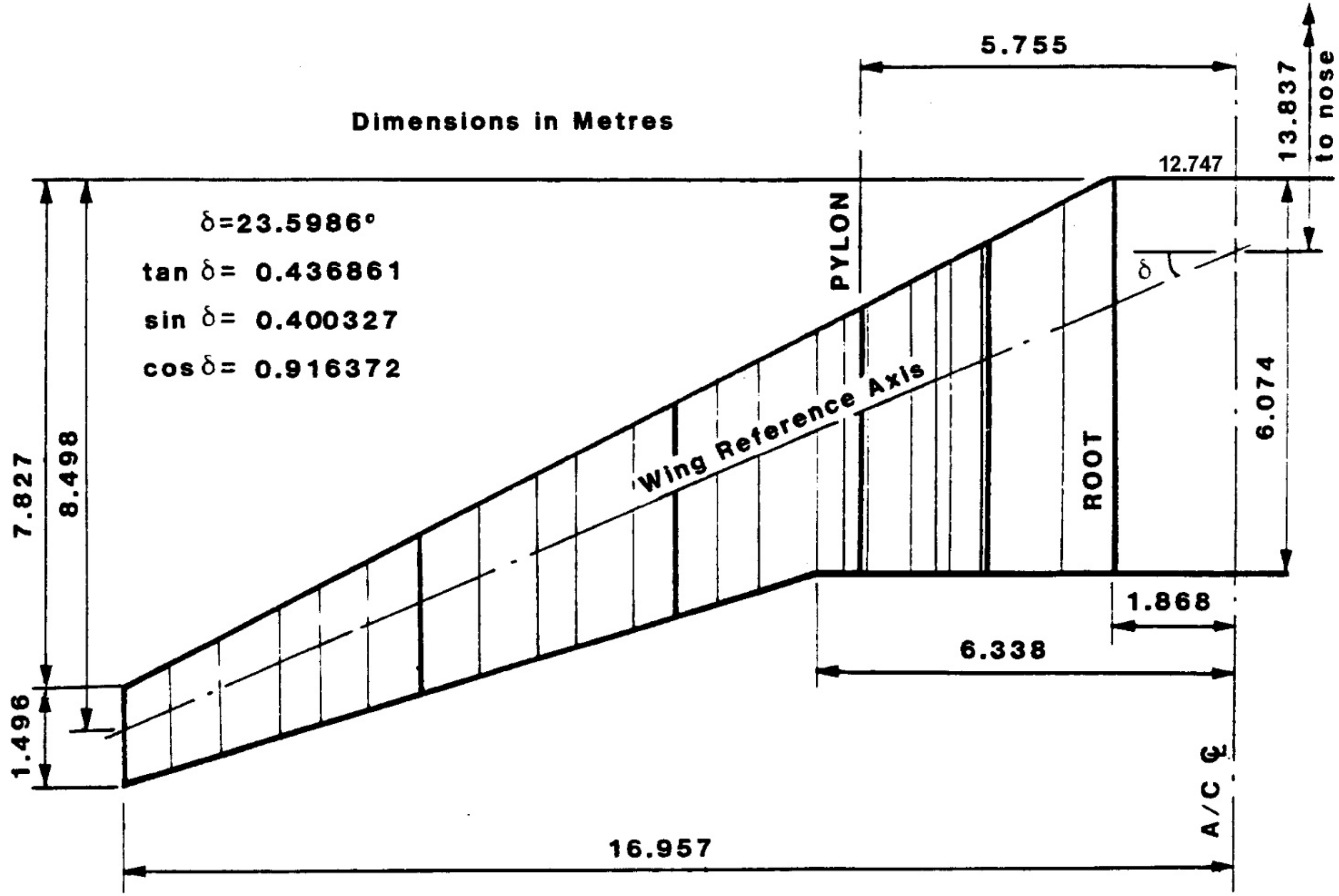
LIFE CYCLE COMPARISON

CAR	Dumped after an average of say 120000 miles If overall average speed is is say 30 mph, then operating life is 4000 hrs Serviced/Inspected every 12000 miles (400 hrs)
MILITARY AIRCRAFT	Operating Life typically 9000 hrs or 20 to 30 years Inspection interval -- typically 18 months depending on aircraft role
CIVIL AIRCRAFT	Warranty Life = 60000 hrs Operating Life = 25 plus years Engine Removal = 3000 hrs (some stay on the ‘wing’ for over 20000 hrs) Landing Gear removal = Life Corrosion Inspection = 10 years Inspection Interval -- nominally 15 months
MISSILE	Operating Life = 10 secs Storage or Shelf Life = 10 years

