Estructuras Detalladas Cargas

Tema 13.1

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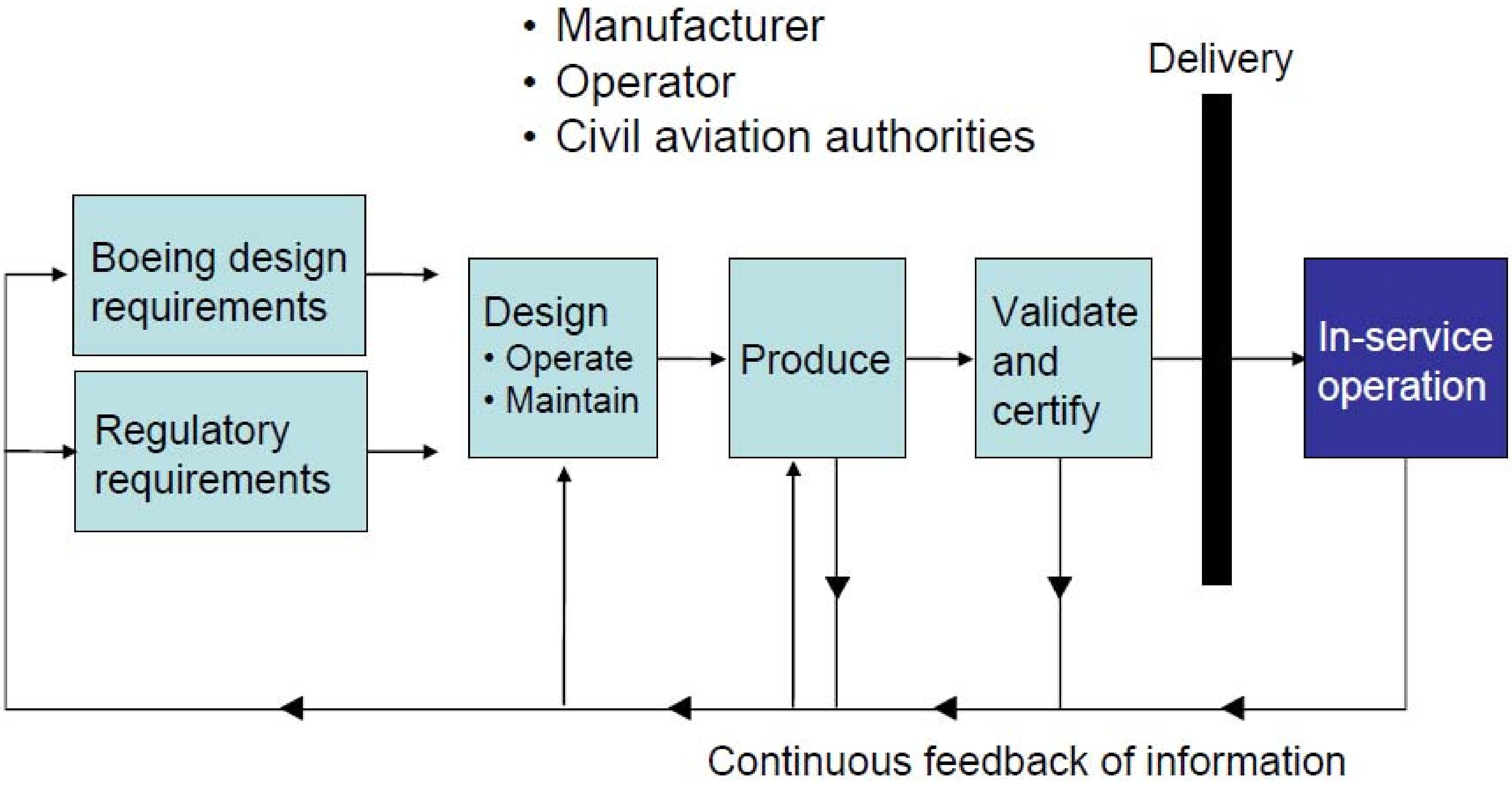
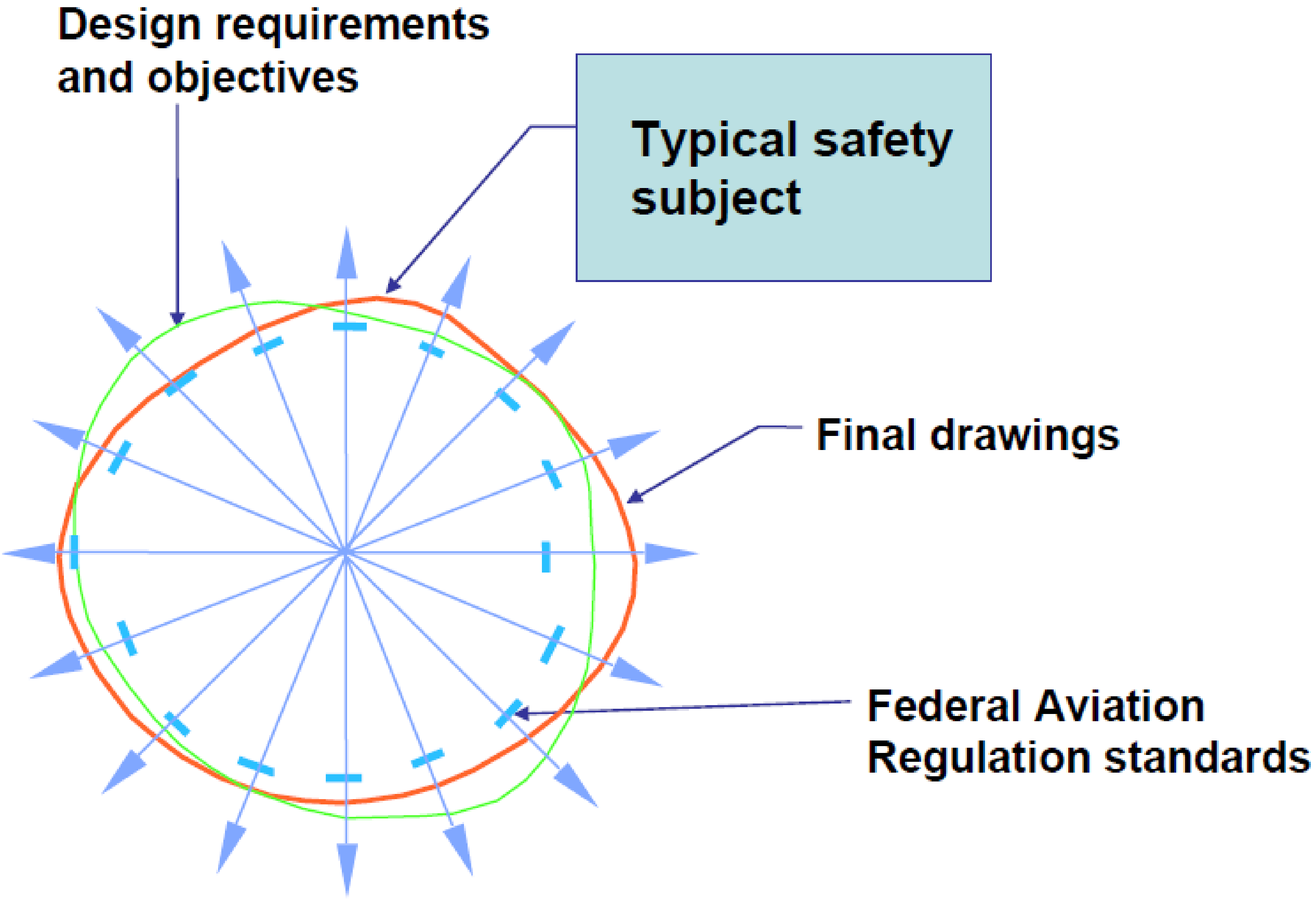
Y Mecánica de Fluidos

Lifetime Safety Cycle

- Entender el ciclo de seguridad a lo largo de la vida útil de un aeronave



Safety Wheel



Design requirements and objectives

Typical safety subject

Final drawings

Federal Aviation Regulation standards

Design Process

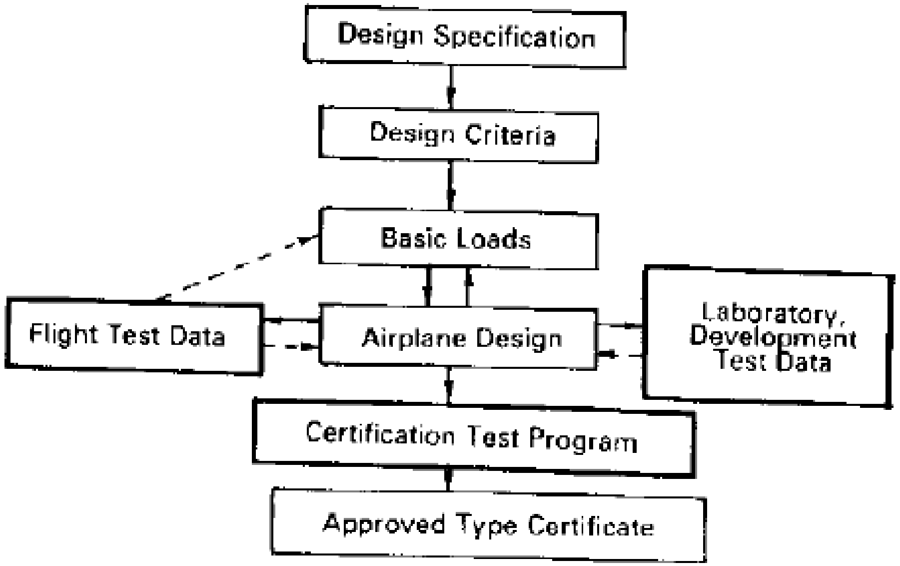
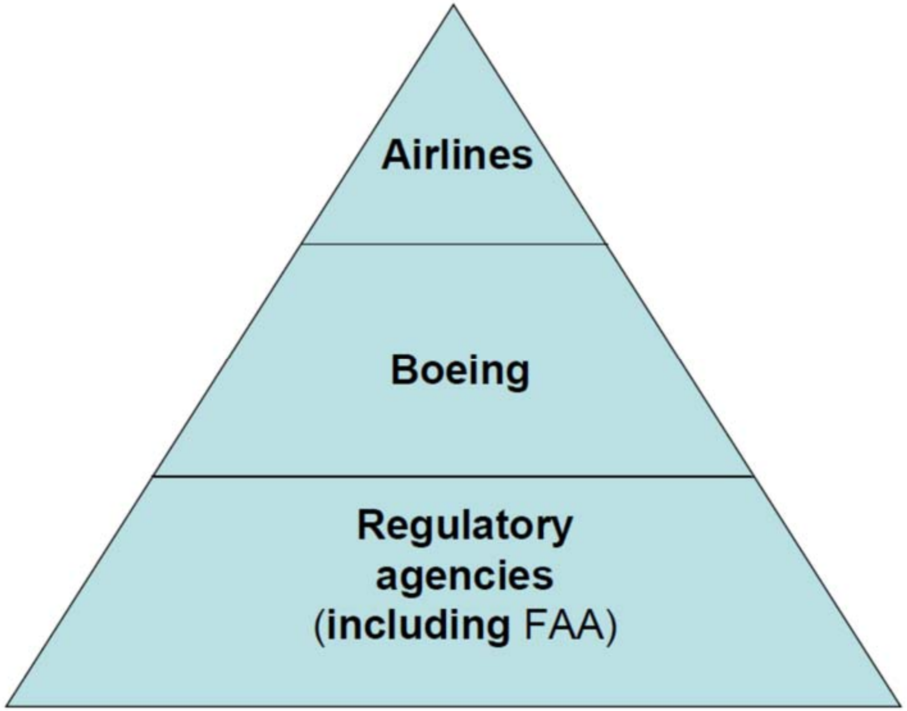


Fig. 1.2.2 Airplane design, development and certification.



