Tema n. 3

POLITECNICO DI TORINO
ESAME DI STATO PER L'ABILITAZIONE ALLA PROFESSIONE DI INGEGNERE INDUSTRIALE

I Sessione 2011 - Sezione A

Settore industriale

Classe 25/S – Ingegneria Aerospaziale

Prova pratica del 28 luglio 2011

Definizione criteri di progetto aero-srutturale per velivolo del settore aviazione sportiva.

La configurazione aerodinamica di un velivolo appartenente al settore dell'aviazione sportiva, categoria acrobatica, è stata progettata ed i relativi parametri di riferimento sono riportati nelle tabelle allegate. Partendo da questi dati, il candidato elabori i Criteri di Progetto aero-strutturale indispensabili all'analisi dei carichi strutturali ed al progetto della configurazione strutturale del velivolo. La normativa di riferimento da utilizzare nelle valutazioni è la EASA CS-23 (vedi allegati).
I paragrafi dei Criteri di Progetto che il candidato dovrà studiare e riportare nella prova sono i seguenti:

1) Masse velivolo caratteristiche per il progetto strutturale.

Stabilire le configurazioni di massa velivolo sulla base dei requisiti richiesti dalla normativa di riferimento, motivando la scelta con l'utilizzo nelle analisi dei carichi di dimensionamento anche citando i relativi paragrafi normativi.
Dato il peso massimo al decollo (MTOW) e il peso a vuoto massimo operativo (MOEW) e le relative posizioni del baricentro è richiesta la definizione ed il calcolo delle seguenti caratteristiche inerziali:

a) Peso massimo all'atterraggio (MLW) assumendo come peso di progetto (design weight) il peso massimo al decollo (MTOW);
b) Posizione longitudinale del baricentro (CGMLW) rispetto all'ogiva dell'elica corrispondente al punto a);
c) Peso minimo di volo (MFW) assumendo una percentuale residua di combustibile del 10% della massima capacità del serbatoio (in deroga a quanto prescritto dalla normativa EASA CS-23 para 23.25 (b)) ed un peso minimo del pilota di 77 Kg;
d) Posizione longitudinale del baricentro (CGMFW) rispetto all'ogiva dell'elica corrispondente al punto c);

2) Diagrammi di progetto fattori di carico / velocità velivolo (Nz/Vac).

Disegnare i diagrammi Fattore di carico/ Velocità velivolo (Nz/Vac) per manovra e raffica associati alla massa velivolo MTOW definita nel punto 1) con riferimento ai requisiti della normativa EASA CS-23 (vedi allegato). Assumere come quota operativa il livello del mare.

3) Criteri di progetto per i carichi al suolo.

Seguendo le indicazioni della norma di riferimento (EASA CS-23) e dai risultati del punto 1) e 2), calcolare i valori di progetto della velocità verticale di progetto del velivolo in atterraggio e dell'angolo di rampa di discesa assumendo che la velocità del velivolo Vac sia uguale a 1.2 Vs (Velocità di stallo) al MLW.

4) Coefficiente di carico ultimo per il dimensionamento strutturale statico

Seguendo le indicazioni della norma di riferimento (EASA CS-23), indicare il valore e spiegare il significato dei coefficienti di carico ultimo da utilizzare per la fattorizzazione delle condizioni di carico strutturale limite di progetto in volo e al suolo.

Dati geometrici velivolo:

ALA			Note
Apertura alare	10.1	m	
Superficie alare	15.08	m2	
Freccia al 25 % della corda alare	9.58	deg	Positiva tip alare indietro
Rapporto di rastremazione	0.44	-	
Corda media aerodinamica (MAC)	1.576	m	
Angolo diedro	+ 3	deg	Rotazione positiva: tip alare in alto
Svergolamento	+ 2	deg	Rotazione positiva: tip alare vs basso
Profilo alare alla C/L della fusoliera	NACA23015	-	C/L: linea centrale logitudinale di fusoliera
Profilo alare all'estremità	NACA23012	-	Con variazione lineare in apertura dei profili
Incidenza del profilo alla radice alare	+ 1	deg	Riferito alla C/L: positivo b. attacco in alto
Posizione del 25% MAC	1.176	m	Distanza dal bordo di fuga con freccia zero (in avanti)
Posizione bordo di fuga dell'ala	3.90	m	Distanza dall'ogiva dell'elica
Posizione verticale TE rispetto alla C/L	0.46	m	Positivo verso il basso