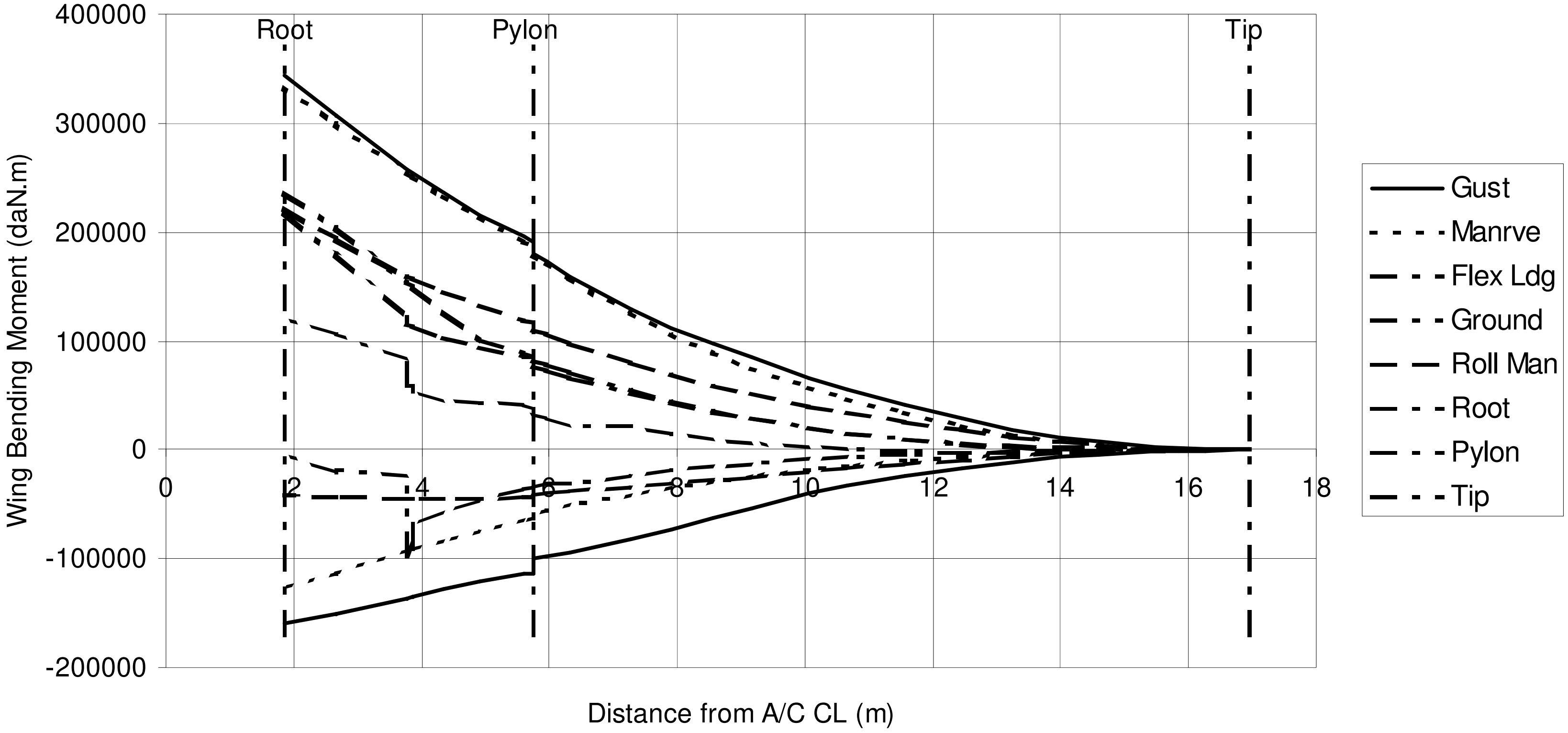
Aircraft Reference Axes



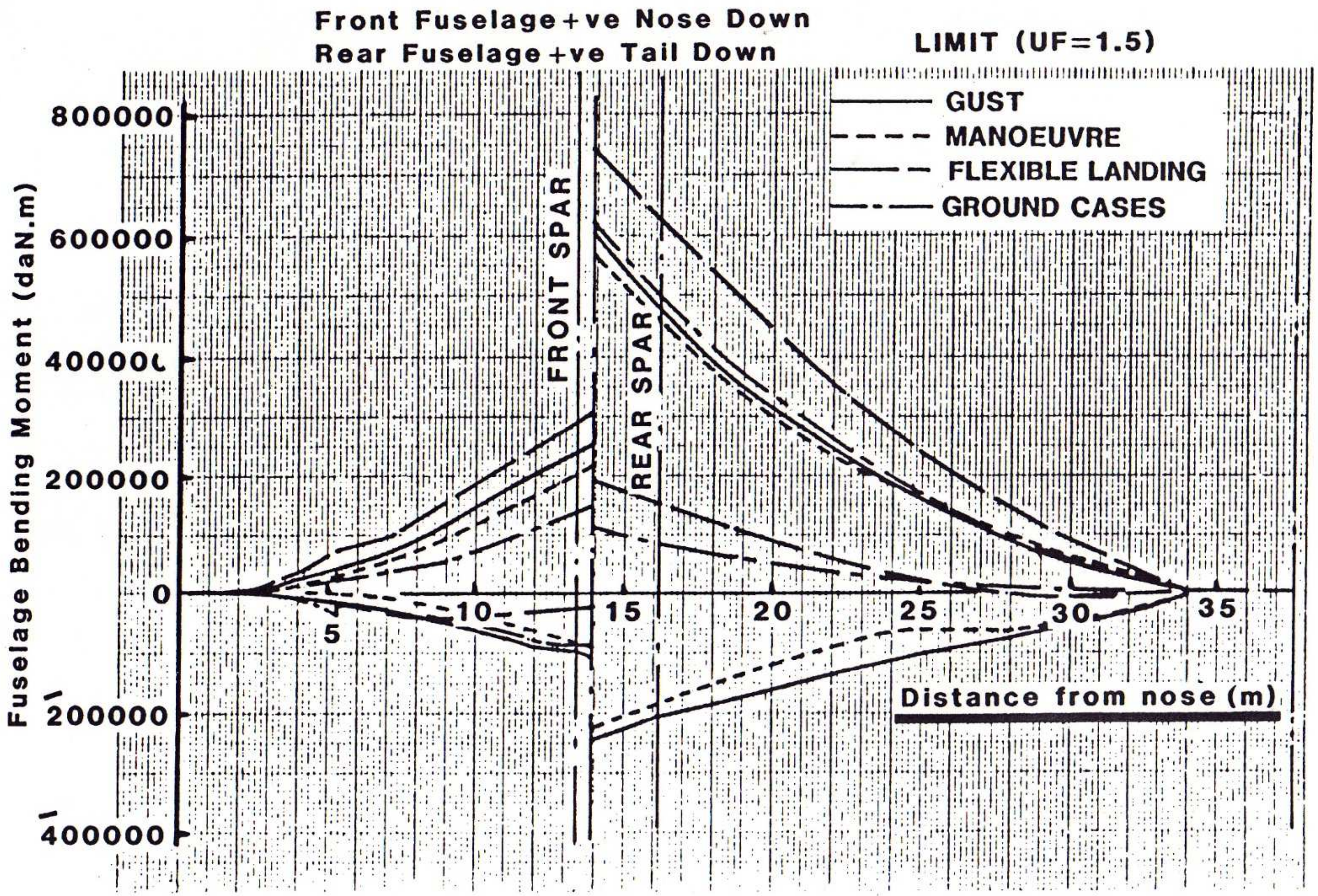
Wing Strip Geometry



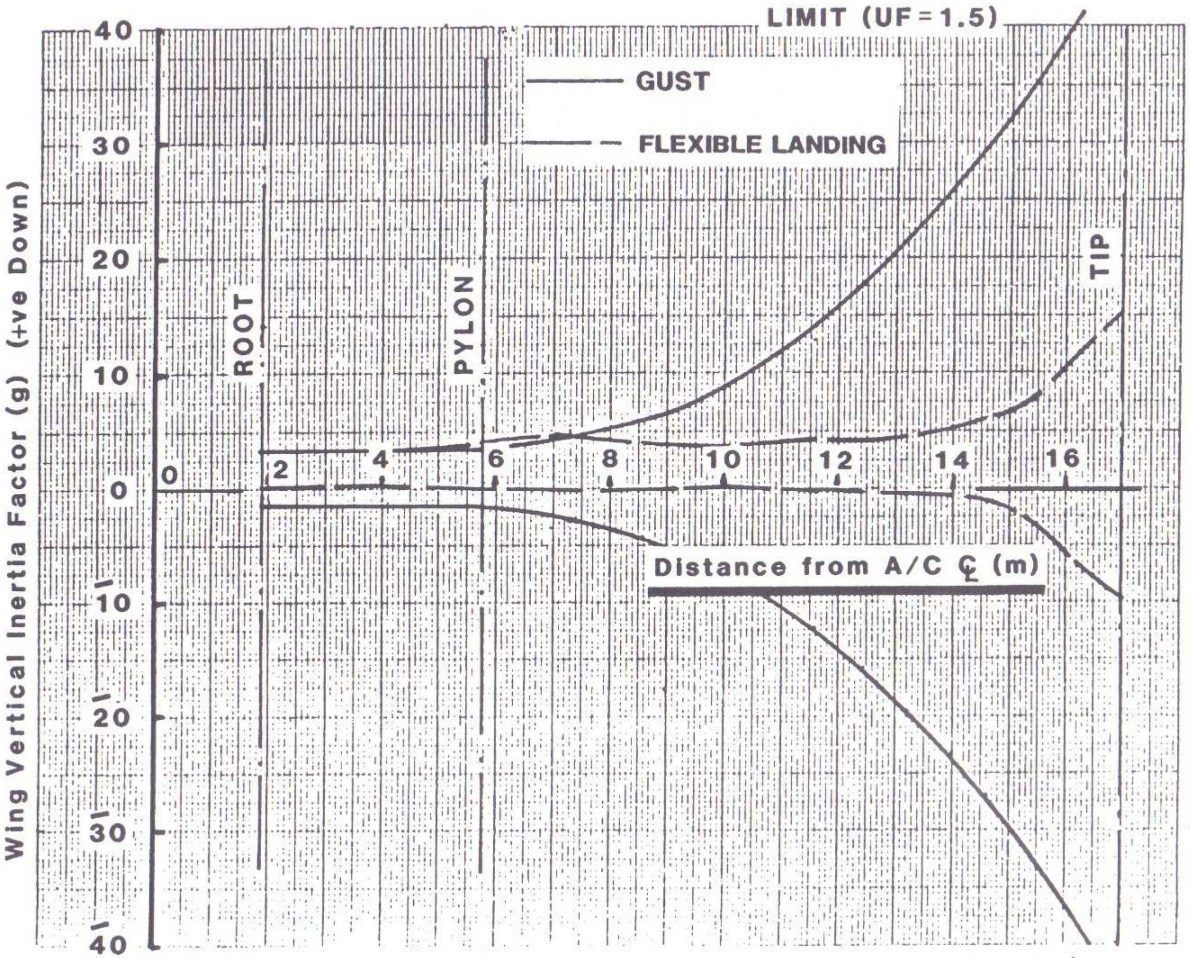
Wing Bending Moment



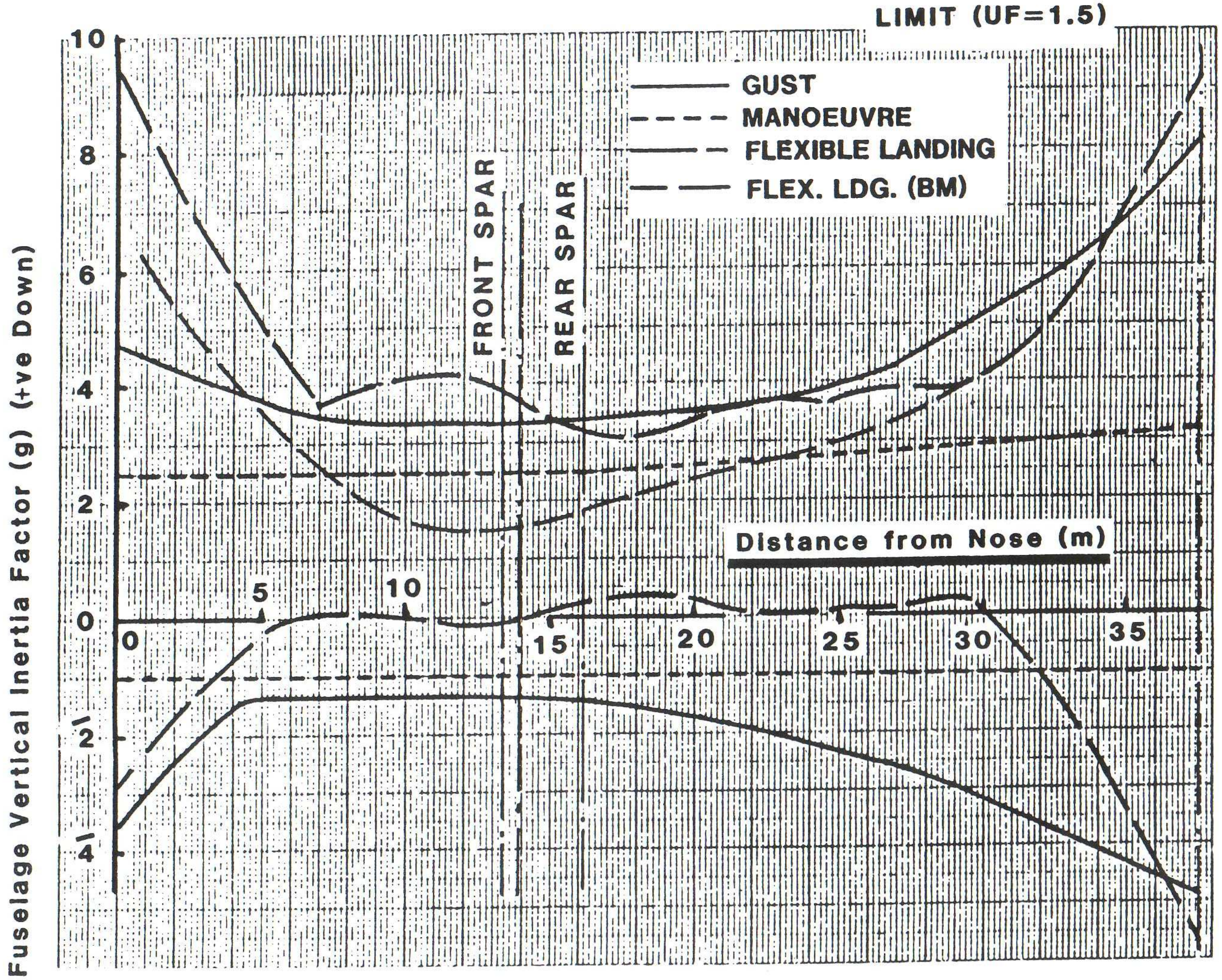
Fuselage Bending Moment



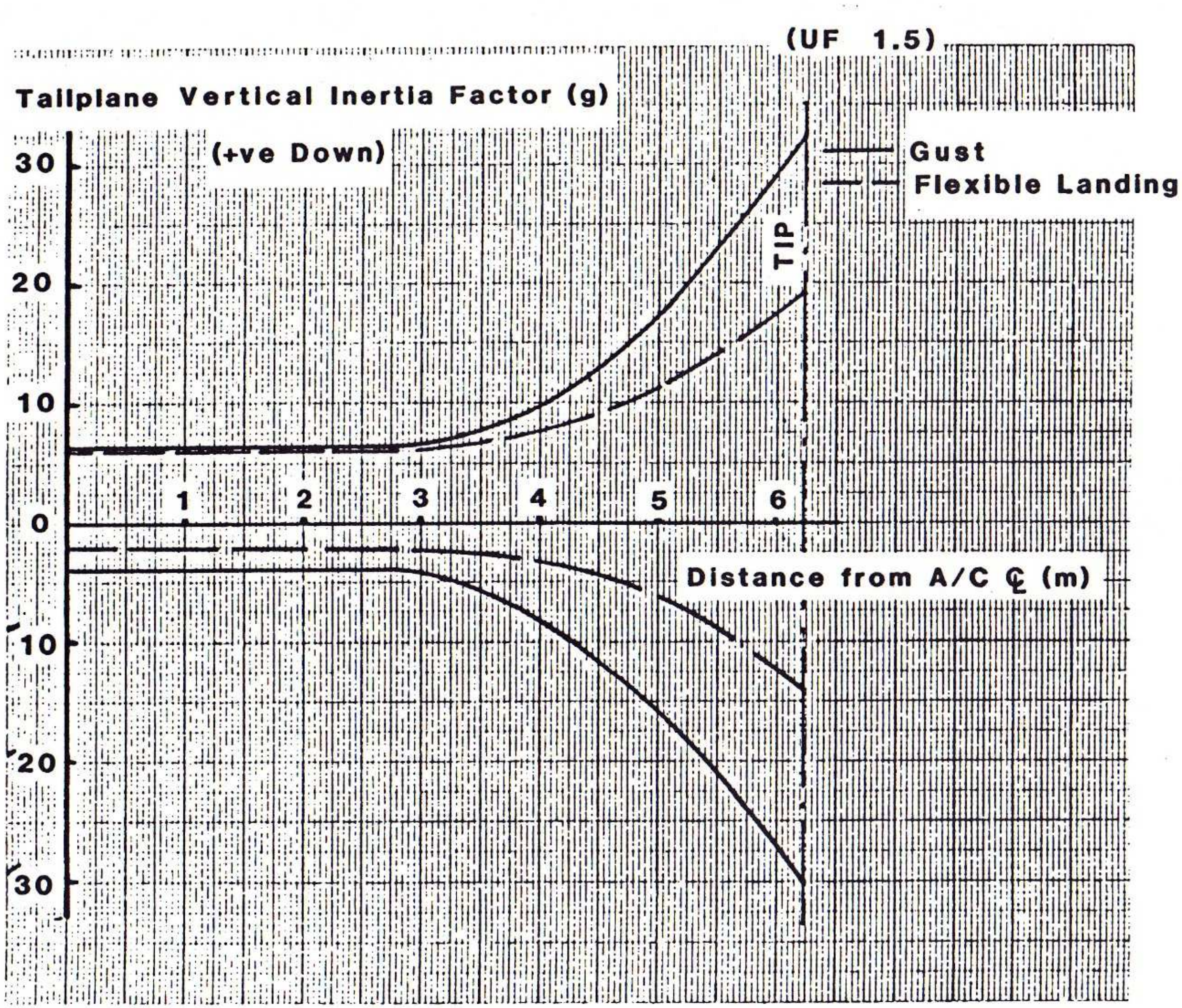
Wing Vertical Inertia Factor



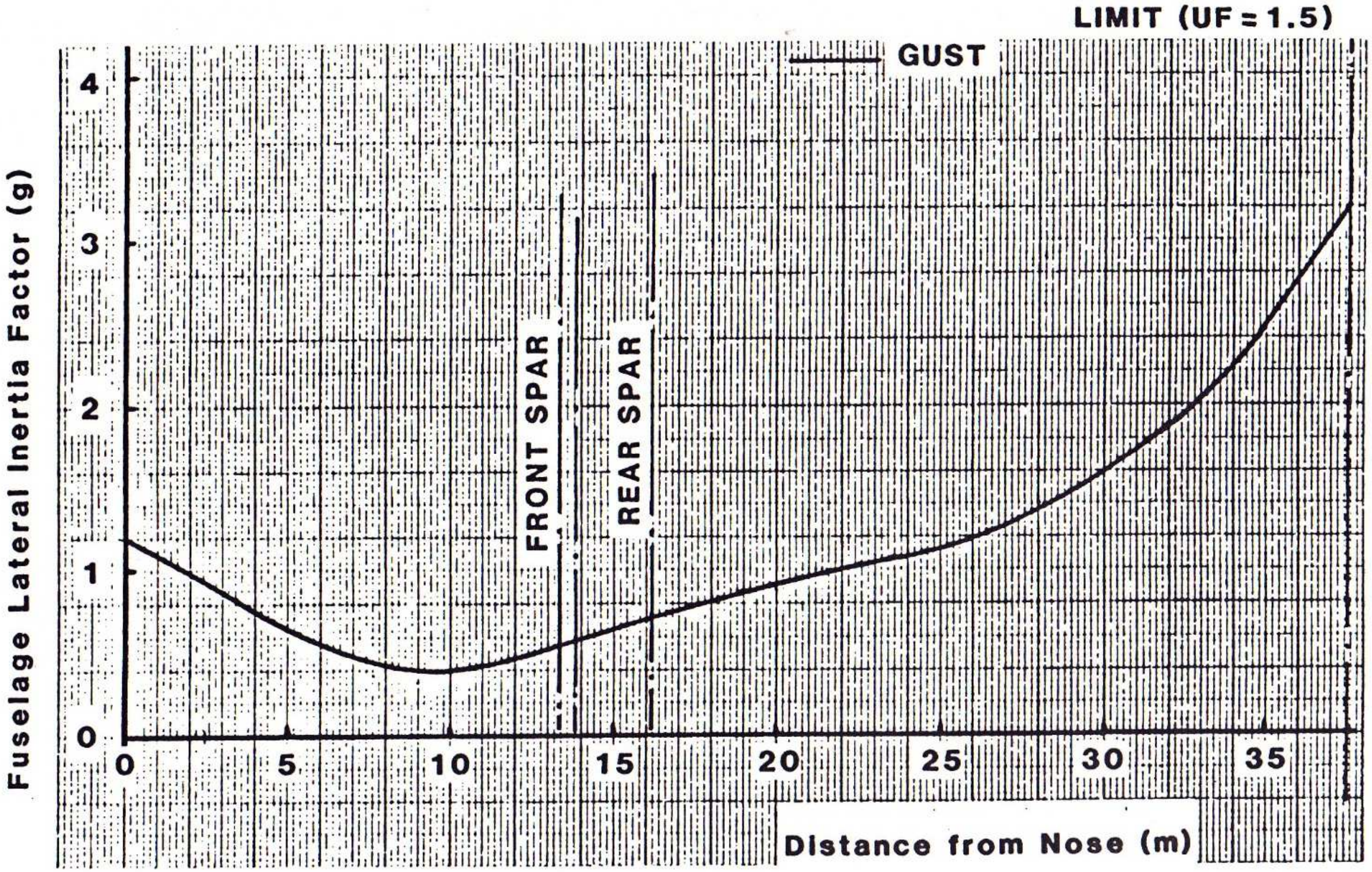