Desarrollo y Pruebas

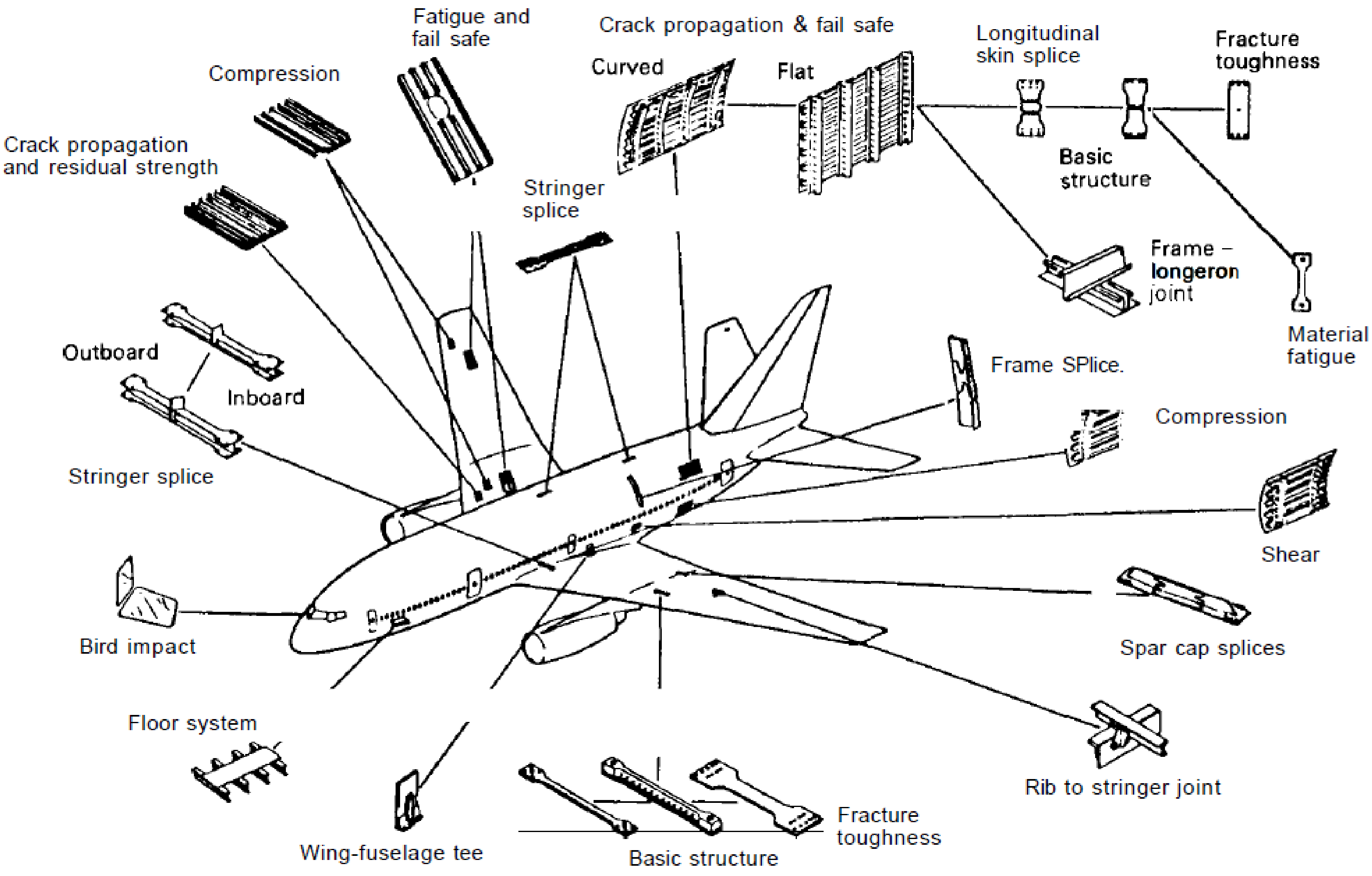
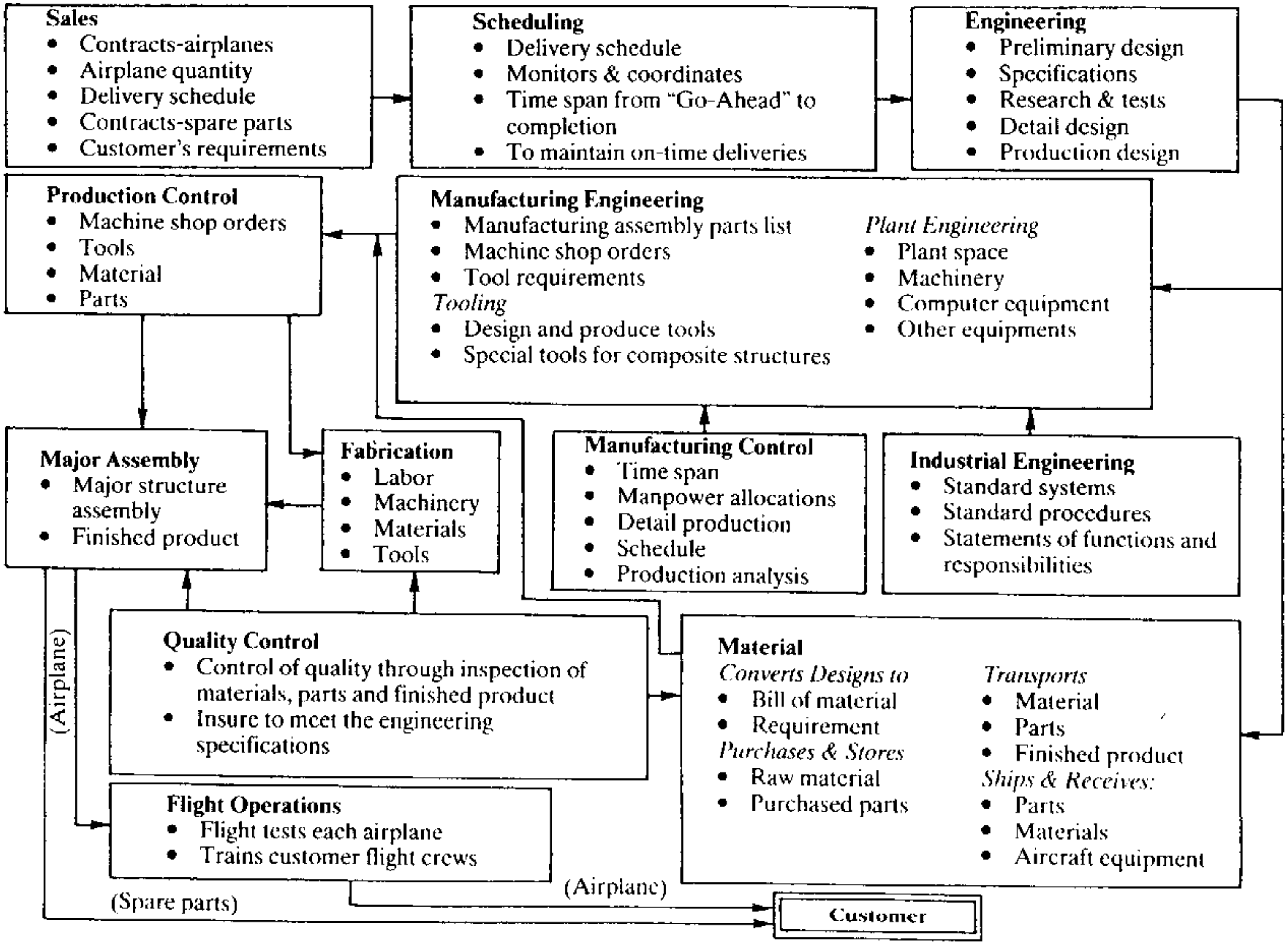


Fig. 1.2.1 Development testing of a transport airplane.



Sales
- Contracts-airplanes
- Airplane quantity
- Delivery schedule
- Contracts-spare parts
- Customer's requirements

Scheduling
- Delivery schedule
- Monitors & coordinates
- Time span from "Go-Ahead" to completion
- To maintain on-time deliveries

Engineering
- Preliminary design
- Specifications
- Research & tests
- Detail design
- Production design

Production Control
- Machine shop orders
- Tools
- Material
- Parts

Manufacturing Engineering
- Manufacturing assembly parts list
- Machine shop orders
- Tool requirements

Tooling
- Design and produce tools
- Special tools for composite structures

Plant Engineering
- Plant space
- Machinery
- Computer equipment
- Other equipments

Major Assembly
- Major structure assembly
- Finished product

Fabrication
- Labor
- Machinery
- Materials
- Tools

Manufacturing Control
- Time span
- Manpower allocations
- Detail production
- Schedule
- Production analysis

Industrial Engineering
- Standard systems
- Standard procedures
- Statements of functions and responsibilities

Quality Control
- Control of quality through inspection of materials, parts and finished product
- Insure to meet the engineering specifications

Material

Converts Designs to
- Bill of material
- Requirement

Purchases & Stores
- Raw material
- Purchased parts

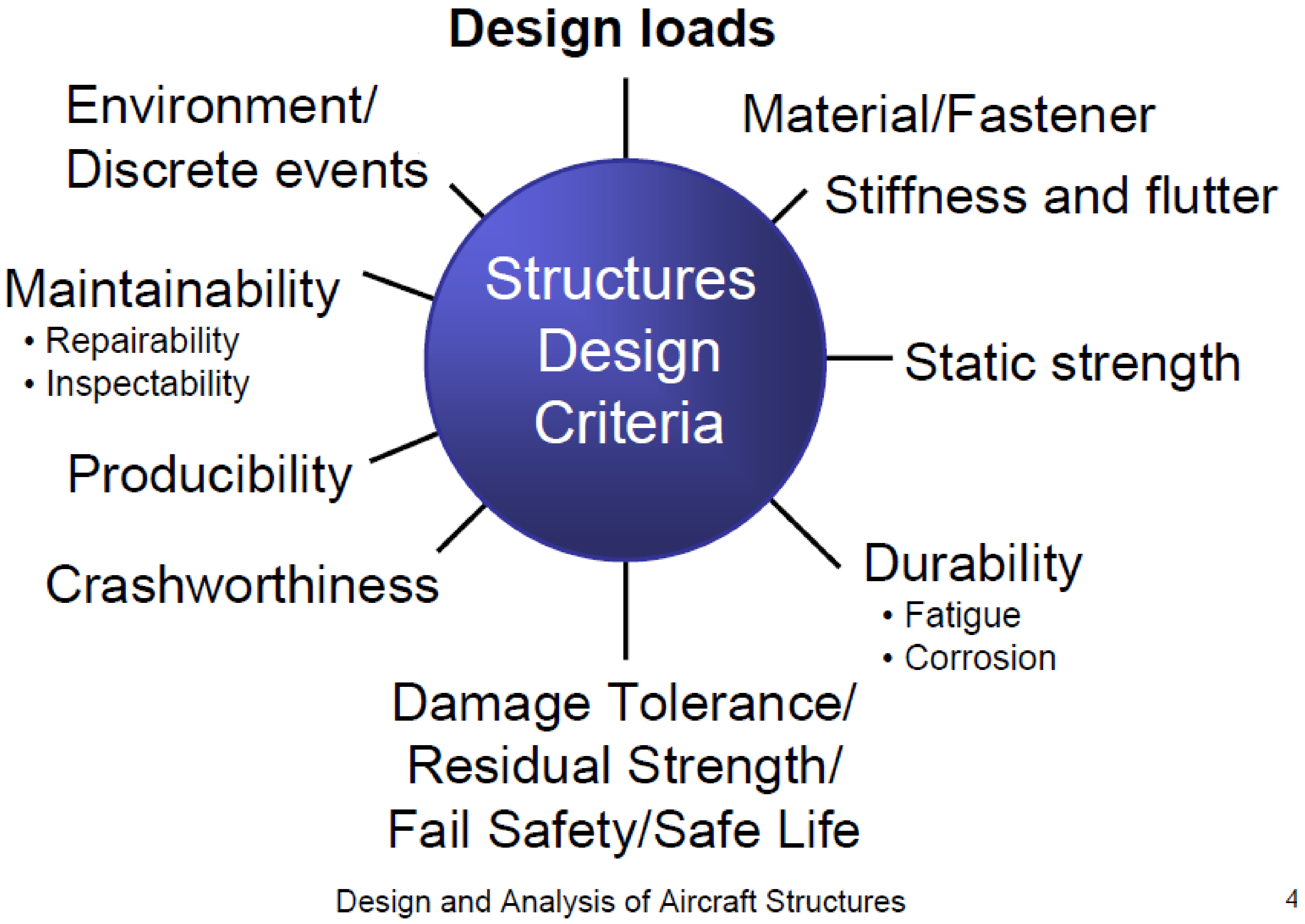
Transports
- Material
- Parts
- Finished product

Ships & Receives:
- Parts
- Materials
- Aircraft equipment

Flight Operations
- Flight tests each airplane
- Trains customer flight crews

Fig. 2.1.1 How an airplane is built.