Fusoliera			Note
Lunghezza	8.14	m	
Altezza	1.27	m	
Larghezza	0.85	m	
Posizione del bordo di fuga dell'ala con freccia zero	3.985	m	Con riferimento all'ogiva dell'elica

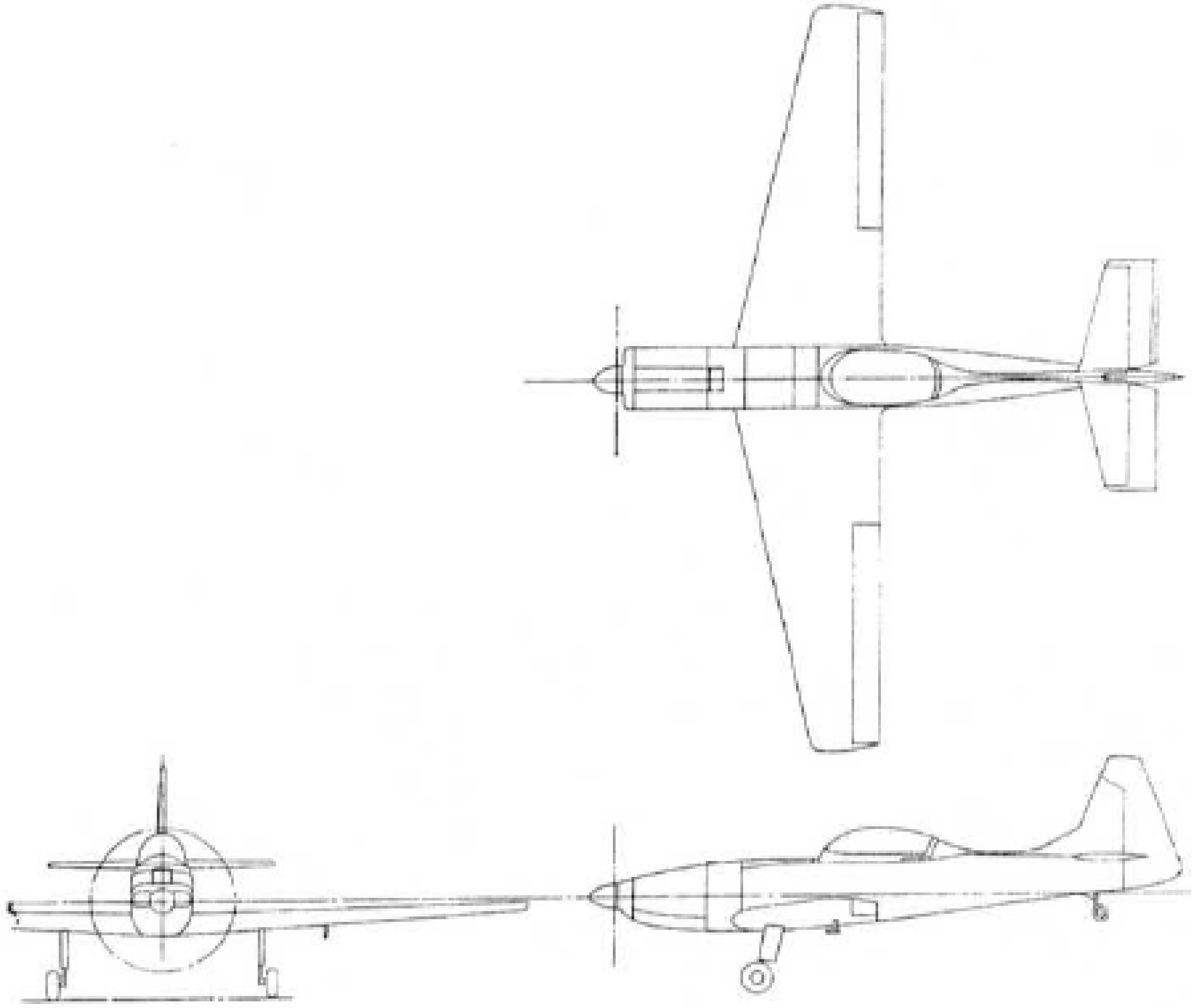
Dati aerodinamici del velivolo:

Ala-Fusoliera			Note
Derivata curva di portanza	4.3	1/rad	La1wb
Angolo incidenza di portanza nulla	-0.72	deg	Relativo alla corda C/L
Coeff. di portanza massimo	1.42	-	CL Max - Volo orizzontale
Coeff. di portanza massimo	1.00	-	CL Max - Volo rovescio
Coeff. di portanza ad incidenza nulla	0.13	-	CL0 - Incidenza riferita alla corda C/L
Posizione CP aerodinamico	0.19	-	Con riferimento alla MAC
Resistenza			
Coeff. di resistenza a portanza nulla	0.038	-	Cdz
Coeff. di portanza indotta	0.065	-	K
			$(C_d = C_{dz} + KC_L^2)$

Dati di massa velivolo:

Elementi			Note
Peso massimo al decollo velivolo (MTOW)	945	Kg	
Posizione c.g. MTOW	2.698	m	Con riferimento all'ogiva dell'elica
Peso massimo pilota e paracadute	100	Kg	
Posizione c.g. pilota	4.00	m	Con riferimento all'ogiva dell'elica
Peso carburante	100	Kg	
Posizione c.g. carburante	2.5	m	Con riferimento all'ogiva dell'elica
Peso massimo a vuoto velivolo operativo (MOEW)	845	Kg	Inclusi pilota, olio e liquidi reffreddamento
Posizione c.g. MOEW	2.722	m	Con riferimento all'ogiva dell'elica

<u>Configurazione generale del velivolo</u>



Allegato:

Estratto normativa di riferimento EASA

Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes CS-23 - Subpart A (General)

Amendment 2 (Corrigendum), 28 September 2010

SUBPART A — GENERAL

CS 23.1 Applicability

(a) This airworthiness code is applicable to –

(1) Aeroplanes in the normal, utility and aerobatic categories that have a seating configuration, excluding the pilot seat(s), of nine or fewer and a maximum certificated take-off weight of 5670 kg (12 500 lb) or less; and

(2) Propeller-driven twin-engined aeroplanes in the commuter category that have a seating configuration, excluding the pilot seat(s), of nineteen or fewer and a maximum certificated take-off weight of 8618 kg (19 000 lb) or less.

CS 23.3 Aeroplane categories

(a) The normal category is limited to non-aerobatic operations. Non-aerobatic operations include –

(1) Any manoeuvre incident to normal flying;

(2) Stalls (except whip stalls); and

(3) Lazy eights, chandelles and steep turns or similar manoeuvres, in which the angle of bank is not more than 60°.

(b) The utility category is limited to any of the operations covered under sub-paragraph (a); plus –

(1) Spins (if approved for the particular type of aeroplane); and

(2) Lazy eights, chandelles, and steep turns, or similar manoeuvres in which the angle of bank is more than 60° but not more than 90°.

(c) The aerobatic category is without restrictions, other than those shown to be necessary as a result of required flight tests.

(d) Commuter category operation is limited to any manoeuvre incident to normal flying, stalls (except whip stalls) and steep turns in which the angle of bank is not more than 60°.

(e) Except for commuter category, aeroplanes may be certificated in more than one category if the requirements of each requested category are met.