Fuselage Vertical Inertia Factor



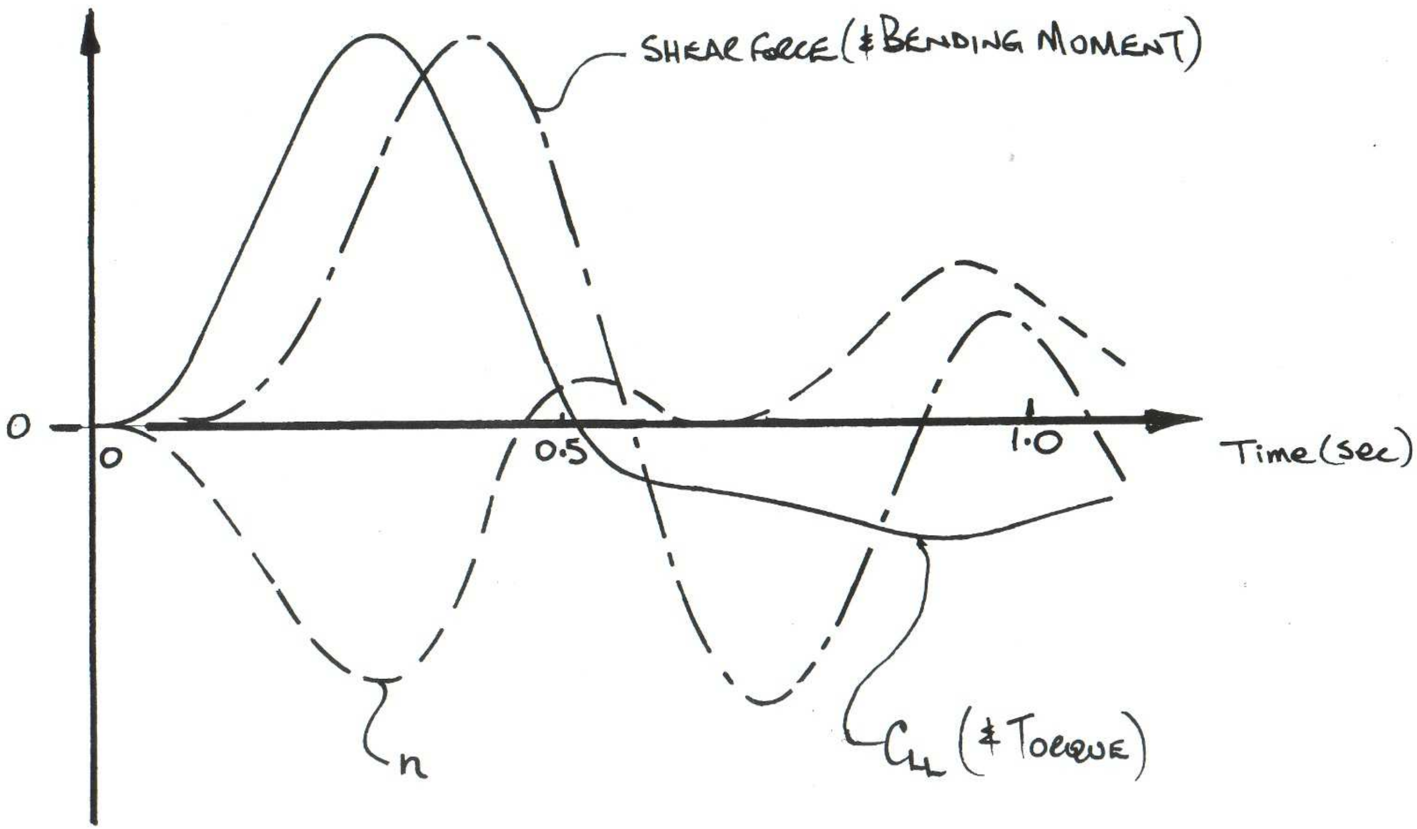
Tailplane Vertical Inertia Factor



Fuselage Lateral Inertia Factor



Typical Time History

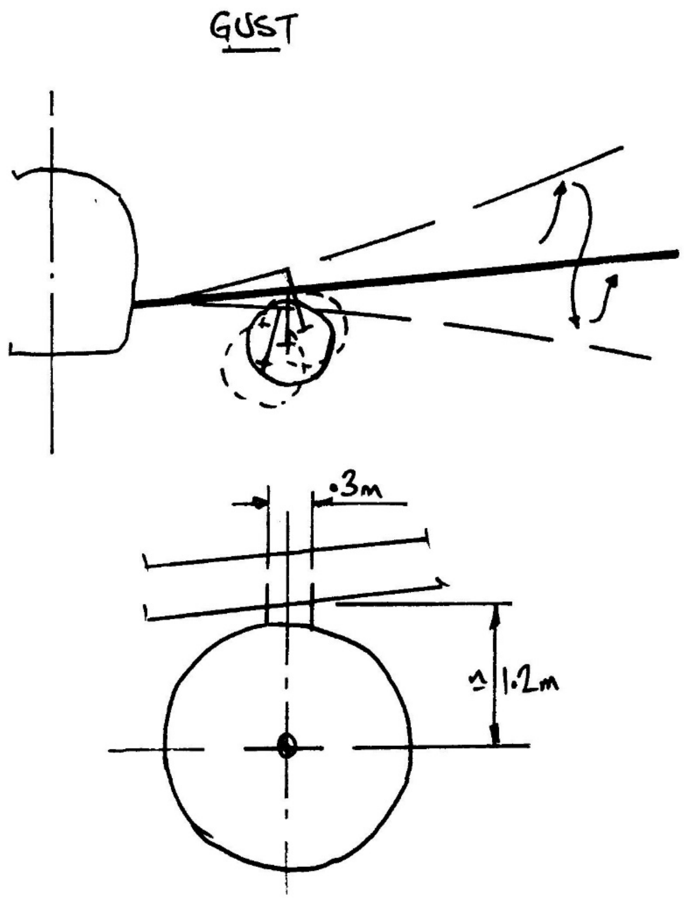


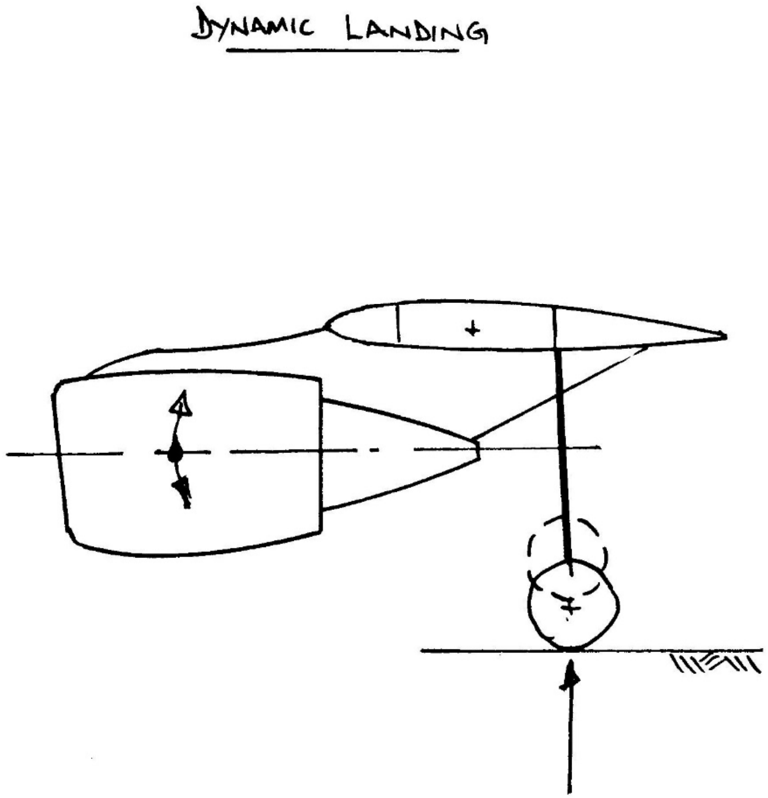
Engine/Pylon/Wing Attachments

Flight Cases	# Gust	1g Vertical	+3g Lateral
	# Manoeuvre	Not Critical	
Ground	# Dynamic Landing	3g Vertical	+0g Lateral