Criterios Diseño Estructural



Design loads

Environment/
Discrete events

Material/Fastener

Stiffness and flutter

Maintainability
- Repairability
- Inspectability

Structures
Design
Criteria

Static strength

Producibility

Crashworthiness

Durability
- Fatigue
- Corrosion

Damage Tolerance/
Residual Strength/
Fail Safety/Safe Life

Design and Analysis of Aircraft Structures 4

Cargas

- Design Loads:
  - Ultimate Loads
  - Limit Loads
  - Operating Loads

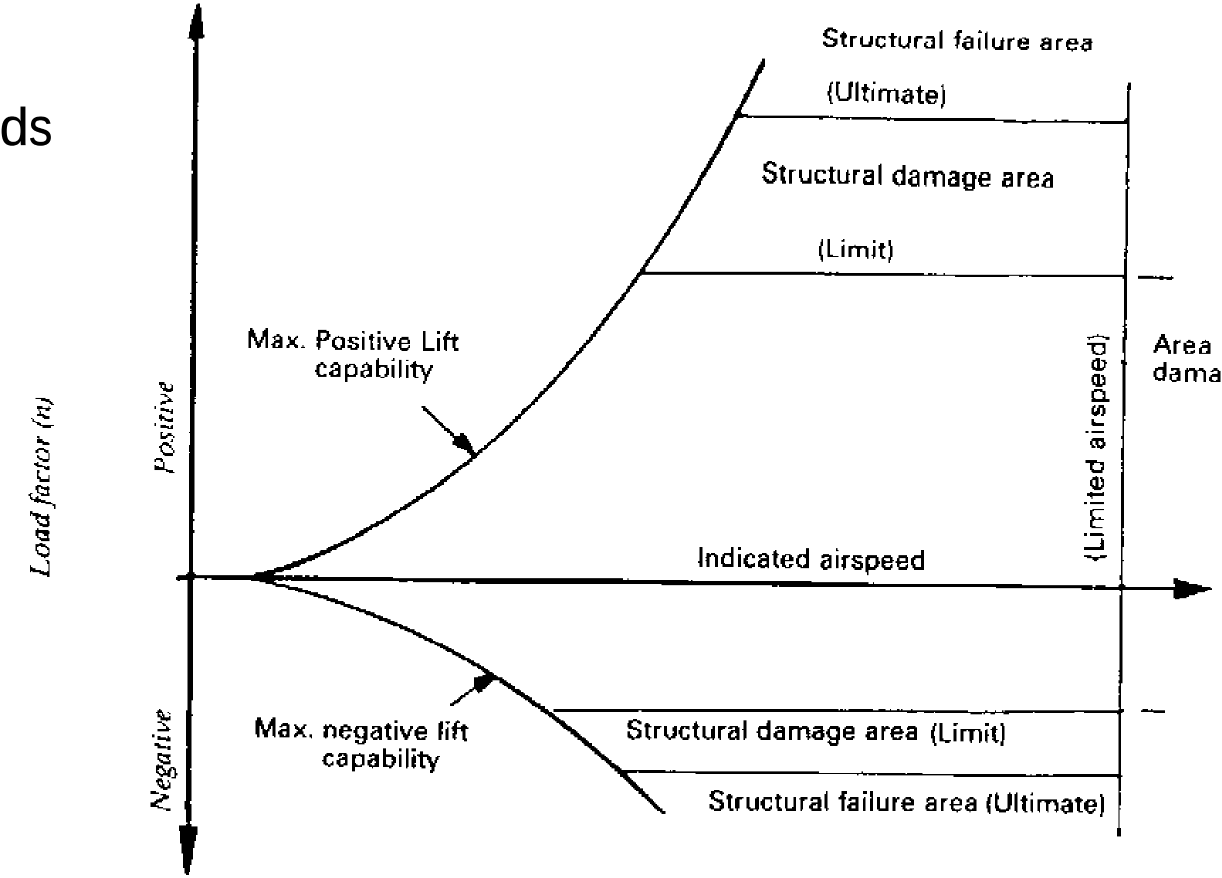


Fig. 3.4.8 Significance of the V-n diagram.

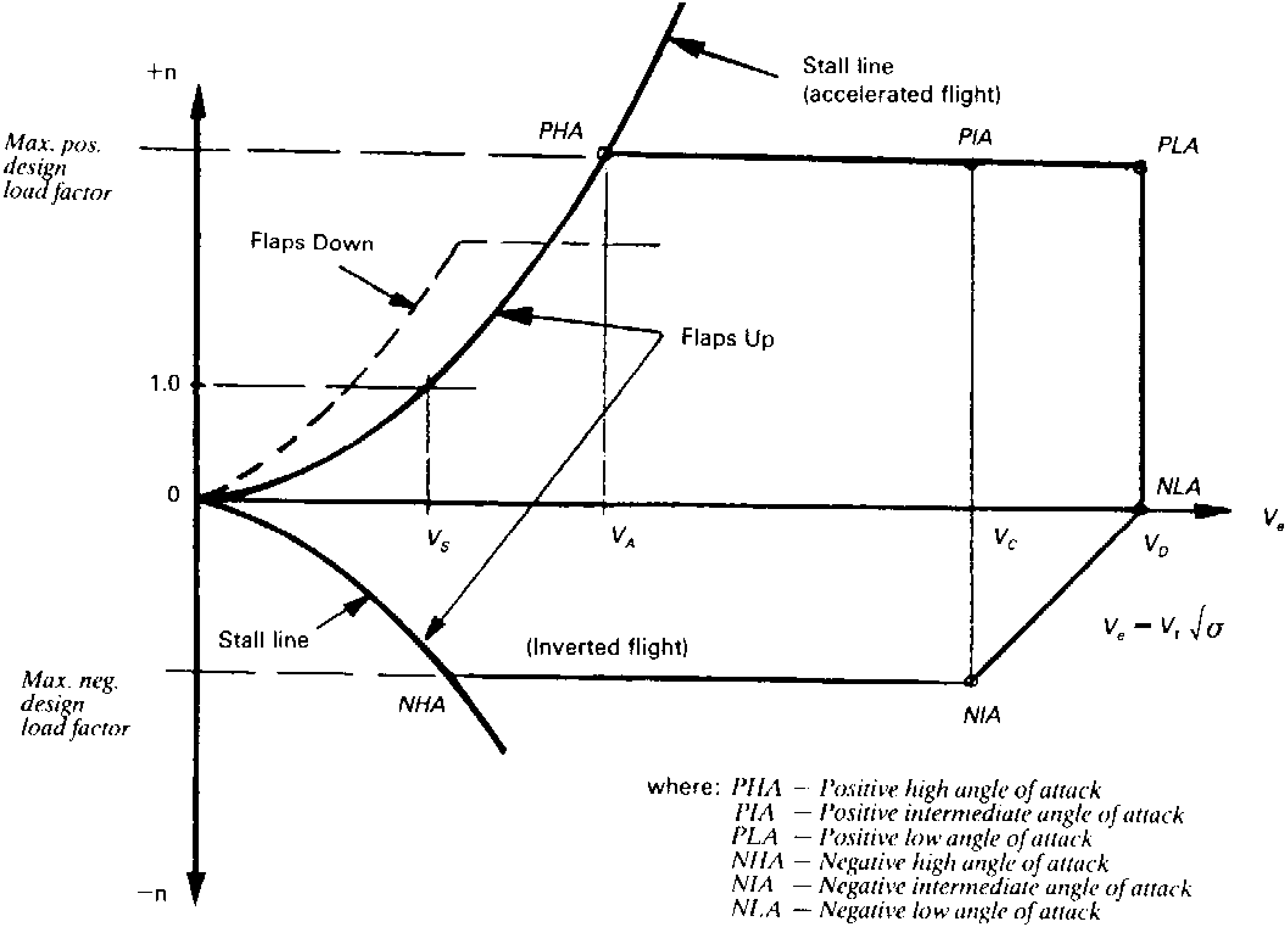


Fig. 3.4.9 Typical V-n Diagram for Maneuver.

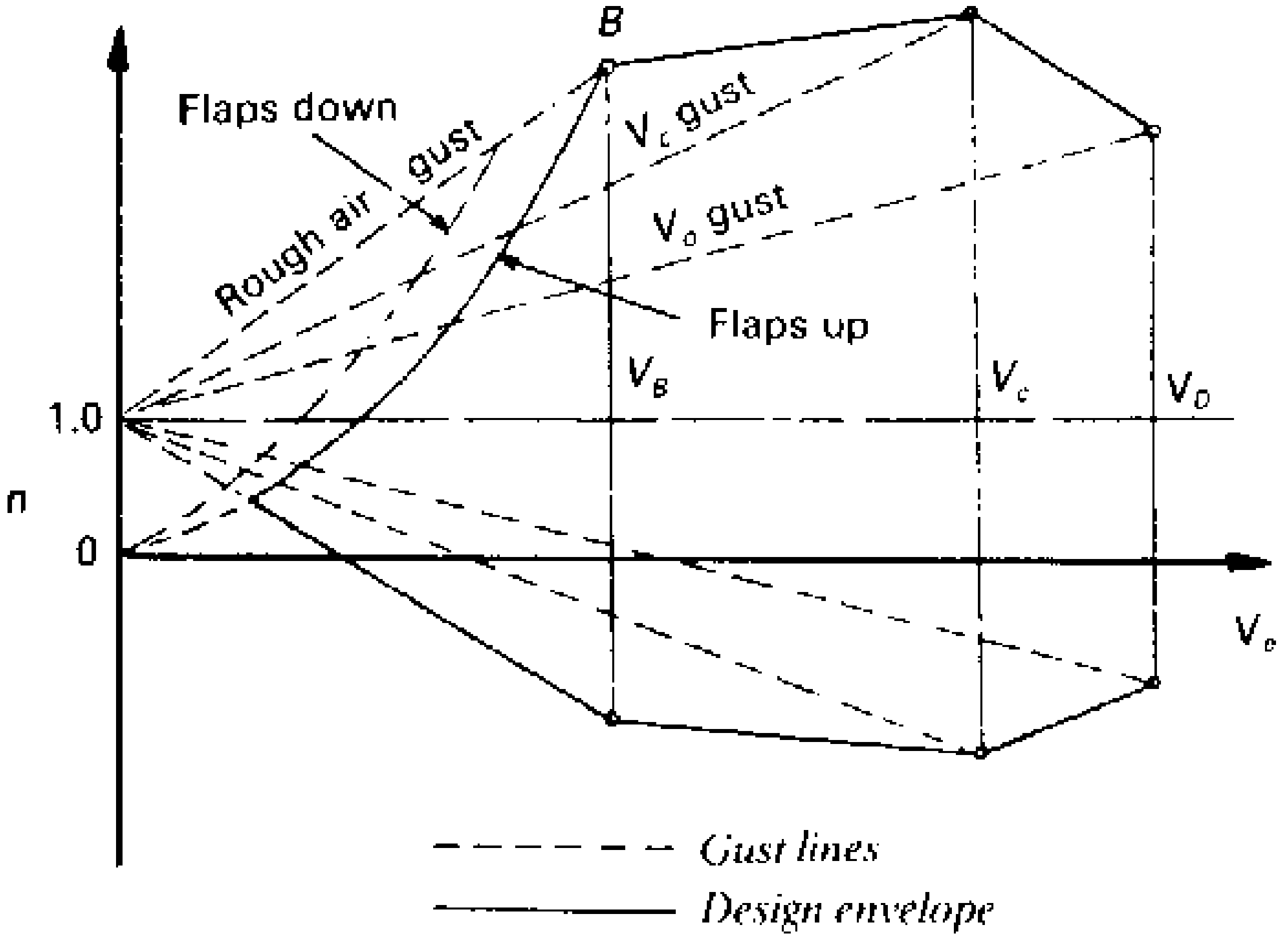


Fig. 3.4.15 V-n Diagram (Gust Envelope).