Subpart B (Flight)

CS-23 BOOK 1

SUBPART B – FLIGHT

GENERAL

CS 23.21 Proof of compliance

(a) Each requirement of this subpart must be met at each appropriate combination of weight and centre of gravity within the range of loading conditions for which certification is requested. This must be shown –

(1) By tests upon an aeroplane of the type for which certification is requested, or by calculations based on, and equal in accuracy to, the results of testing; and

(2) By systematic investigation of each probable combination of weight and centre of gravity, if compliance cannot be reasonably inferred from combinations investigated.

(b) The following general tolerances are allowed during flight testing. However, greater tolerances may be allowed in particular tests –

Item	*Tolerance*
Weight	+5%, –10%
Critical items affected by weight	+5%, –1%
C.G.	±7% total travel

CS 23.23 Load distribution limits

(a) Ranges of weight and centres of gravity within which the aeroplane may be safely operated must be established and must include the range for lateral centres of gravity if possible loading conditions can result in significant variation of their positions.

(b) The load distribution must not exceed –

(1) The selected limits;

(2) The limits at which the structure is proven; or

(3) The limits at which compliance with each applicable flight requirement of this subpart is shown.

CS 23.25 Weight limits

(a) *Maximum weight*. The maximum weight is the highest weight at which compliance with each applicable requirement of CS-23 (other than those complied with at the design landing weight) is shown. The maximum weight must be established so that it is –

(1) Not more than the least of –

(i) The highest weight selected by the applicant; or

(ii) The design maximum weight, which is the highest weight at which compliance with each applicable structural loading condition of CS-23 (other than those complied with at the design landing weight) is shown; or

(iii) The highest weight at which compliance with each applicable flight requirement is shown, and,

(2) Not less than the weight with:-

(i) Each seat occupied, assuming a weight of 77kg (170 lbs) for each occupant for normal and commuter category aeroplanes, and 86kg (190 lbs) for utility and acrobatic category aeroplanes, except that seats other than pilot seats may be placarded for a lesser weight; and

(A) Oil at full capacity, and

(B) At least enough fuel for maximum continuous power operation of at least 30 minutes for day-VFR approved aeroplanes and at least 45 minutes for night-VFR and IFR approved aeroplanes; or

(ii) The required minimum crew, and fuel and oil to full tank capacity.

(b) *Minimum weight*. The minimum weight (the lowest weight at which compliance with each applicable requirement of CS-23 is shown) must be established so that it is not more than the sum of –

(1) The empty weight determined under CS 23.29;

(2) The weight of the required minimum crew (assuming a weight of 77 kg (170 lb) for each crew member); and

(3) The weight of –

(i) For turbojet powered aeroplanes, 5% of the total fuel capacity of that particular fuel tank arrangement under investigation; and

(ii) For other aeroplanes, the fuel necessary for one-half hour of operation at maximum continuous power.

Subpart C (Structure)

GENERAL

CS 23.301 Loads

(a) Strength requirements are specified in terms of limit loads (the maximum loads to be expected in service) and ultimate loads (limit loads multiplied by prescribed factors of safety). Unless otherwise provided, prescribed loads are limit loads.

(b) Unless otherwise provided, the air, ground and water loads must be placed in equilibrium with inertia forces, considering each item of mass in the aeroplane. These loads must be distributed to conservatively approximate or closely represent actual conditions. Methods used to determine load intensities and distribution on canard and tandem wing configurations must be validated by flight test measurement unless the methods used for determining those loading conditions are shown to be reliable or conservative on the configuration under consideration.

(c) If deflections under load would significantly change the distribution of external or internal loads, this redistribution must be taken into account.

(d) Simplified structural design criteria may be used if they result in design loads not less than those prescribed in CS 23.331 to 23.521. For aeroplanes described in appendix A, paragraph A23.1, the design criteria of Appendix A of CS-23 are an approved equivalent of CS 23.321 to 23.459. If Appendix A is used, the entire Appendix must be substituted for the corresponding paragraphs of this CS-23.