		-1g Vertical	+0g Lateral
	# Thrust	Maximum Forward	
		Reverse Thrust (take as 40% of Forward value)	
Crash/Failure	# Wheels up Landing (Aircraft sliding on Pod)		
	# Fan Blade Failure (Engine out of balance)		

Additional factor of 1.25 applied to Wing Attachments to ensure that the Engine/Pylon can break away without rupturing the Fuel Tanks

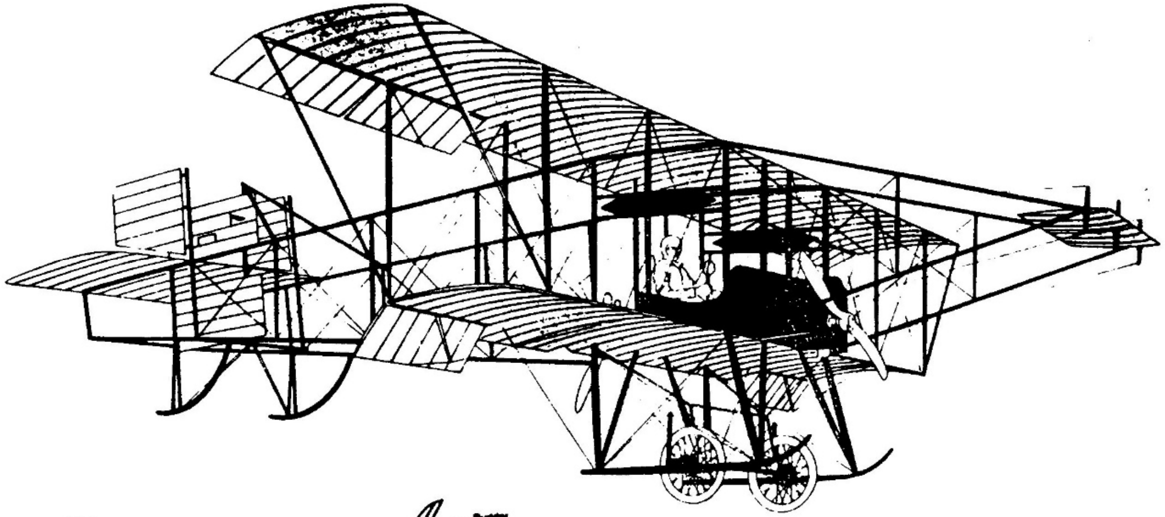
Pendulum/Nodding Effect

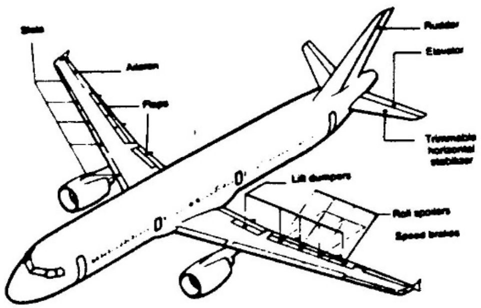




FLY-BY-WIRE

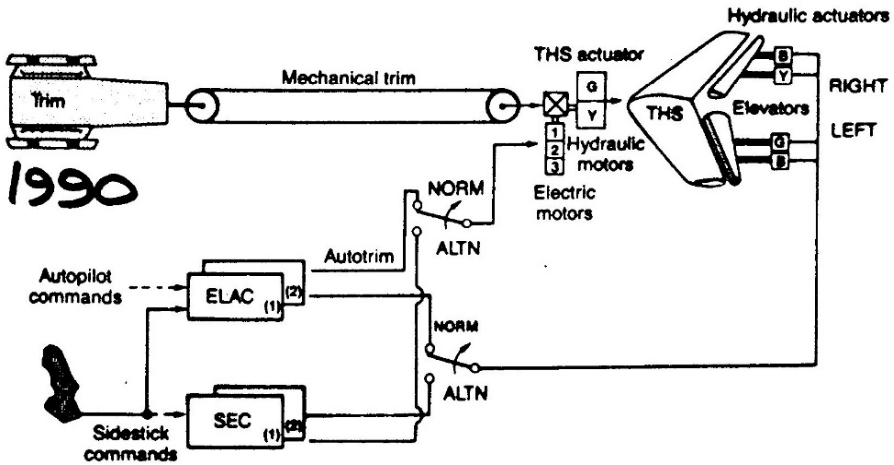
CIRCA 1910





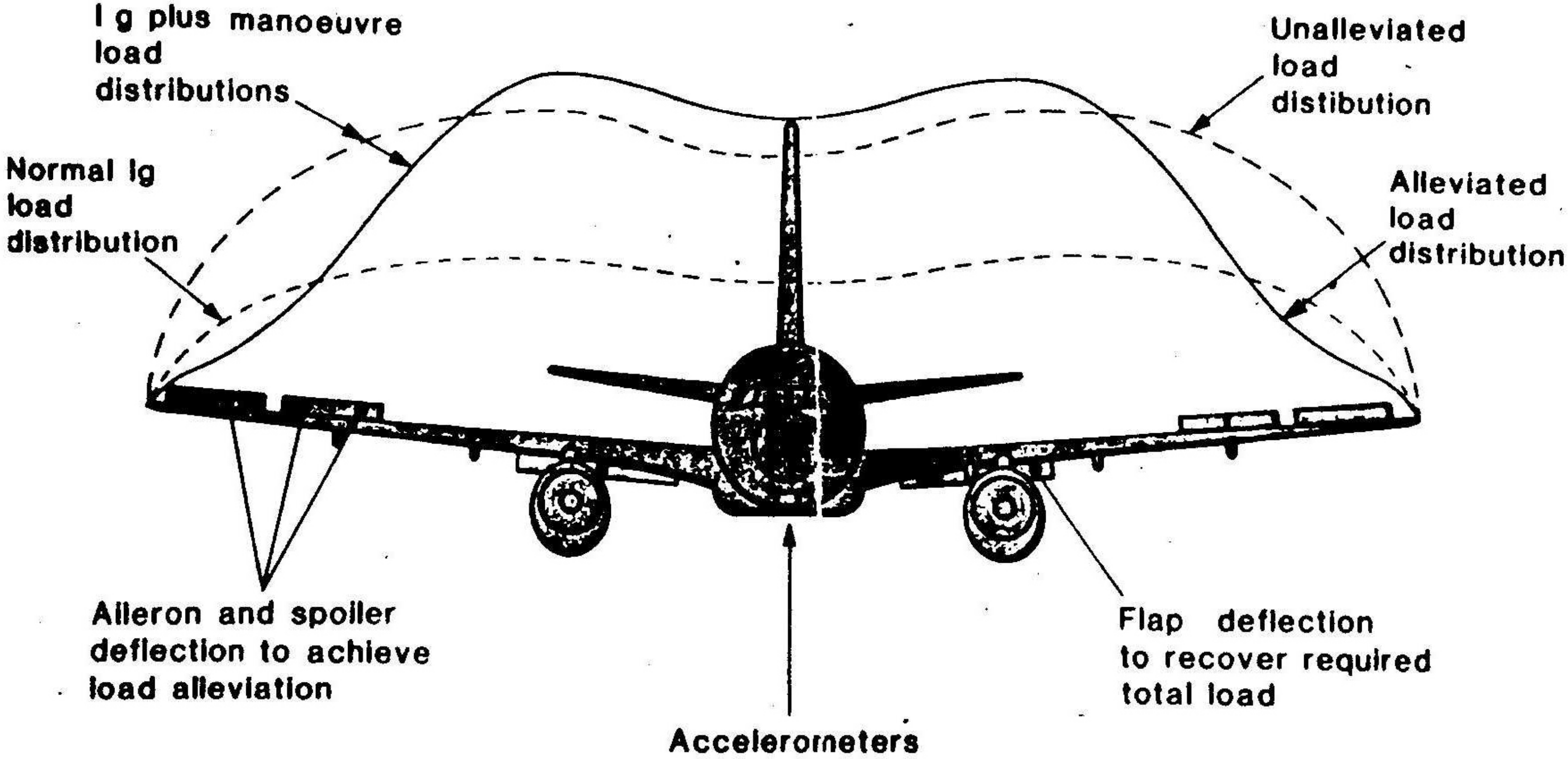
CIRCA 1990

THS Trimmable horizontal stabilizer	Hydraulics
ELAC Elevator and aileron computer	B Blue system
SEC Spoiler and elevator computer	G Green system
	Y Yellow system