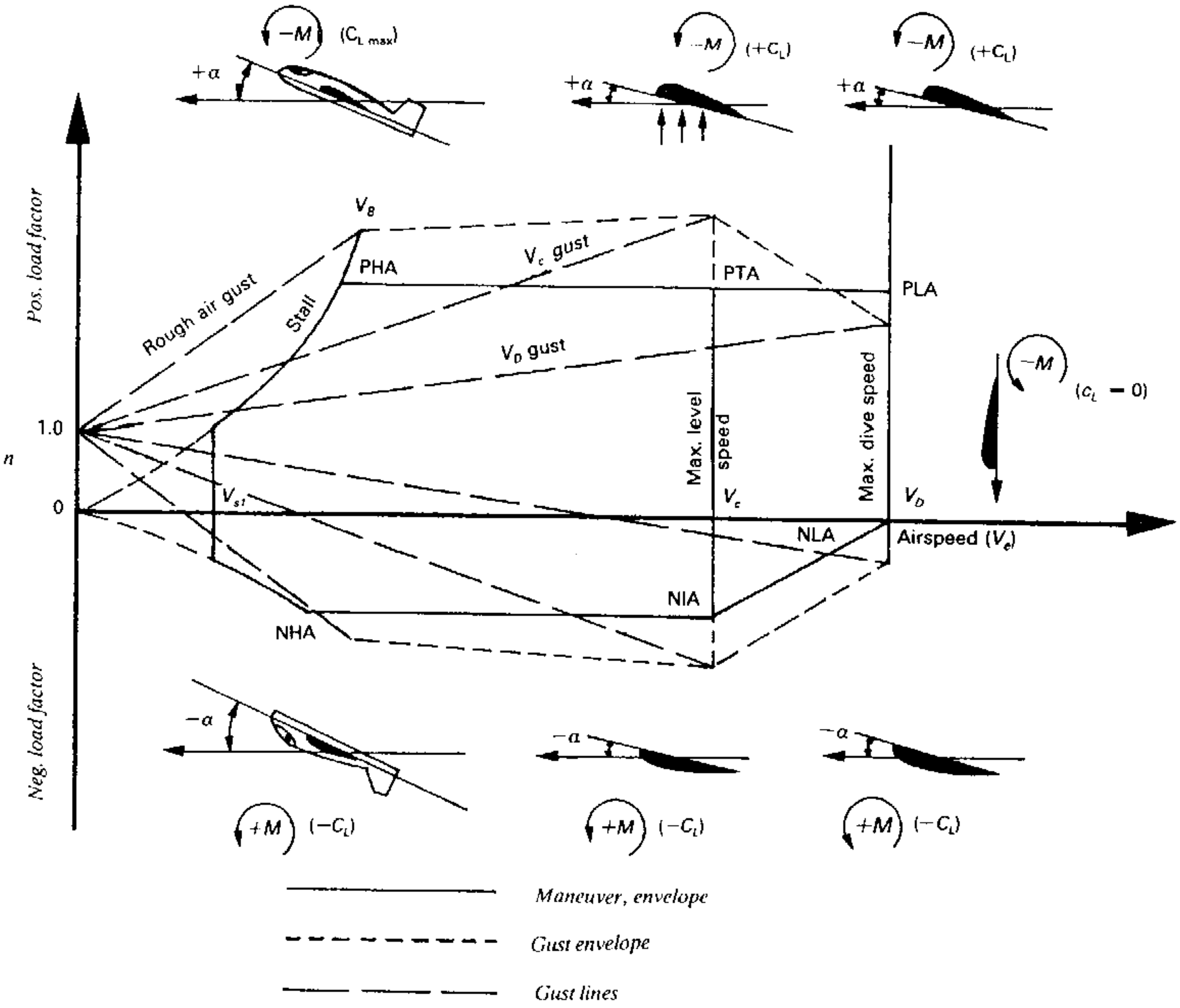


Fig. 3.4.16 Combined flight envelope (V-n diagram) – fighter.

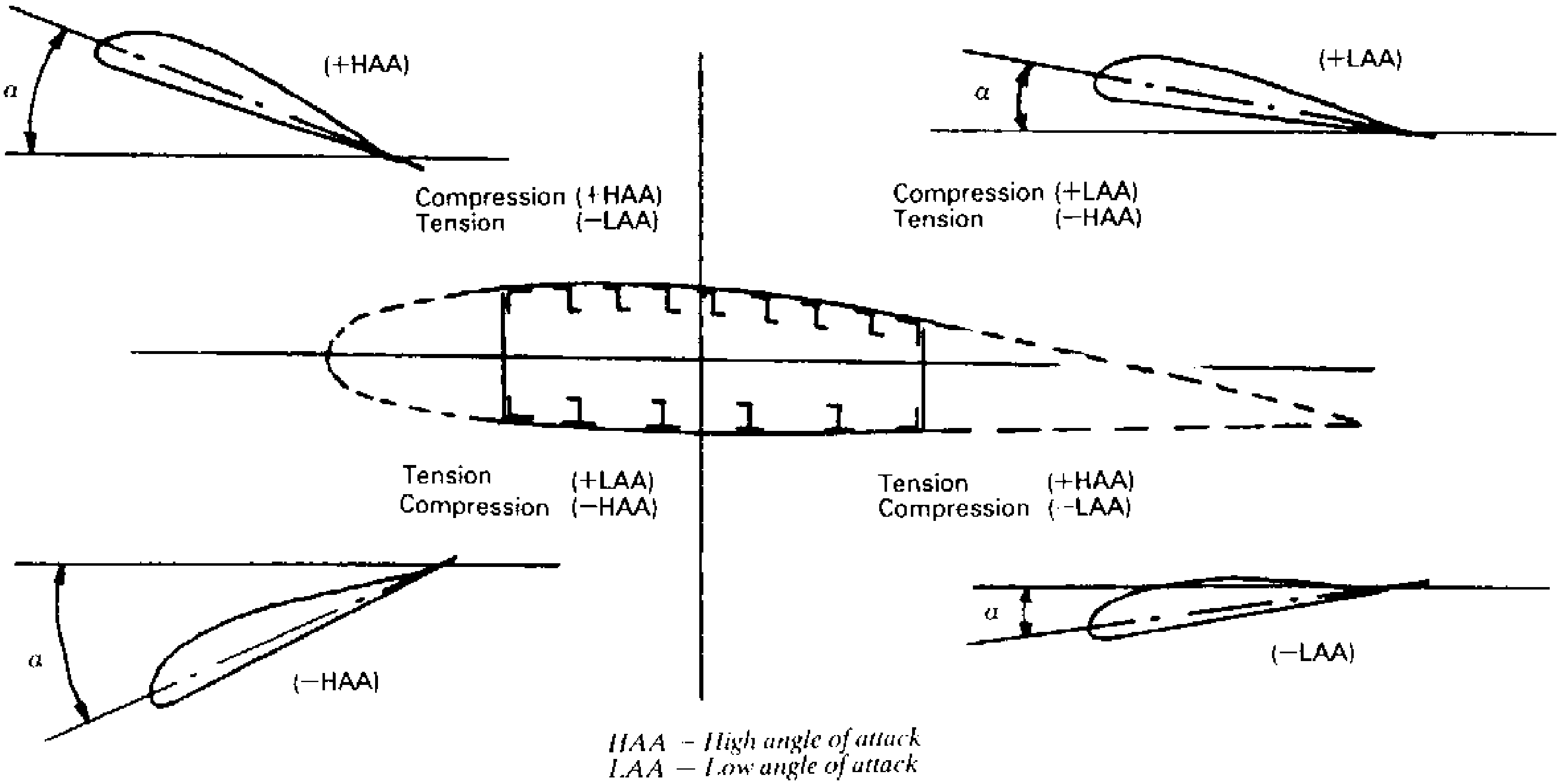


Fig. 3.5.6 Critical conditions for wing box structure.