CS 23.302 Canard or tandem wing configurations

The forward structure of a canard or tandem wing configuration must –

(a) Meet all requirements of subpart C and subpart D of CS-23 applicable to a wing; and

(b) Meet all requirements applicable to the function performed by these surfaces.

CS 23.303 Factor of safety

Unless otherwise provided, a factor of safety of 1·5 must be used.

CS 23.305 Strength and deformation

(a) The structure must be able to support limit loads without detrimental, permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation.

(b) The structure must be able to support ultimate loads without failure for at least three seconds, except local failures or structural instabilities between limit and ultimate load are acceptable only if the structure can sustain the required ultimate load for at least three seconds. However, when proof of strength is shown by dynamic tests simulating actual load conditions, the three second limit does not apply.

CS 23.307 Proof of structure
(See AMC 23.307)

(a) Compliance with the strength and deformation requirements of CS 23.305 must be shown for each critical load condition. Structural analysis may be used only if the structure conforms to those for which experience has shown this method to be reliable. In other cases, substantiating load tests must be made. Dynamic tests, including structural flight tests, are acceptable if the design load conditions have been simulated.

(b) Certain parts of the structure must be tested as specified in Subpart D of CS-23.

FLIGHT LOADS

CS 23.321 General
(See AMC 23.321 (c))

(a) Flight load factors represent the ratio of the aerodynamic force component (acting normal to the assumed longitudinal axis of the aeroplane) to the weight of the aeroplane. A positive flight load factor is one in which the aerodynamic force acts upward, with respect to the aeroplane.

(b) Compliance with the flight load requirements of this subpart must be shown –

(1) At each critical altitude within the range in which the aeroplane may be expected to operate;

(2) At each weight from the design minimum weight to the design maximum weight; and

(3) For each required altitude and weight, for any practicable distribution of disposable load within the operating limitations specified in CS 23.1583 to 23.1589.

(c) When significant the effects of compressibility must be taken into account.

CS 23.331 Symmetrical flight conditions

(a) The appropriate balancing horizontal tail load must be accounted for in a rational or conservative manner when determining the wing loads and linear inertia loads corresponding to any of the symmetrical flight conditions specified in CS 23.331 to 23.341.

(b) The incremental horizontal tail loads due to manoeuvring and gusts must be reacted by the angular inertia of the aeroplane in a rational or conservative manner.

(c) Mutual influence of the aerodynamic surfaces must be taken into account when determining flight loads.

CS 23.333 Flight envelope

(a) *General.* Compliance with the strength requirements of this subpart must be shown at any combination of airspeed and load factor on and within the boundaries of a flight envelope (similar to the one in sub-paragraph (d)) that represents the envelope of the flight loading conditions specified by the manoeuvring and gust criteria of sub-paragraphs (b) and (c) respectively.

(b) *Manoeuvring envelope.* Except where limited by maximum (static) lift coefficients, the aeroplane is assumed to be subjected to symmetrical manoeuvres resulting in the following limit load factors:

(1) The positive manoeuvring load factor specified in CS 23.337 at speeds up to V_D;

(2) The negative manoeuvring load factor specified in CS 23.337 at V_C; and

(3) Factors varying linearly with speed from the specified value at V_C to 0·0 at V_D for the normal and commuter category, and -1·0 at V_D for the aerobatic and utility categories.

(c) *Gust envelope*

(1) The aeroplane is assumed to be subjected to symmetrical vertical gusts in level flight. The resulting limit load factors must correspond to the conditions determined as follows:

(i) Positive (up) and negative (down) gusts of 50 fps at V_C must be considered at altitudes between sea level and 6096 m (20 000 ft). The gust velocity may be reduced linearly from 50 fps at 6096 m (20 000 ft) to 25 fps at 15240 m (50 000 ft); and

(ii) Positive and negative gusts of 25 fps at V_D must be considered at altitudes between sea level and 6096 m (20 000 ft). The gust velocity may be reduced linearly from 25 fps at 6096 m (20 000 ft) to 12·5 fps at 15240 m (50 000 ft).