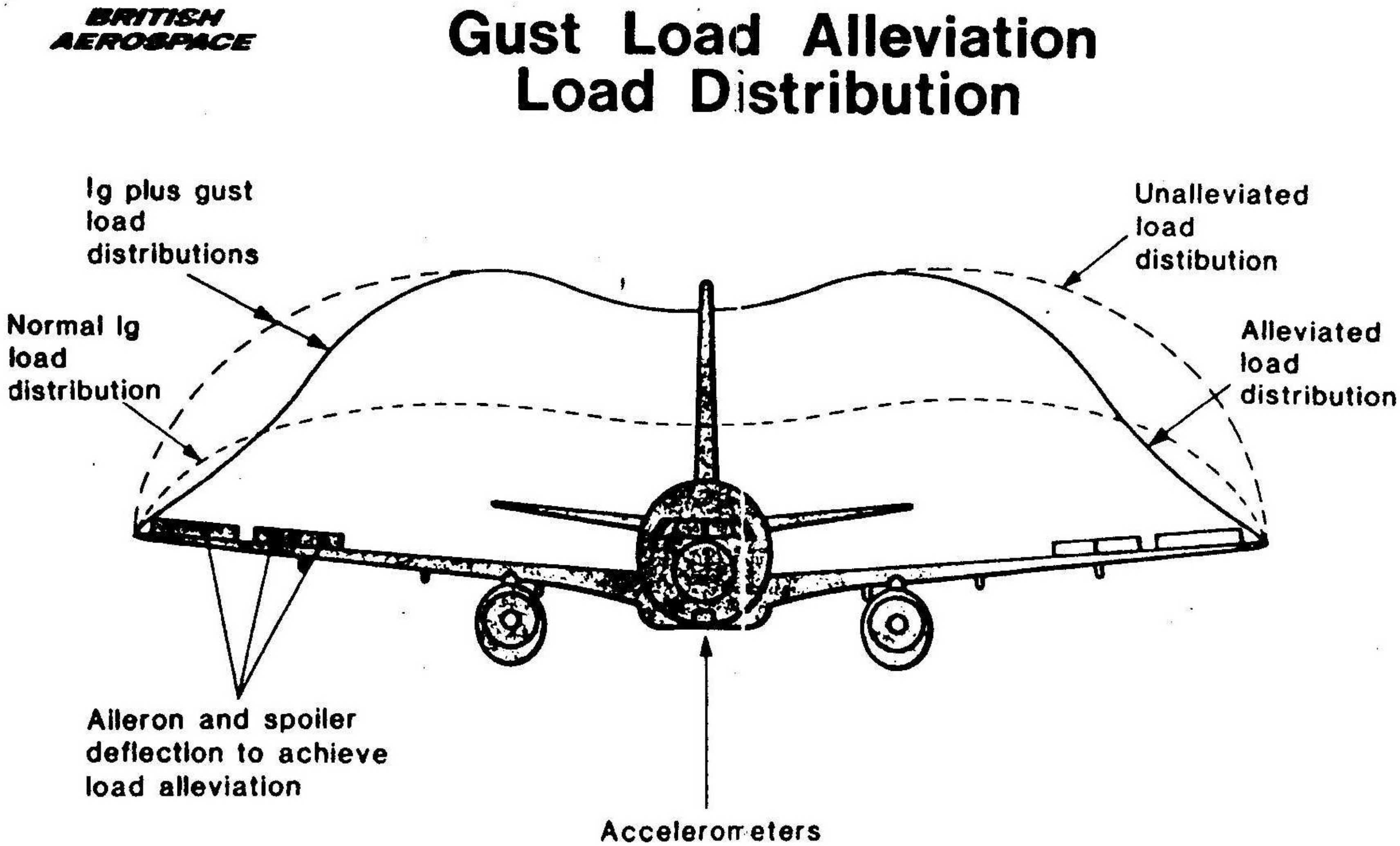


BRITISH AEROSPACE

Manoeuvre Load Alleviation
Load Distribution



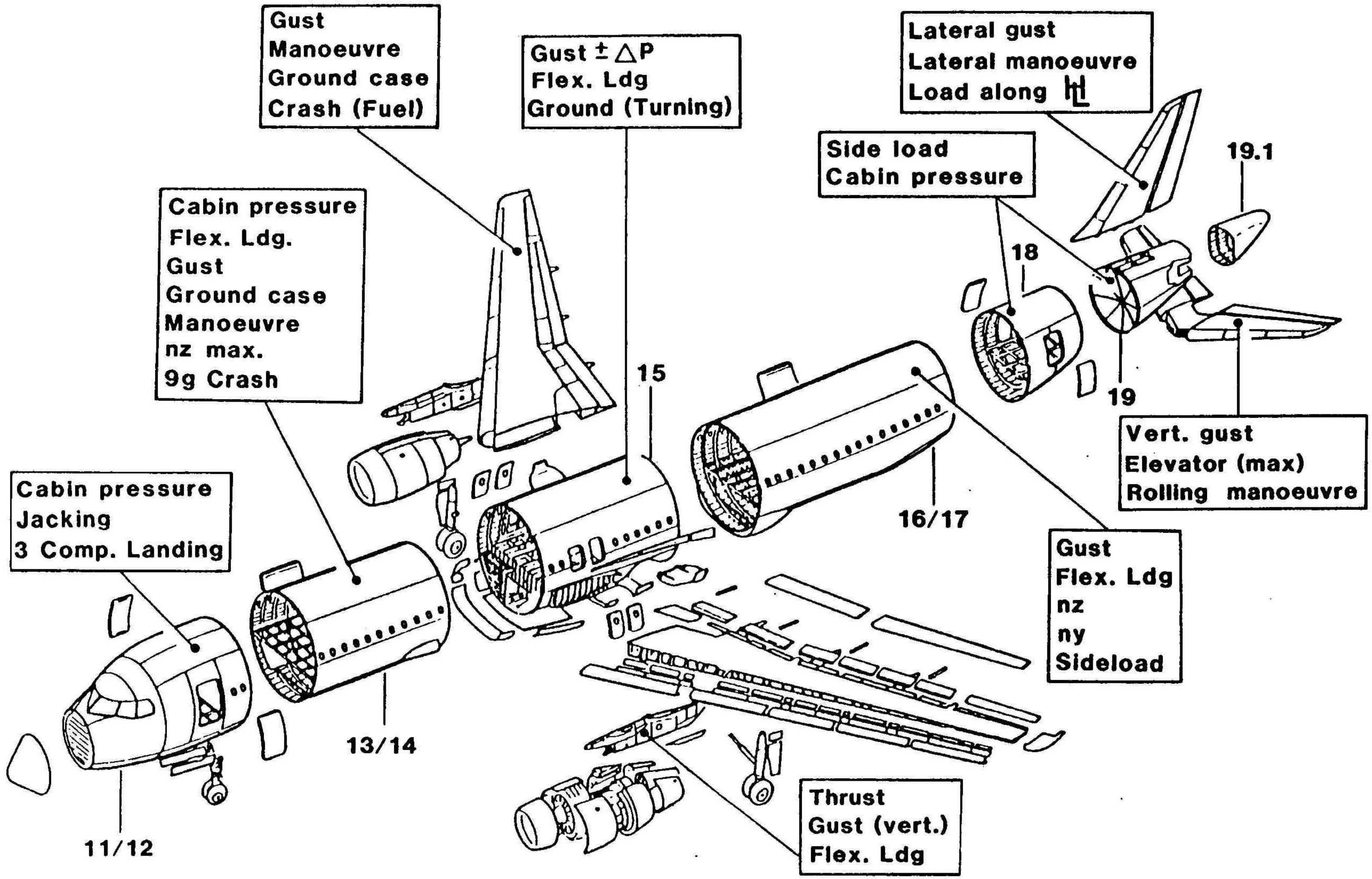
Gust Load Alleviation
Load Distribution



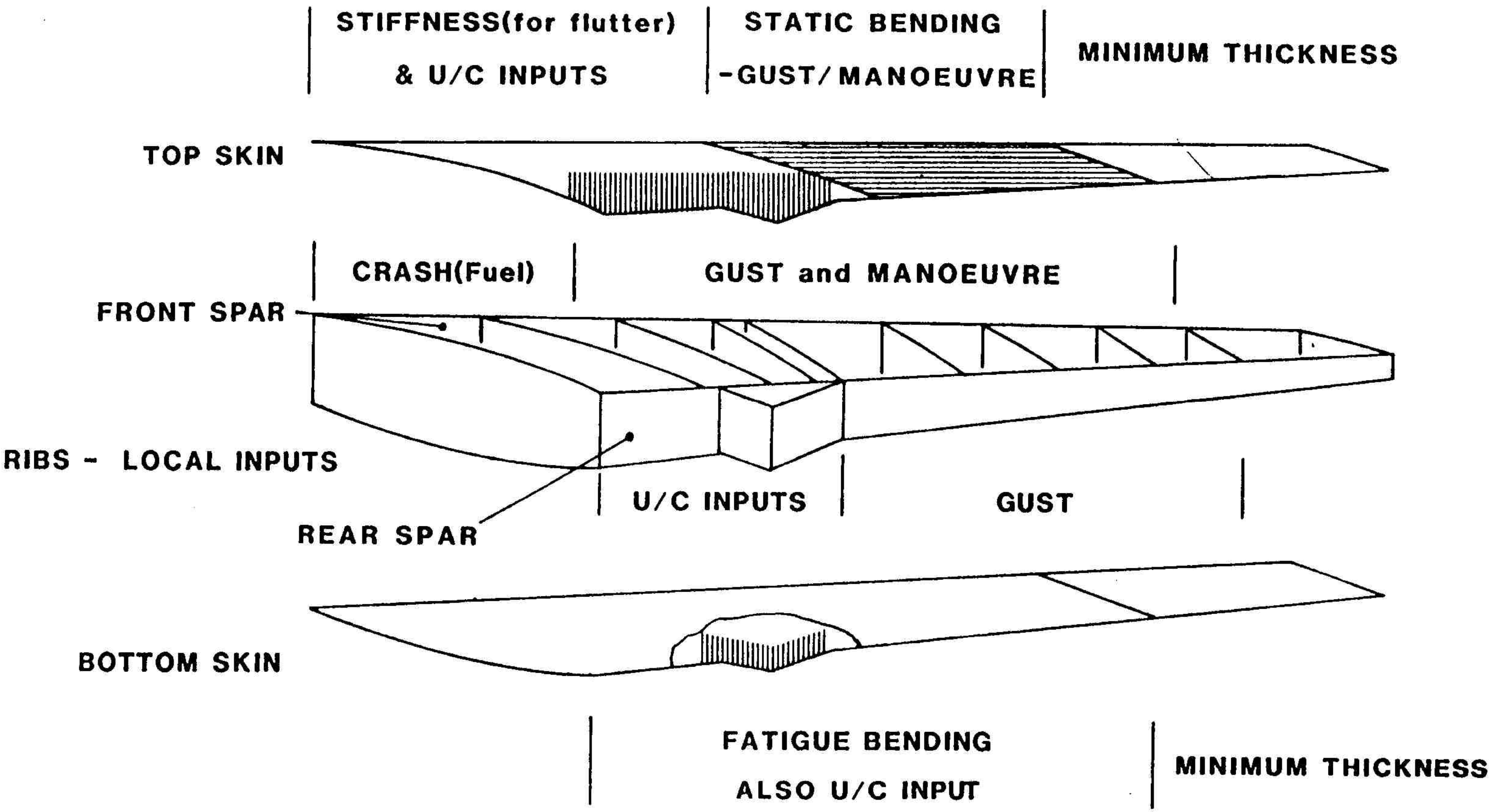
Effect of Load Alleviation

STATION		SHEAR (daN)		MOMENT (daN.m)		TORQUE (daN.m)	
		MAX	MIN	MAX	MIN	MAX	MIN
WING ROOT $\eta = \cdot 110$ A/C AXES	LAF	46731	-16269	314169	-137583	82820	-155809
	NO LAF	49967	-16269 AB	368324	-134909	68177	-173737
WING ROOT $\eta = \cdot 110$ REF. AXIS	LAF	46731	-16269	343204	-158754	37197	-50434
	NO LAF	49967	-16269 AB	405676	-151194	33926	-54952
WING $\eta = \cdot 339$ REF AXIS	LAF	35441	-17008	179944	-100134	16676	-19624
	NO LAF	40678	-17008 AB	217300	-77214	14038	-19624 AB
WING $\eta = \cdot 681$ REF AXIS	LAF	15025	-9927	40936	-23974	6787	-6404
	NO LAF	17567	-7270	46020	-20079	5463	-6404 AB
FRONT FUSELAGE JUST FORWARD OF WING	LAF	34633	-15092	237526	-99791		
	NO LAF	34553	-15092 AB	232034	-99791 AB		
REAR FUSELAGE JUST AFT OF WING	LAF	19620	-53619	477714	-204340		
	NO LAF	19620 AB	-60618	502228	-204340 AB		
TAIL PLANE $\eta = \cdot 125$ REF AXIS.	LAF	7116	-6714	21318	-18706	1096	-3633
	NO LAF	6805	-7276	20511	-20376	1040	-3633 AB.