Envolvente Xcg

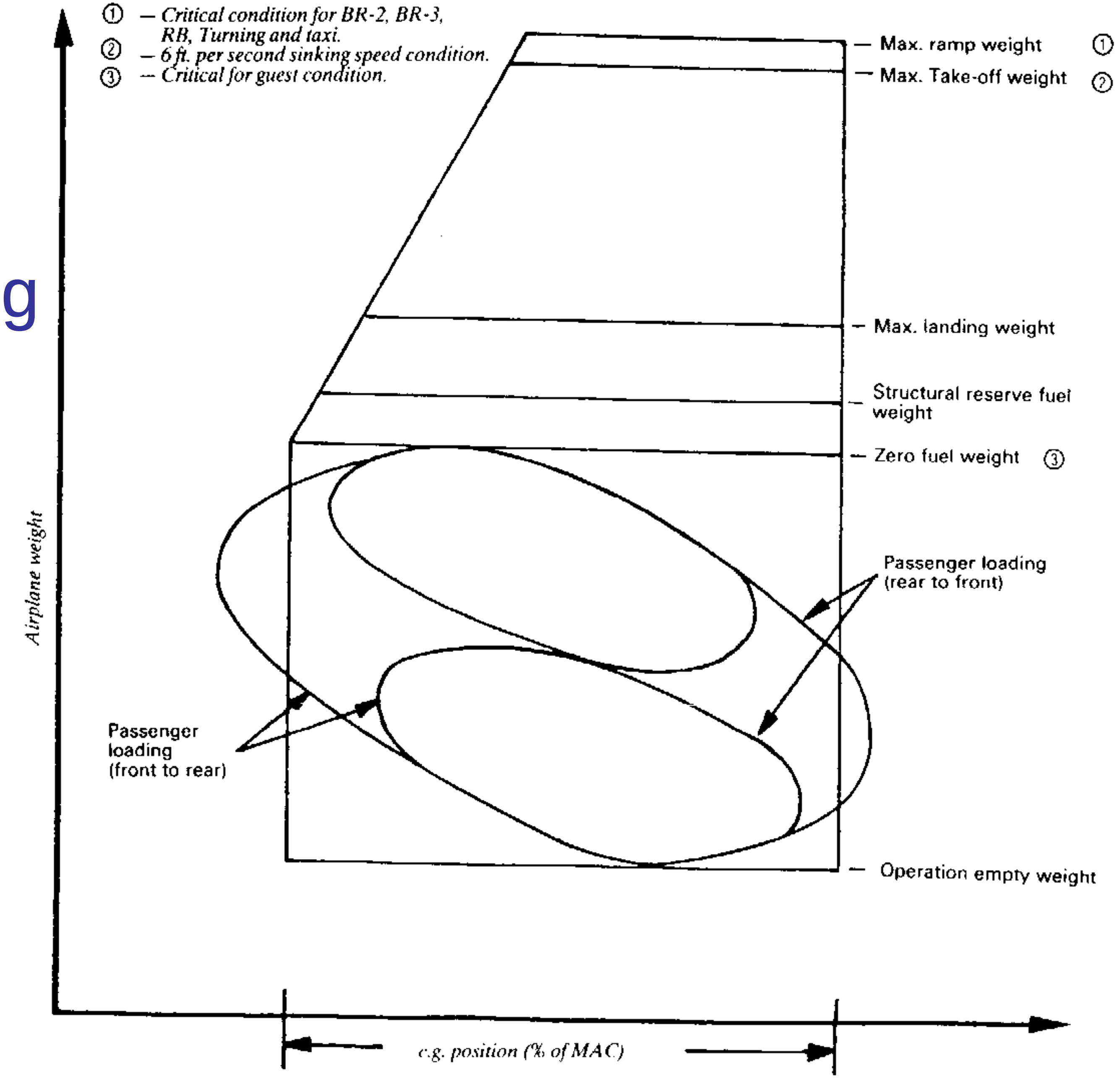
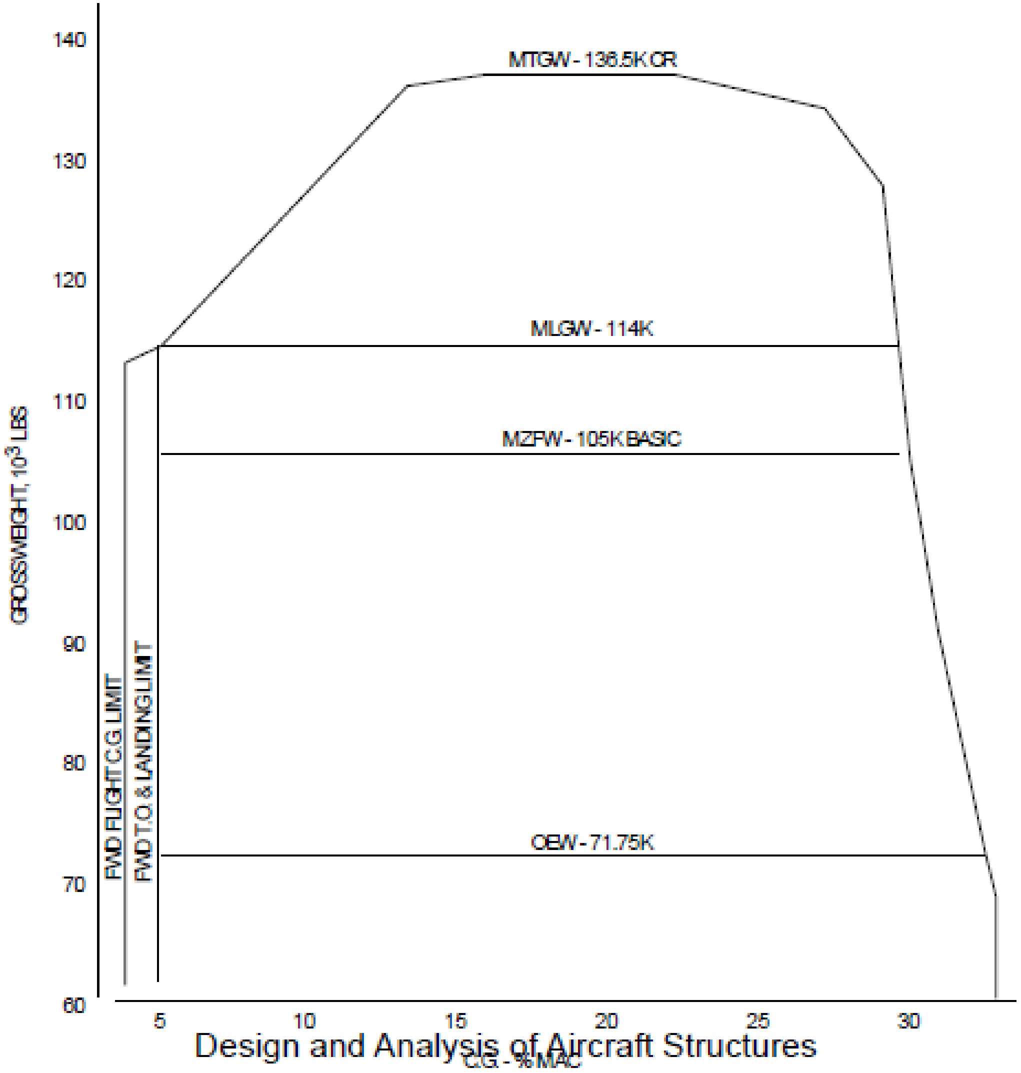


Fig. 3.4.5 Typical c.g. envelope of a commercial transport.

Gross Weight Versus CG Diagram, 737-300



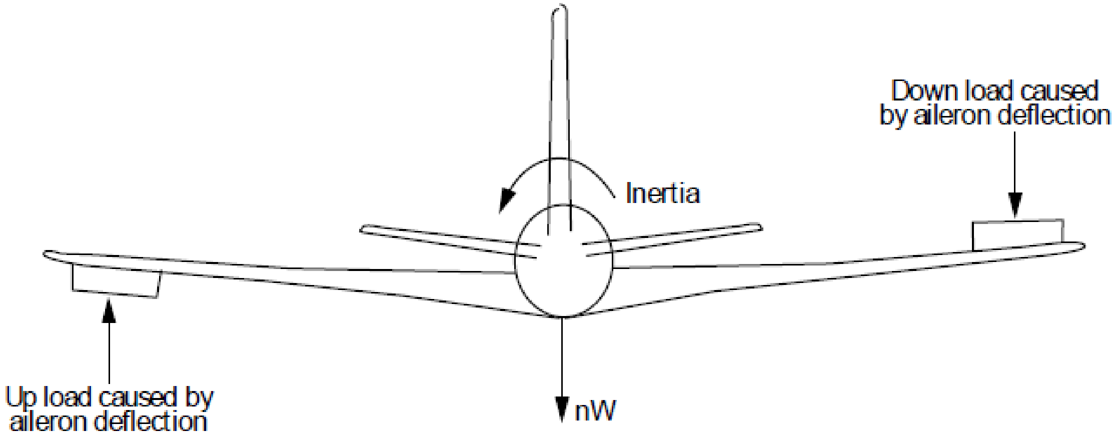
Design and Analysis of Aircraft Structures

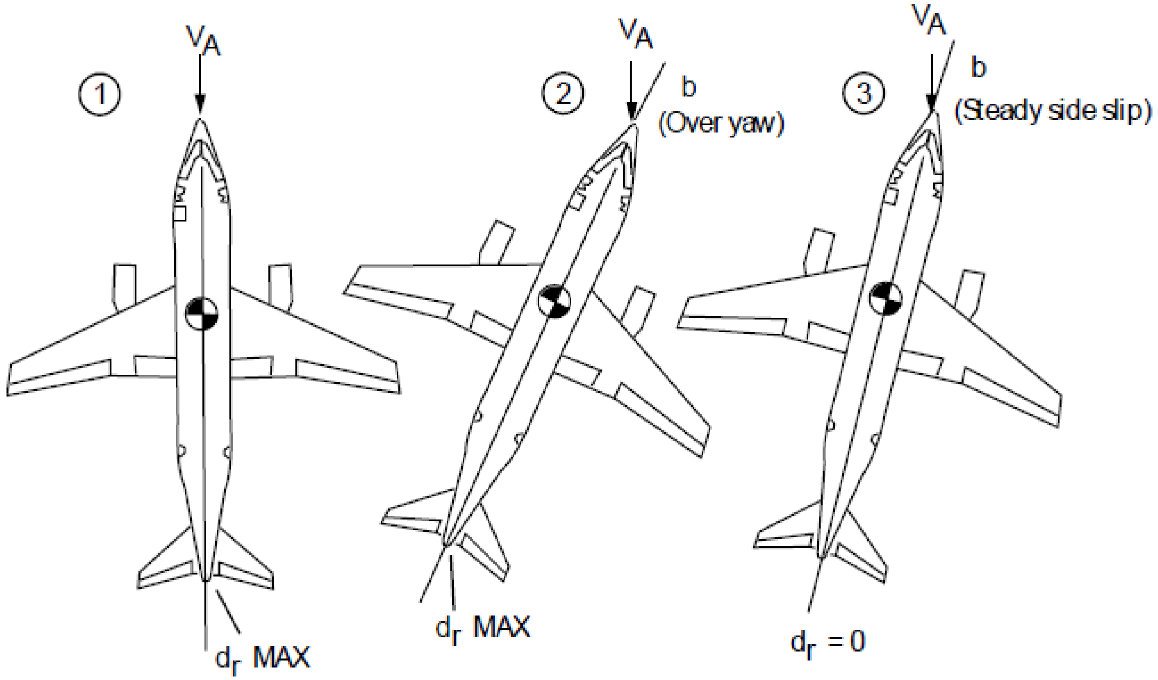
8-36

Cargas Externas

- Control Surfaces
  - Roll Maneuver
  - Yawing Maneuver
- Turbulencias Atmesfericas
  - Termales
  - Winjd shears
  - Jet stream
- Tren de Aterrizaje
  - Two point and three point level landing
  - Max wheel loads, level landing
  - Tail down landing
  - One-wheel landing
  - Lateral drift landing
  - Take-off run
  - Braked roll
  - Ground turning
  - Nose wheel yawing
  - Pivoting
  - Towing
- Aerodynamic Surfaces