(iii) In addition, for commuter category aeroplanes, positive (up) and negative (down) rough air gusts of 66 fps at V_B must be considered at altitudes between sea level and 6096 m (20 000 ft). The gust velocity may be reduced linearly from 66 fps at 6096 m (20 000 ft) to 38 fps at 15240 m (50 000 ft).

(2) The following assumptions must be made:

(i) The shape of the gust is –

$$U = \frac{U_{de}}{2}\left(1 - \cos\frac{2\pi s}{25\bar{C}}\right)$$

where –

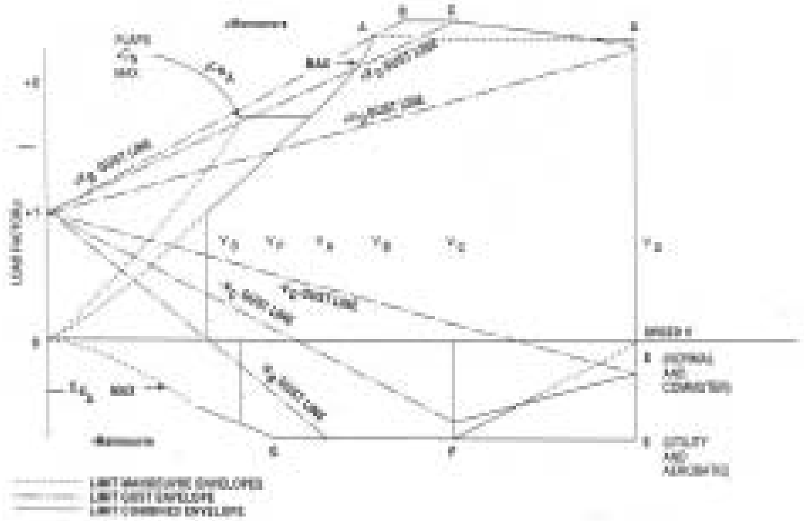
s = Distance penetrated into gust (ft.);

$\bar{C}$ = Mean geometric chord of wing (ft.); and

U_{de} = Derived gust velocity referred to in sub-paragraph (1) linearly with speed between V_C and V_D.

(ii) Gust load factors vary linearly with speed between V_C and V_D.

(d) *Flight envelope*



Note: Point G need not be investigated when the supplementary condition specified in CS 23.369 is investigated.

CS 23.335 Design airspeeds

Except as provided in sub-paragraph (a) (4) , the selected design airspeeds are equivalent airspeeds (EAS).

(a) *Design cruising speed, V_C.* For V_C the following apply:

(1) V_C (in knots) may not be less than –

(i) 33 $\sqrt{W/S}$ (for normal, utility and commuter category aeroplanes); <u>and</u>

(ii) 36 $\sqrt{W/S}$ (for aerobatic category aeroplanes).

where W/S = wing loading at design maximum take-off weight lb/ft^2.

(2) For values of W / S more than 20, the multiplying factors may be decreased linearly with W / S to a value of 28·6 where W / S = 100.

(3) V_C need not be more than 0·9 V_H at sea level.

(4) At altitudes where an M_D is established, a cruising speed M_C limited by compressibility may be selected.

(b) *Design dive speed, V_D.* For V_D the following apply:

(1) V_D/M_D may not be less than 1·25 V_C/M_C; and

(2) With $V_{C\,min}$, the required minimum design cruising speed, V_D may not be less than –

(i) 1·40 $V_{C\,min}$ for normal and commuter category aeroplanes;

(ii) 1·50 $V_{C\,min}$ for utility category aeroplanes; and

(iii) 1·55 $V_{C\,min}$ for aerobatic category aeroplanes.

(3) For values of W / S more than 20, the multiplying factors in sub-paragraph (2) may be decreased linearly with W / S to a value of 1·35 where W / S = 100.