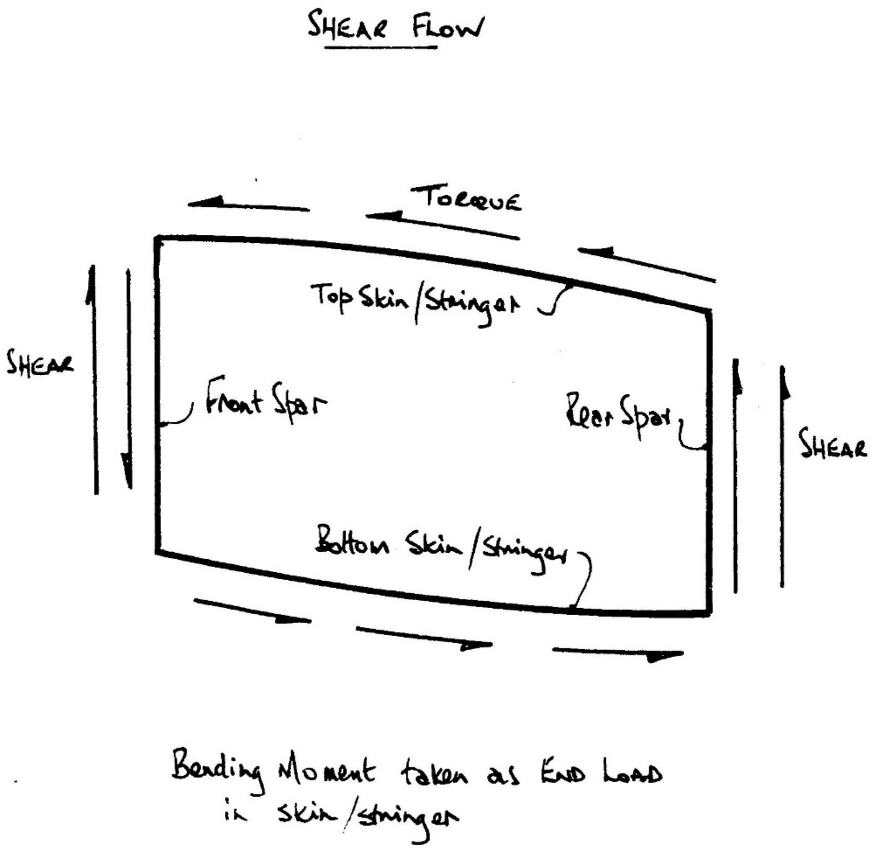
TYPICAL DIMENSIONING CASES

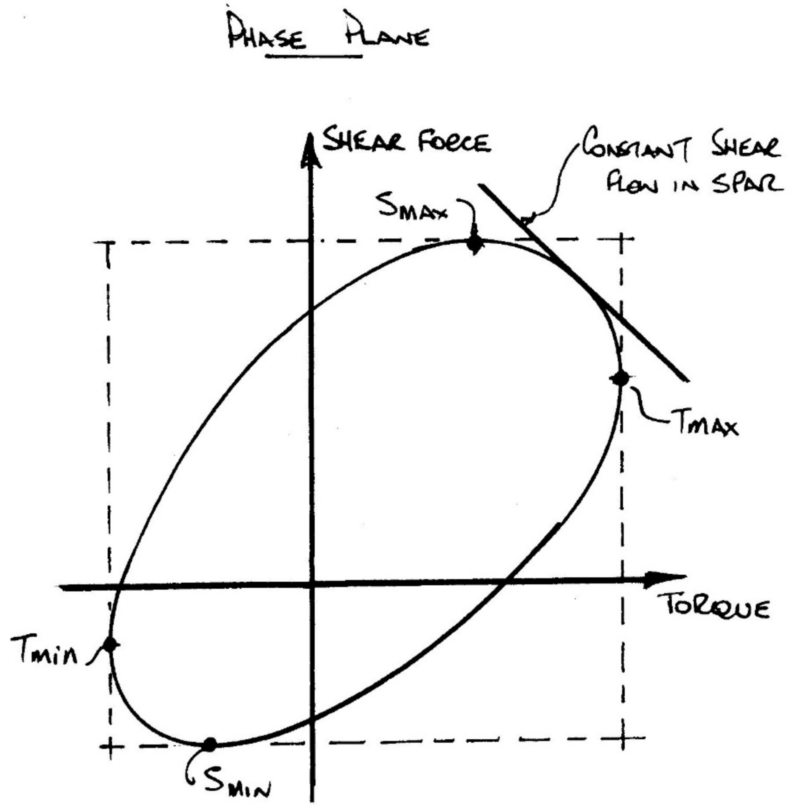


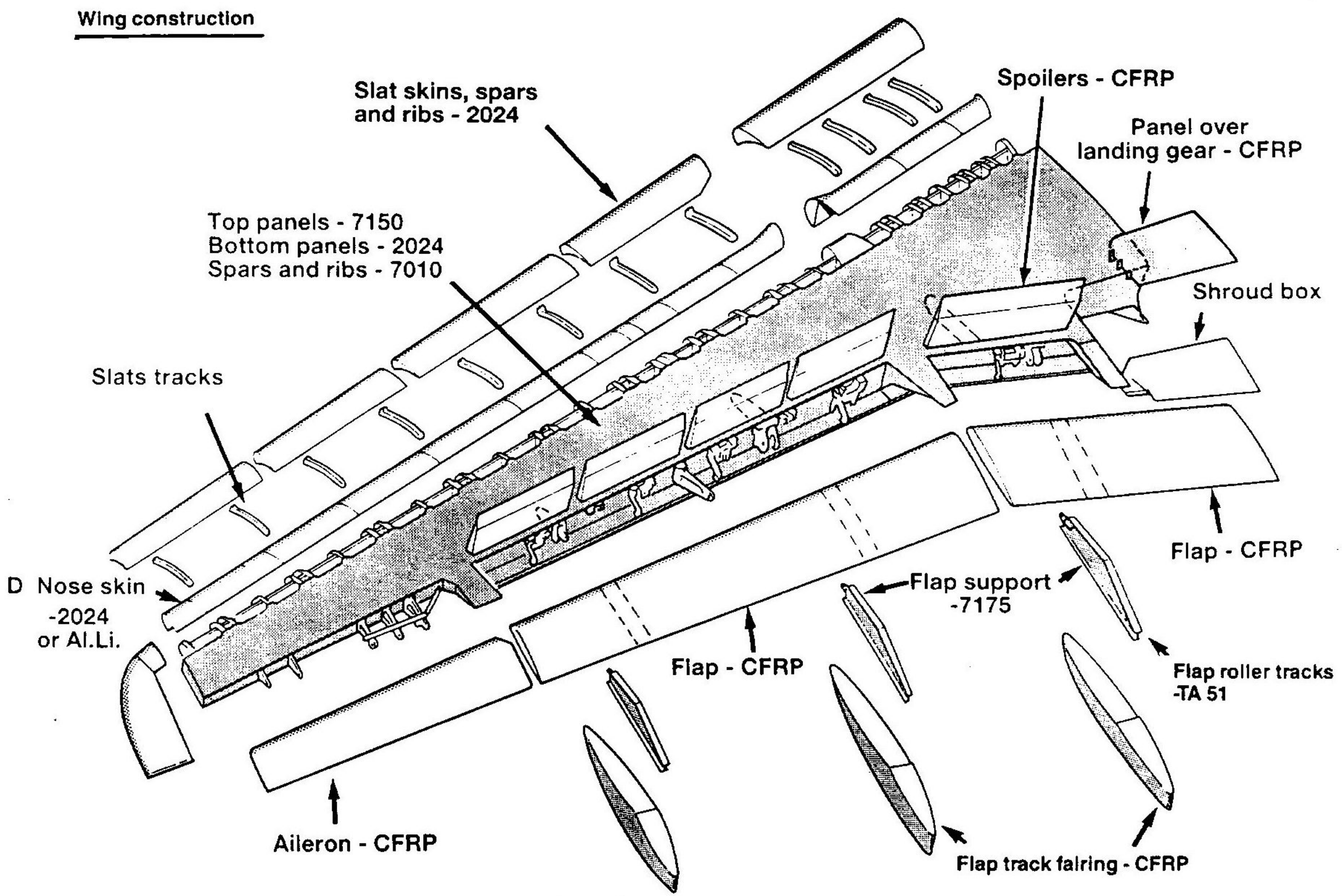
WING BOX DESIGN CASES



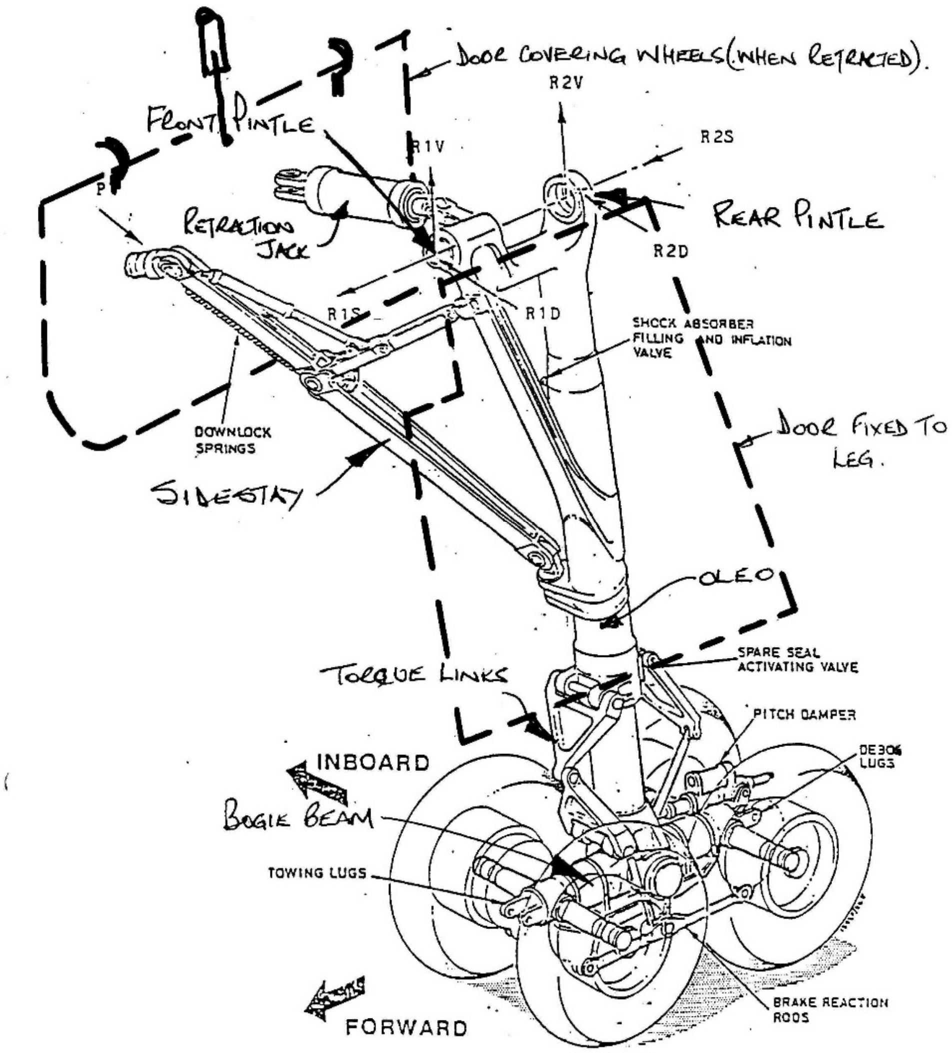
Shear/Torque Combinations





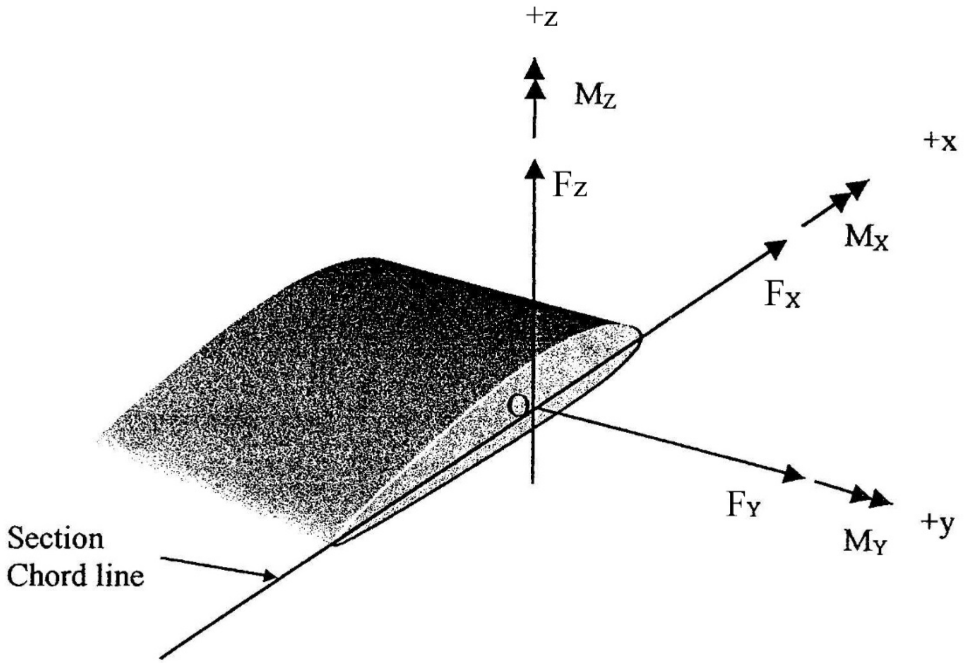

Wing construction
Slat skins, spars
and ribs - 2024
Spoilers - CFRP
Panel over
landing gear - CFRP
Top panels - 7150
Bottom panels - 2024
Spars and ribs - 7010
Shroud box
Slats tracks
Flap - CFRP
D Nose skin
-2024
or Al.Li.
Flap support
-7175
Flap - CFRP
Flap roller tracks
-TA 51
Aileron - CFRP
Flap track fairing - CFRP

TYPICAL LANDING GEAR (MAIN)



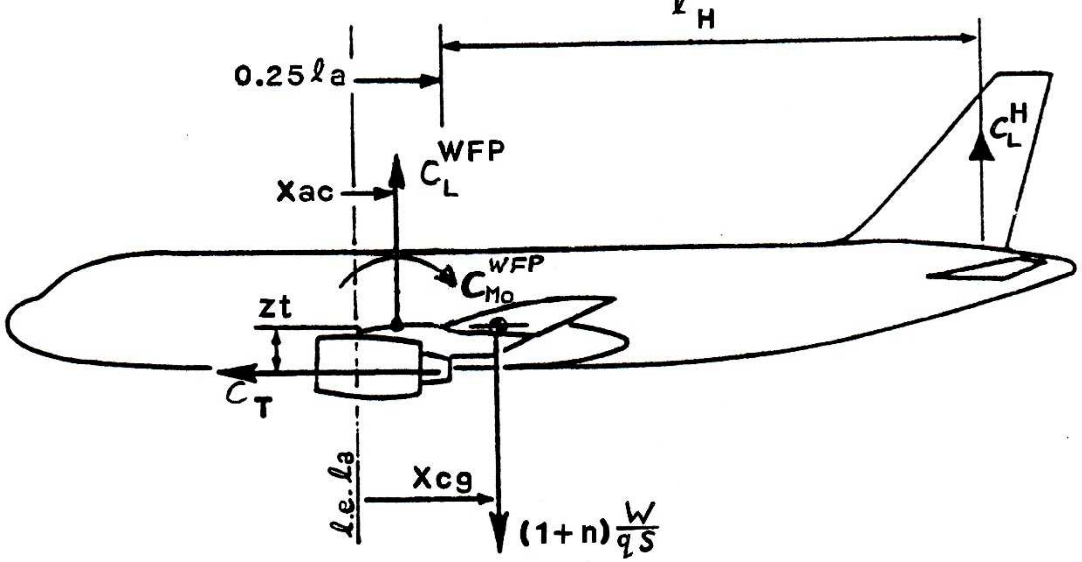
FOUR WHEEL BOGIE M.L.G.