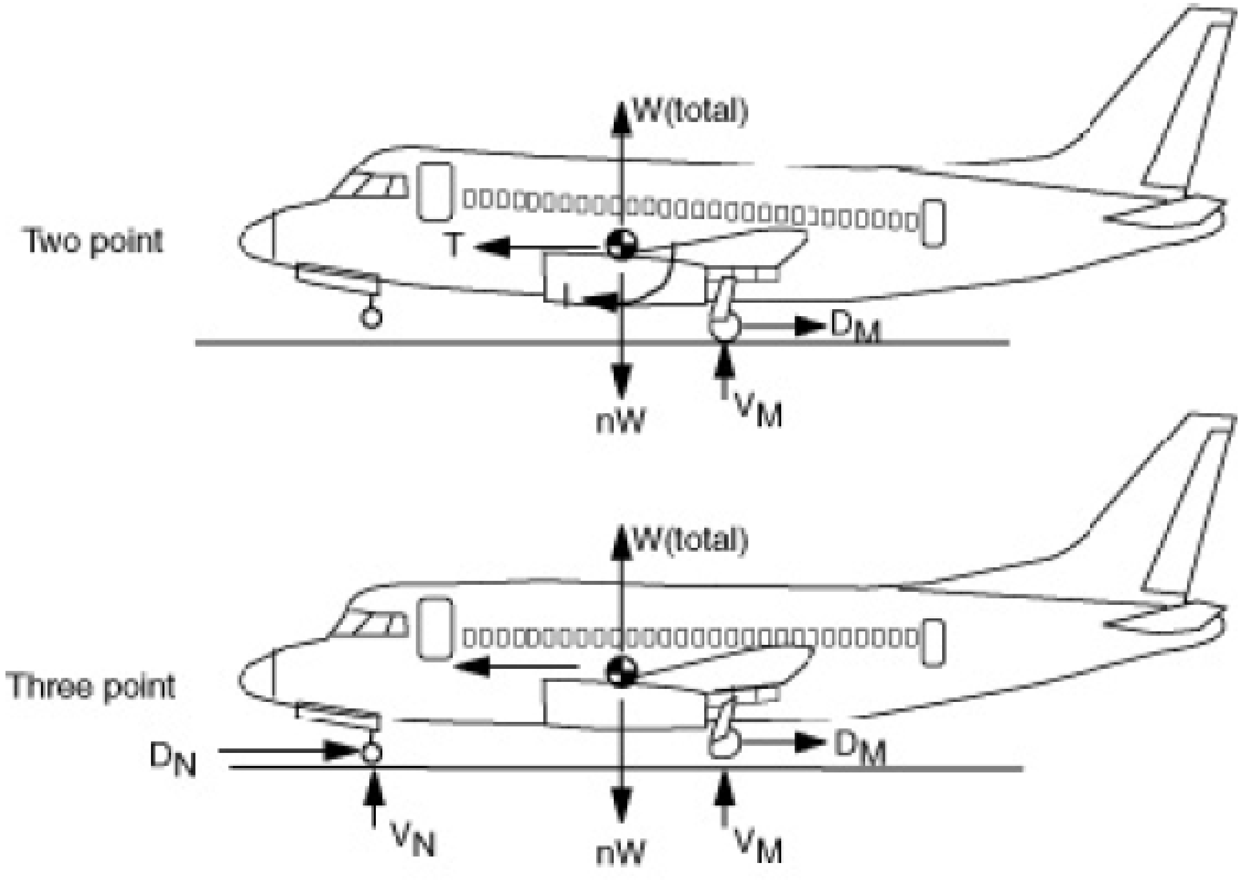
Control Surfaces Loads





Landing gear loads

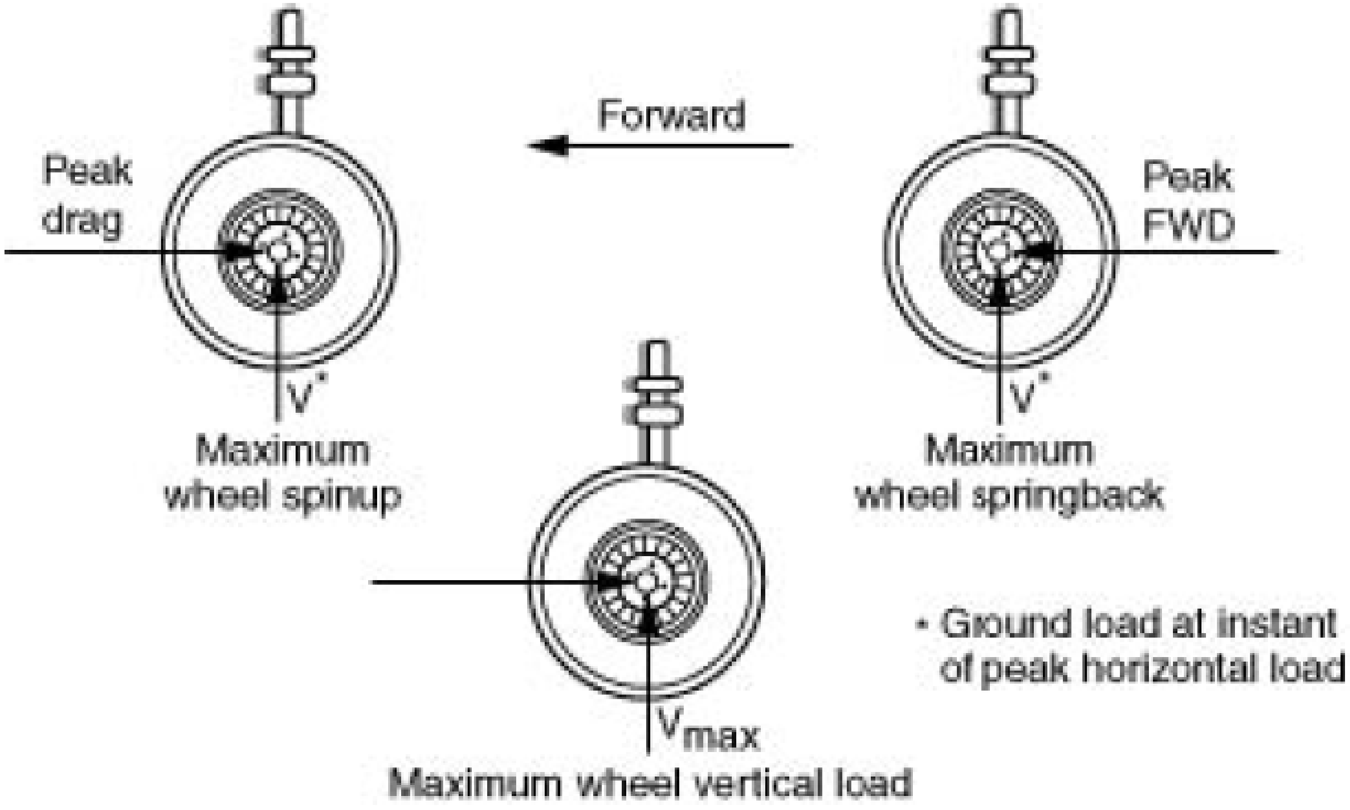
Two Point and Three Point, Level Landing



I = angular inertia force necessary for equilibrium
T = forward component of inertia force