(4) Compliance with sub-paragraphs (1) and (2) need not be shown if V_D/M_D is selected so that the minimum speed margin between V_C/M_C and V_D/M_D is the greater of the following:

(i) The speed increase resulting when, from the initial condition of stabilised flight at V_C/M_C, the aeroplane is assumed to be upset, flown for 20 seconds along a flight path 7·5° below the initial path and then pulled up with a load factor of 1·5 (0·5 g. acceleration increment). At least 75% maximum continuous power for reciprocating engines and maximum cruising power for turbines, or, if less, the power required for V_C/M_C for both kinds of engines, must be assumed until the pull-up is initiated, at which point power reduction and pilot-controlled drag devices may be used; and

(ii) Mach 0·05 for normal, utility, and aerobatic category aeroplanes (at altitudes where M_D is established).

(iii) Mach 0·07 for commuter category aeroplanes (at altitudes where M_D is established) unless a rational analysis, including the effects of automatic systems, is used to determine a lower margin. If a rational analysis is used, the minimum speed margin must be enough to provide for atmospheric variations (such as horizontal gusts, and the penetration of jet streams or cold fronts), instrument errors, airframe production variations, and must not be less than Mach 0·05.

(c) *Design manoeuvring speed V_A.* For V_A, the following applies:

(1) V_A may not be less than $V_S\sqrt{n}$ where –

(i) V_S is a computed stalling speed with flaps retracted at the design weight, normally based on the maximum aeroplane normal force coefficients, C_{NA}; and

(ii) n is the limit manoeuvring load factor used in design.

(2) The value of V_A need not exceed the value of V_C used in design.

(d) *Design speed for maximum gust intensity, V_B.* For V_B, the following applies:

(1) V_B may not be less than the speed determined by the intersection of the line representing the maximum positive lift $C_{N\,MAX}$ and the line representing the rough air gust velocity on the gust V-n diagram, or $V_{S1}\sqrt{n_g}$, whichever is less, where –

(i) n_g the positive aeroplane gust load factor due to gust, at speed V_C (in accordance with CS 23.341), and at the particular weight under consideration; and

(ii) V_{S1} is the stalling speed with the flaps retracted at the particular weight under consideration.

(2) V_B need not be greater than V_C.

CS 23.337 Limit manoeuvring load factors

(a) The positive limit manoeuvring load factor n may not be less than –

(1) $2{\cdot}1+\frac{24000}{W+10000}$ for normal and commuter category aeroplanes (where W = design maximum take-off weight lb), except that n need not be more than 3·8;

(2) 4·4 for utility category aeroplanes; or

(3) 6·0 for aerobatic category aeroplanes.

(b) The negative limit manoeuvring load factor may not be less than –

(1) 0·4 times the positive load factor for the normal, utility and commuter categories; or

(2) 0·5 times the positive load factor for the aerobatic category.

(c) Manoeuvring load factors lower than those specified in this paragraph may be used if the aeroplane has design features that make it impossible to exceed these values in flight.

CS 23.341 Gust load factors (See AMC 23.341 (b))

(a) Each aeroplane must be designed to withstand loads on each lifting surface resulting from gusts specified in CS 23.333(c).

(b) The gust load for a canard or tandem wing configuration must be computed using a rational analysis, or may be computed in accordance with sub-paragraph (c) provided that the resulting net loads are shown to be conservative with respect to the gust criteria of CS 23.333(c).

(c) In the absence of a more rational analysis the gust load factors must be computed as follows:

$$n = 1 \pm \frac{k_g \rho_0 U_{de} V a}{2(W/S)}$$

where –

$$k_g = \frac{0.88\mu_g}{5.3+\mu_g} = \text{gust alleviation factor;}$$

$$\mu_g = \frac{2(W/S)}{\rho \bar{C} a g} = \text{aeroplane mass ratio;}$$

EMERGENCY LANDING CONDITIONS

CS 23.561 General

(a) The aeroplane, although it may be damaged in emergency landing conditions, must