Sign Conventions



Fx +ve forward	Mx +ve tip down
Fy +ve outboard	My +ve nose up
Fz +ve up	Mz +ve tip forward

Longitudinal Equilibrium



For trim i.e. equilibrium in pitch

Resolving vertically

$$C_L = C_L^{WFP} + C_L^H . S_H/S . q_H/q = nW/qS$$

Moments about CG (for trim $C_{MO}=0$)

$$C_{MO} = C_{MO}^{WFP} + C_L^{WFP}(x_{cg}-x_{ac})/l_a + C_T . zt/l_a - C_L^H . S_H/S((l_H-x_{cg})/l_a+0.25) . q_H/q$$

Longitudinal Equilibrium

The following assumptions will be made

Refer ALL data to the wing reference area and AMC
Thrust = zero (sets $C_T=0$)
$q_H/q=1.0$

Re-arranging the vertical equation to be

$$C_L^{WFP}= C_L-C_L^H$$

and substituting into the moment equation and solving for C_L^H

$$C_L^H=[C_{MO}^{WFP}+ C_L(x_{cg}-x_{ac})/l_a]/[(l_H-x_{ac})/l_a+0.25]$$

Longitudinal Equilibrium - Notation

C_L	Aircraft Lift Coefficient
W	Aircraft Mass (kg)
n	Manoeuvre g (-1.0 to 2.5)
q	Dynamic Pressure ($\frac{1}{2}\rho V^2$)
C_L^{WFP}	Lift Coefficient due to Wing, Fuselage and Pod (Tail Off)
C_L^{H}	Lift Coefficient due to Tailplane
C_{MO}^{WFP}	Pitching Moment Coefficient at zero lift (often written as C_{MO})
x_{ac}/l_a	Aerodynamic Centre
X_{cg}/l_a	Aircraft CG
l_a	Aerodynamic Mean Chord
l_H	Distance ¼ AMC(wing) to ¼ AMC(tailplane)

Longitudinal Equilibrium - Example

For UB90

$S = 122.4\ m^2$ $\quad$ $S_H = 31\ m^2$

$l_a = 4.193\ m$ $\quad$ $l_H = 17.588\ m\ (l_H/l_a = 4.1946)$

$C_{MO}^{WFP} = -0.155$ $\quad$ $x_{ac}/l_a = 0.16$

For W = 66000kg and CG (x_{cg}/l_a) at 31% (0.31 AMC)

With n = 2.5g and q = 18500 N/m^2

$C_L = nW/qS = (2.5 \times 66000 \times 9.80665)/(18500 \times 122.4) = 0.71458$

$C_L^H = [\ -0.155 + (0.71458 \times (0.31 - 0.16))]\ /\ [(4.1946 - 0.16) + 0.25]$

$= -0.01116$

$CL^{WFP} = 0.71458 - (-0.01116) = 0.72574$

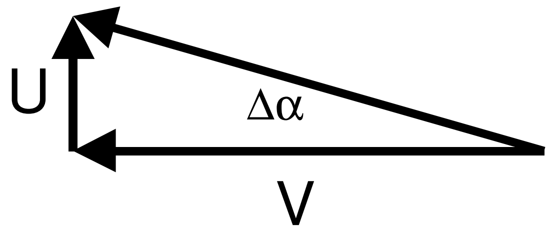
To see the effect of n and CG, suggest trying n= 2.5, 1, 0 and -1g

and CG = 15, 25, 35 and maybe 45%

GUST LOADS

Consider the effect of a vertical upgust on an aircraft in steady flight

The change in incidence is $\Delta\alpha = \dfrac{U}{V}$ radians



Lift Curve Slope is $\dfrac{dC_L}{d\alpha} = a_1$ and hence

change in lift coefficient, $\Delta C_L = a_1.\Delta\alpha$

Change in lift (ΔL) is $qS\,\Delta C_L$

Expanding all the terms

$$\Delta L = \frac{1}{2}\rho_0 V^2 S.\frac{U}{V}a$$

However, in reality,

- “sharp-edged” gusts do not exist
- lift does not grow directly with change in incidence
- aircraft responds in heave and pitch also reducing effect of gust

GUST LOADS

The actual increase in lift by the time the gust has reached its maximum velocity will be less than that implied by $\Delta\alpha$

Hence $$\Delta\alpha = K\frac{U}{V}$$

where K is the *gust alleviation factor* (which will normally be less than unity)

Based on experimental data (see NACA Report 1206)

$$K = \frac{0.88\mu}{5.3+\mu}$$

where the aircraft mass ratio, $$\mu = \frac{2Wg}{\rho caSg}$$

and W = aircraft mass (kg), S = wing area (m^2), *c* = wing mean geometric chord (m), *a* = lift curve slope, ρ = air density at appropriate altitude (kg/m^3) (ρ_o = 1.225 kg/m^3).

Hence $$\Delta L = \frac{1}{2}\rho_0 V^2 S\frac{U}{V}aK$$

GUST LOADS

The change in aircraft load factor due to gust is

$$\Delta n = \frac{\Delta L}{W}$$

$$\Delta n = \frac{KaUV\,\rho_0 S}{2Wg}$$

Total load factor acting on the aircraft is

$n = 1 \pm \Delta n$ as a gust can act up or down

$$n = 1 \pm \frac{KaUV\rho_0 S}{2W}$$

In Imperial units $\Delta n = \dfrac{KaUVS}{498W}$ where $\dfrac{1}{498} = \dfrac{0.002377 \times 1.69}{2}$

GUST LOADS - EXAMPLE

For UB90

W (Aircraft Mass) = 66000 kg S (Wing Area) = 122.4 m^2

c (Geometric Mean Chord) = 3.609 m

V = 337.9 kts (EAS) (173.83 m/s) u (Gust Velocity) = 50 ft/sec (15.24 m/s)

ρ_0 (Density at Sea Level) = 1.225 kg/m^3 ρ (Density at 20000ft) = 0.6527 kg/m^3

a (Lift curve slope) = 7.219

$$\mu = \frac{2 \times 66000 \times 9.80665}{0.6527 \times 3.609 \times 7.219 \times 122.4 \times 9.80665} = 63.418$$

$$K = \frac{0.88 \times 63.418}{5.3 + 63.418} = 0.812$$

$$\Delta n = \frac{0.812 \times 7.219 \times 15.24 \times 173.83 \times 1.225 \times 122.4}{2 \times 66000 \times 9.80665} = 1.799$$

$$n = 1 \pm 1.799 = 2.799 \quad \text{or} \quad -0.799$$

Lift Curve Slope for Gust Calcuation

$a = a_{WFP} + a_H \, S_H/S_W \, (1 - d\varepsilon/d\alpha)$

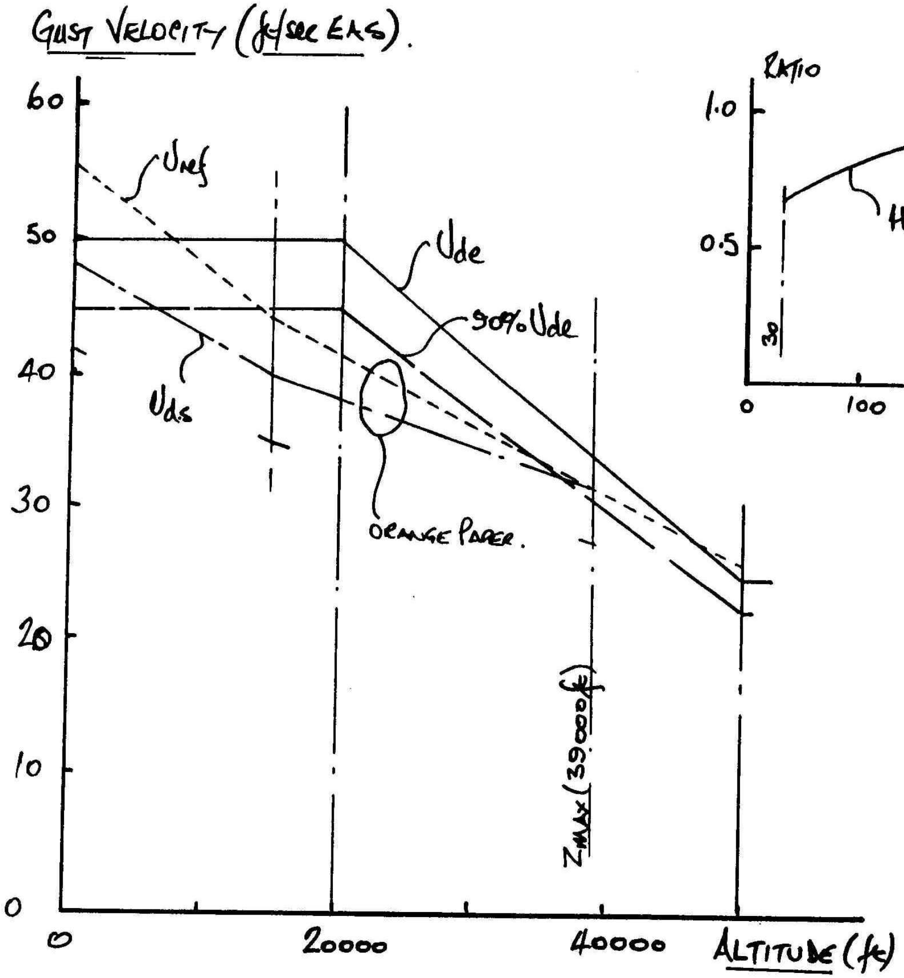
$a_{WFP} = 6.68$ $\quad a_H = 3.8$

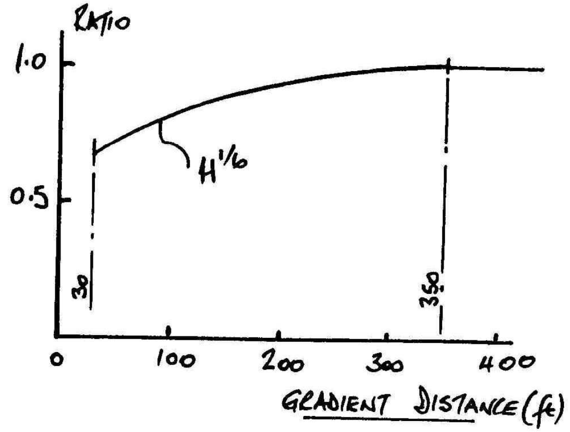
$S_W = 122.4$ m2 $\quad S_H = 31$ m2

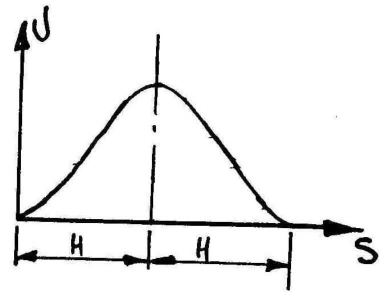
$d\varepsilon/d\alpha = 0.44$ (Downwash at Tail location)

$a = 6.68 + 0.539 = 7.219$

Gust Velocities at V_C

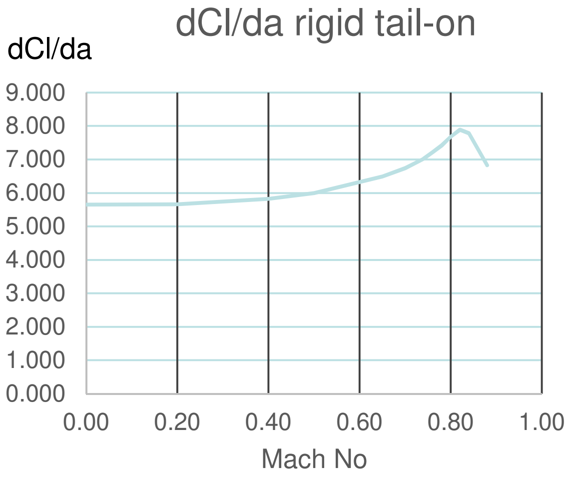






$$U = \frac{U_{de}}{2}\left(1 - \cos\frac{\pi S}{H}\right)$$

Trend study to indicate the worst case



$$\Delta n = \frac{KaUV\,\rho_0 S}{2Wg}$$

Δn is a function of = aUV