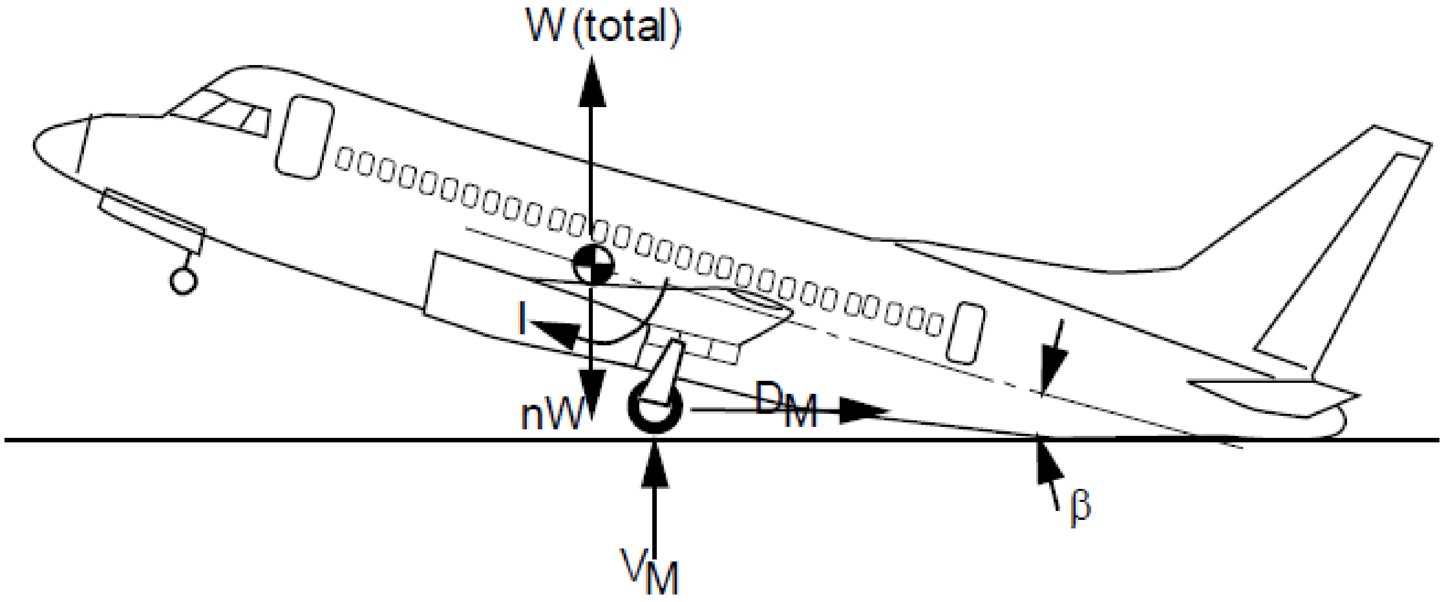
Landing gear loads

Max Wheel Loads, Level Landing



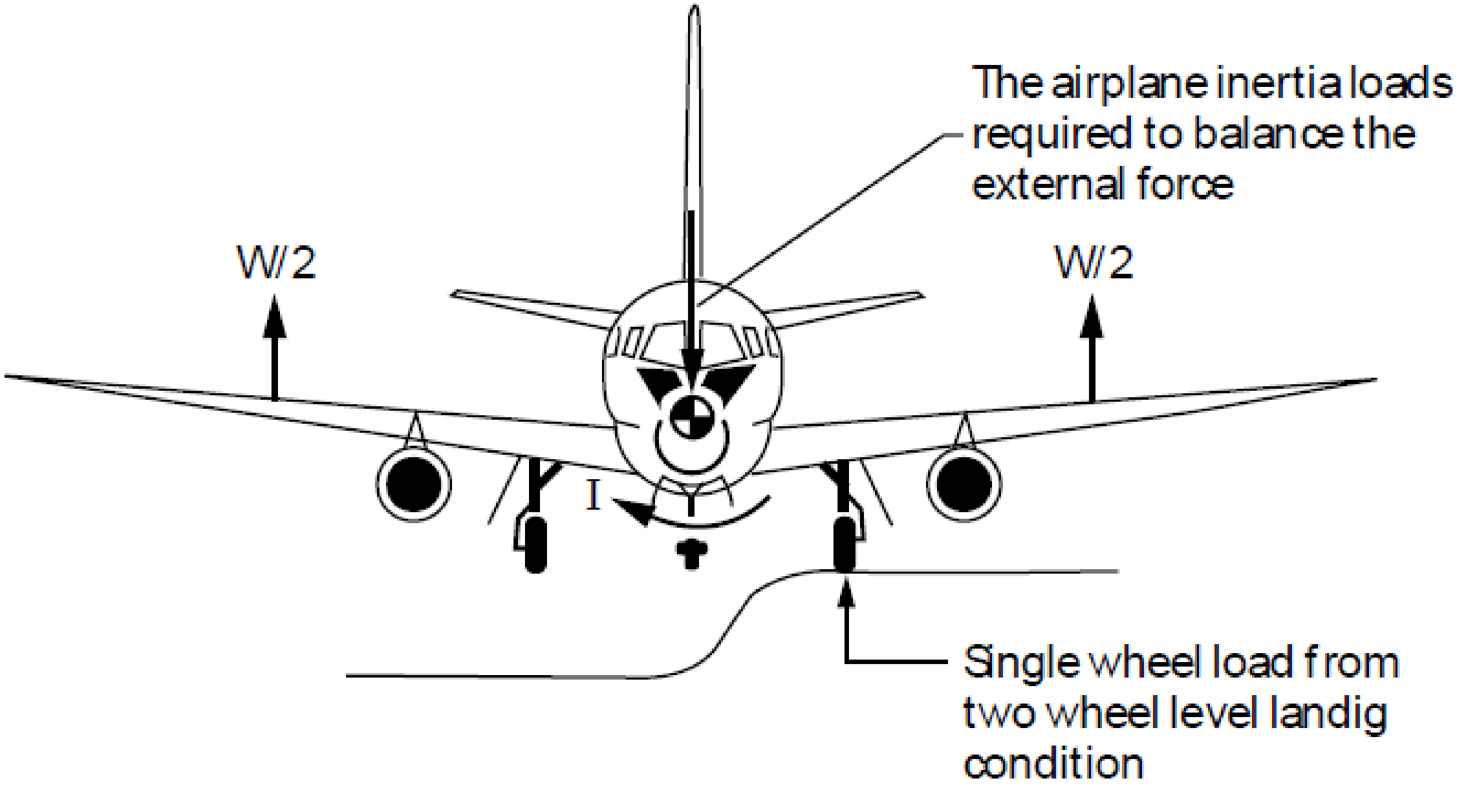
Landing gear loads

Tail Down Landing



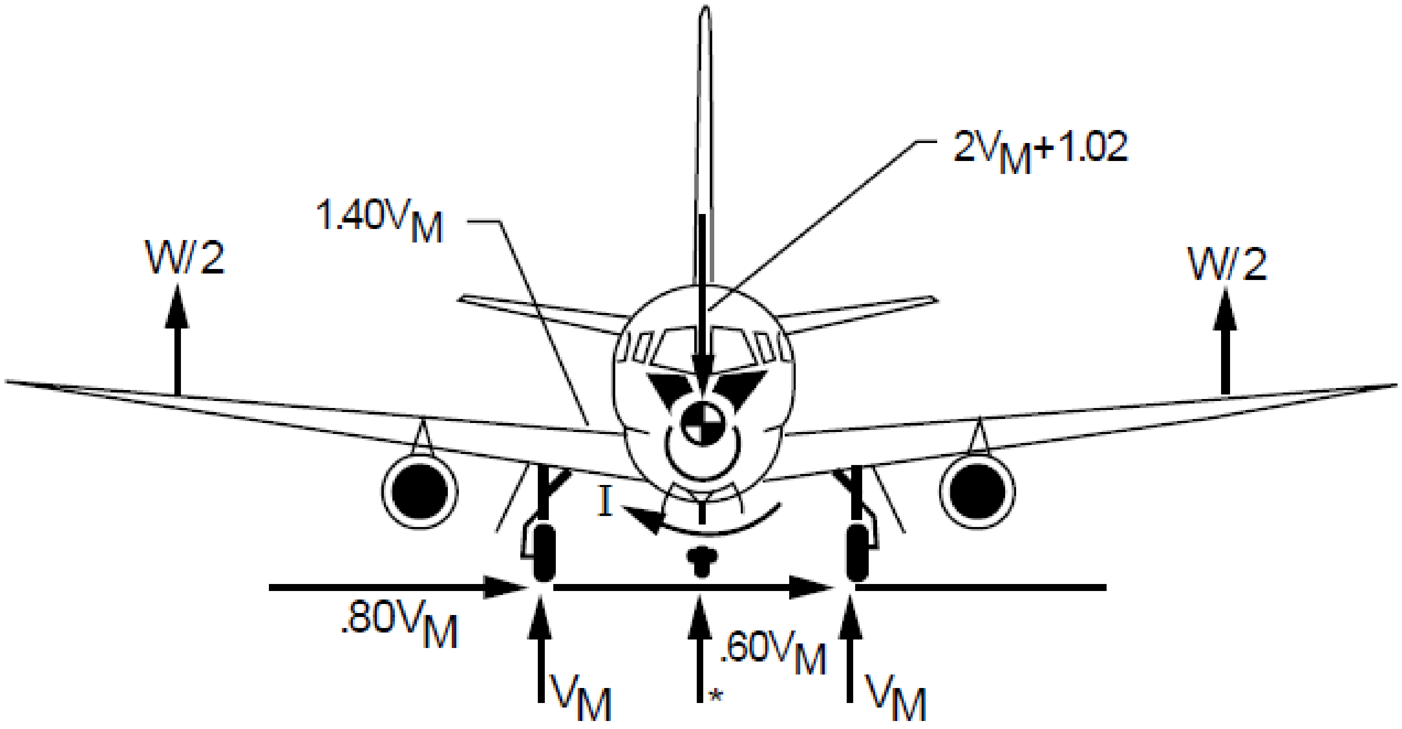
Landing gear loads

One-Wheel landing



Landing gear loads

Lateral Drift Landing

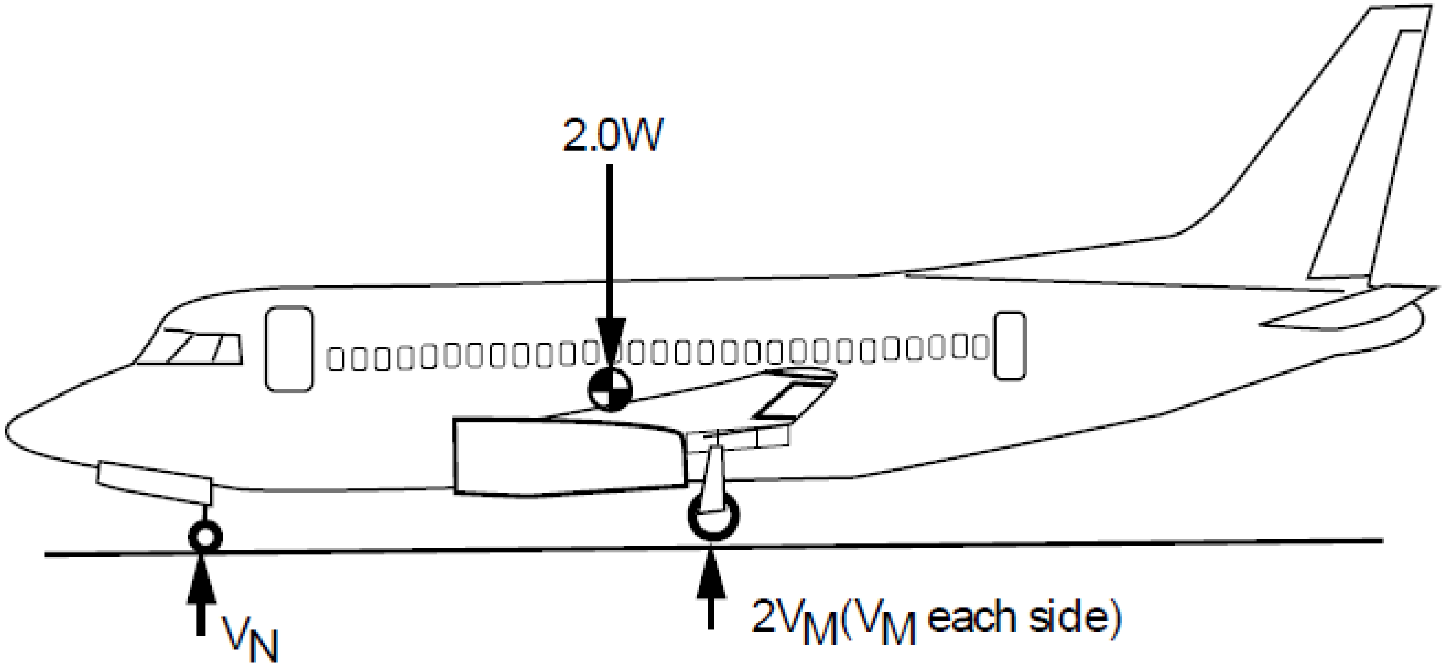


V_M = One-half the maximum vertical ground reaction obtained at each main gear in the level landing conditions

* Nose gear ground reaction = 0

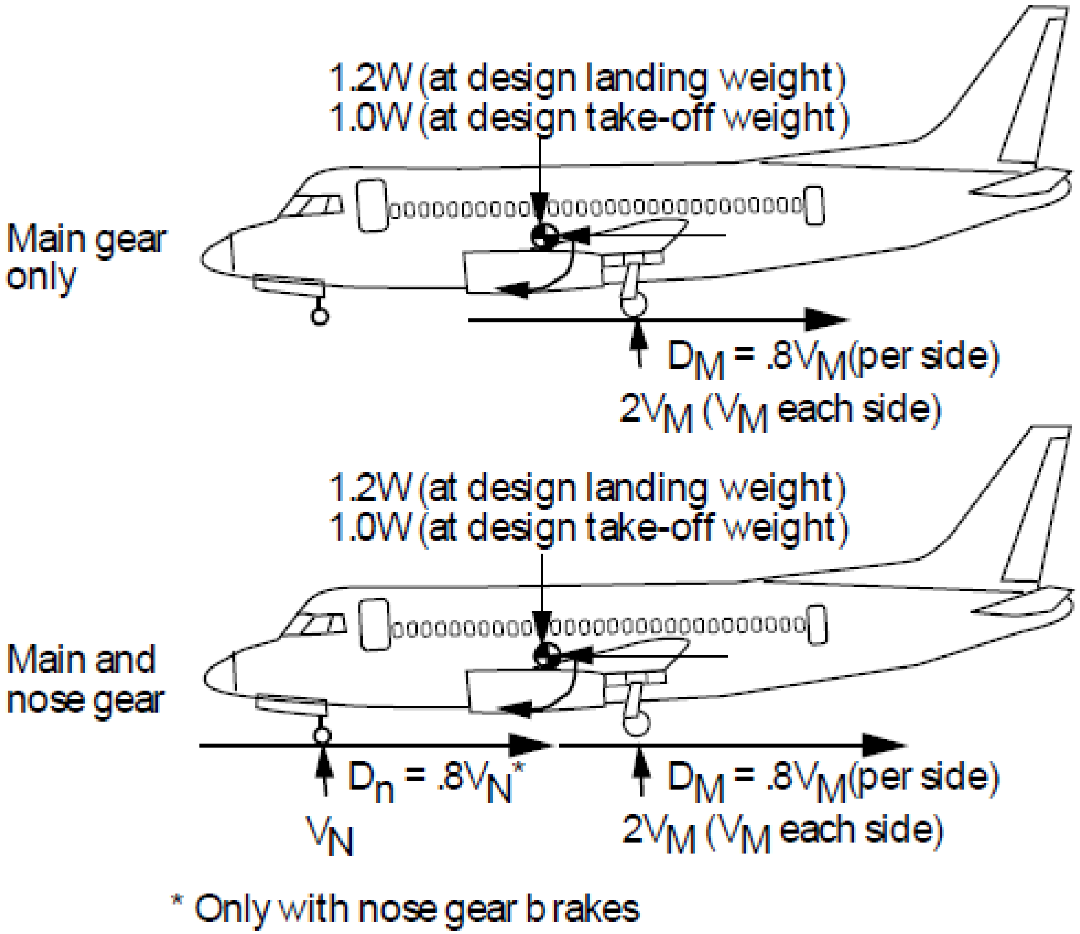
Landing gear loads

Takeoff Run



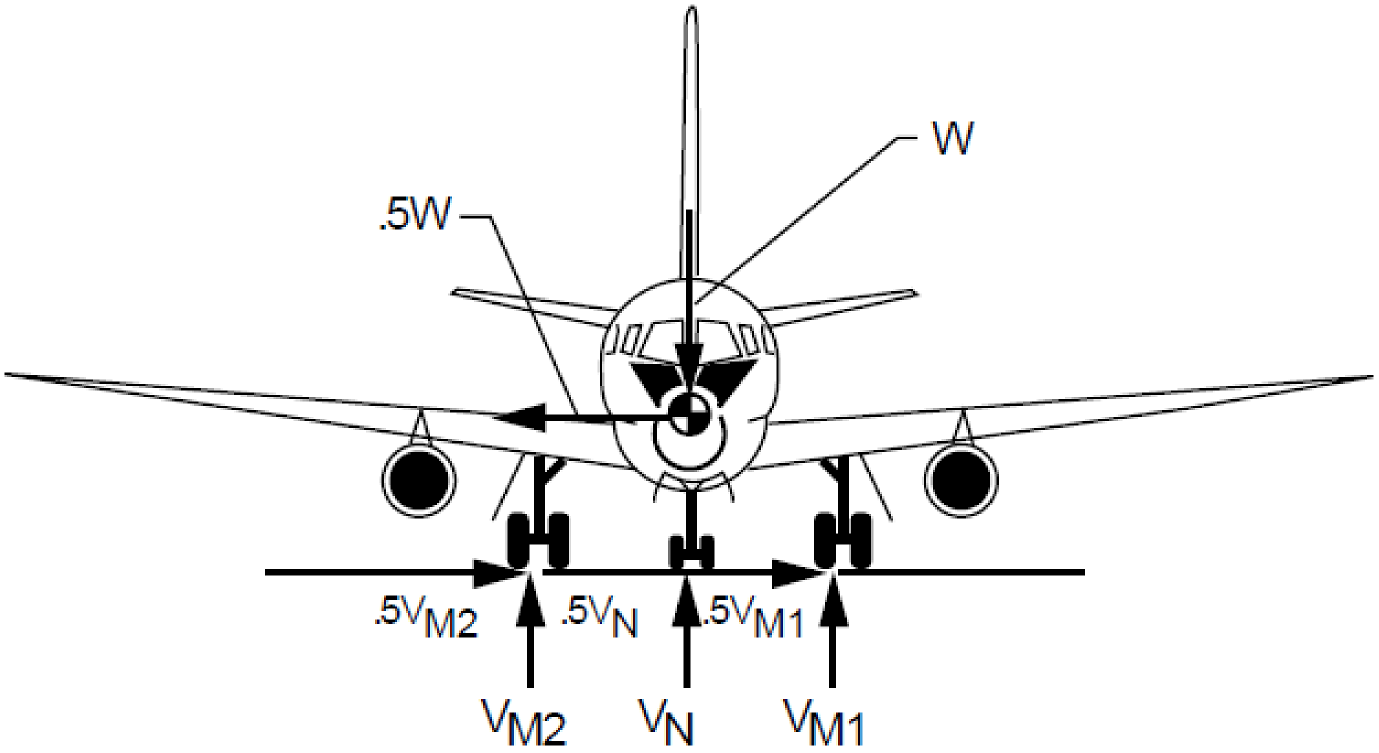
Landing gear loads

Braked Roll



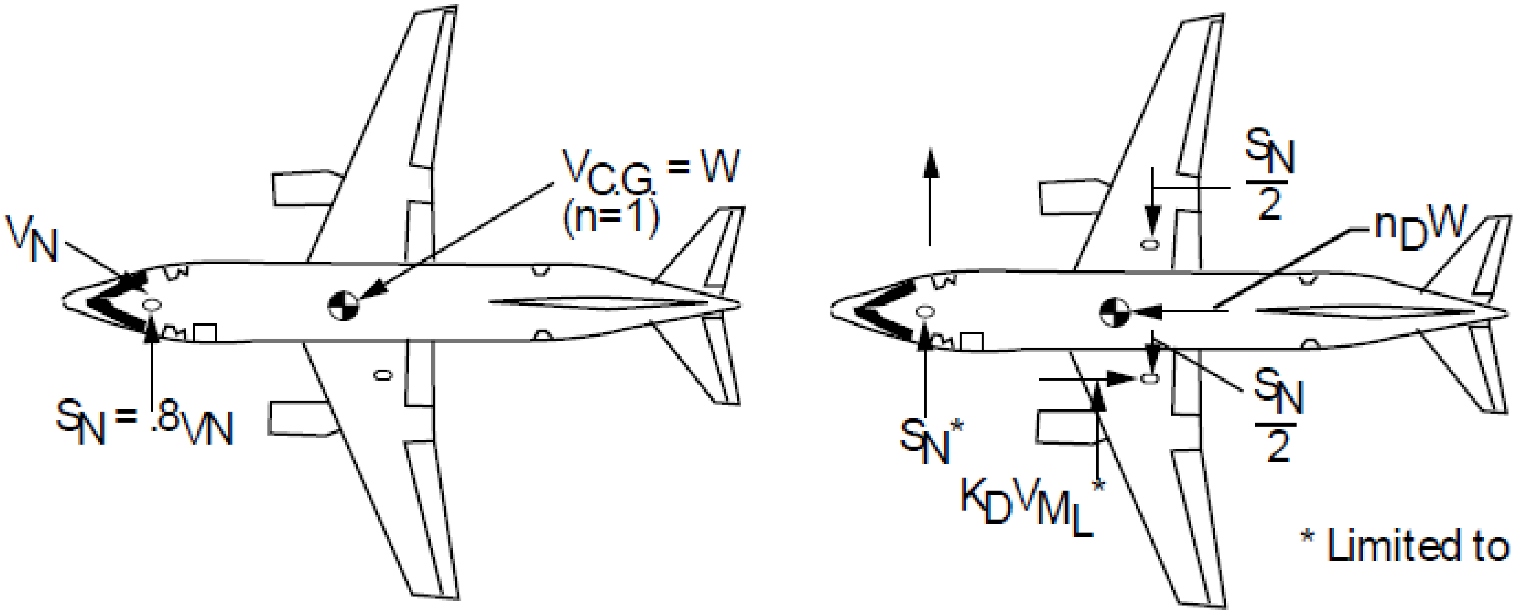
Landing gear loads

Ground Turning



Landing gear loads

Nose Wheel Yawing

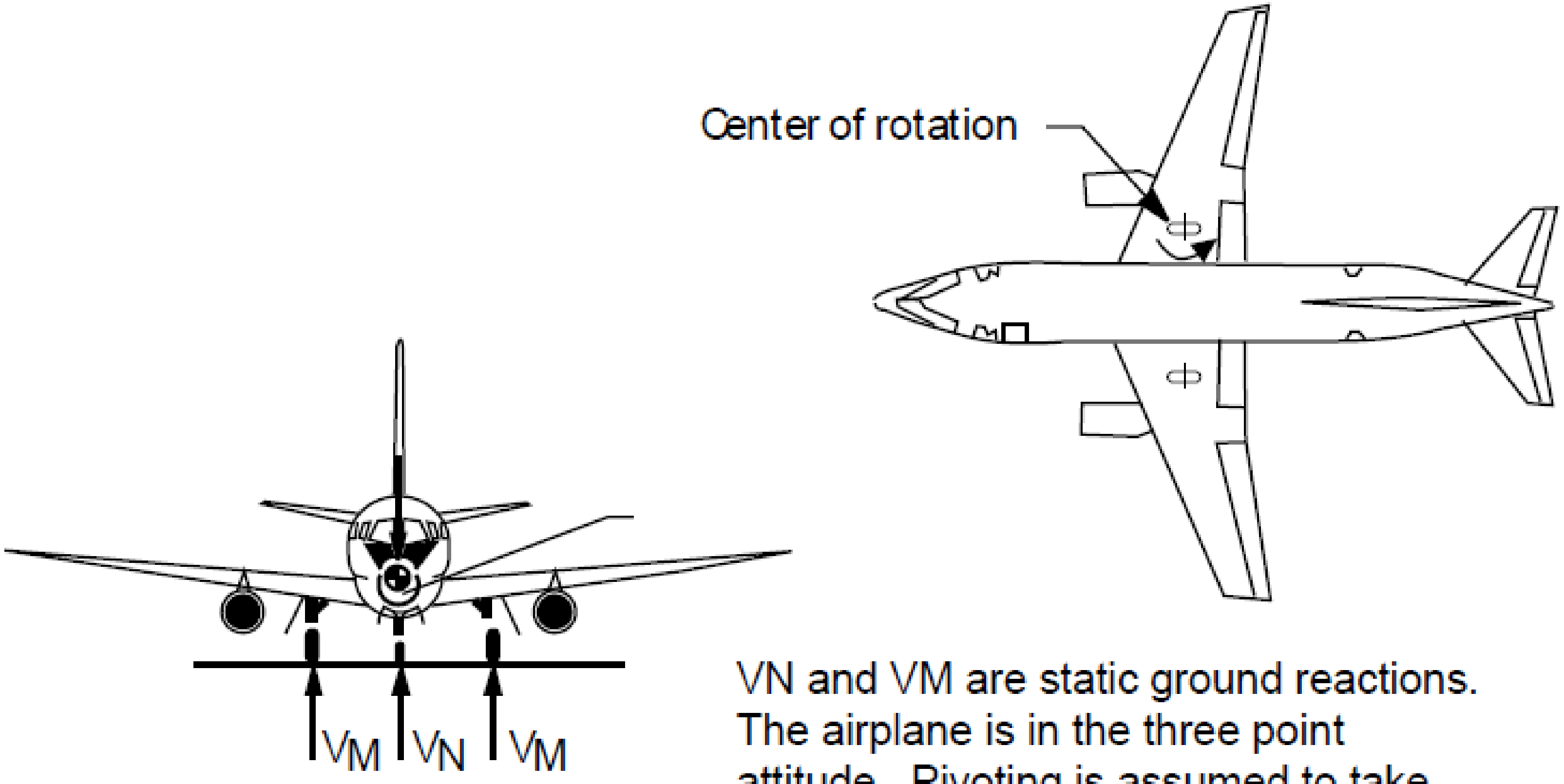


Nose gear side load

Unsymmetrical braking

Landing gear loads

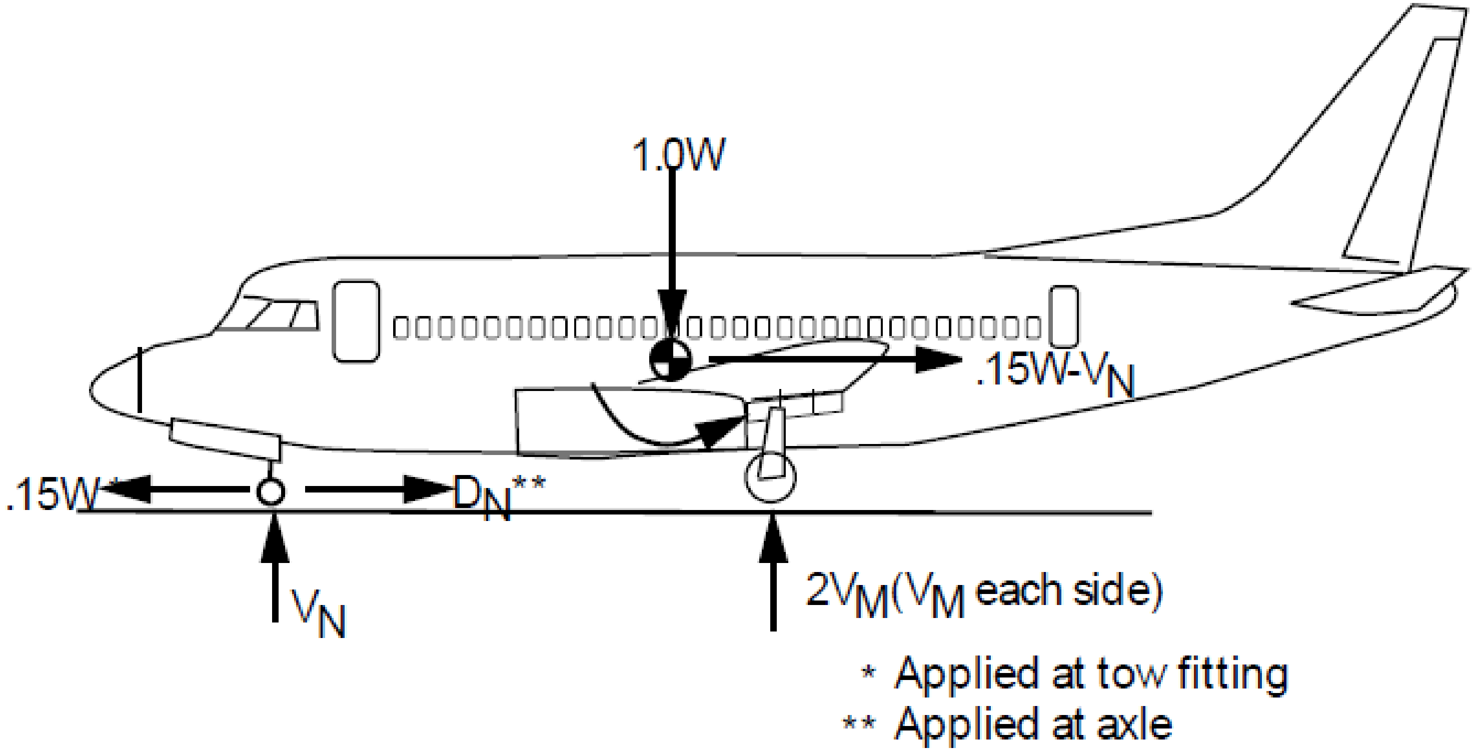
Pivoting



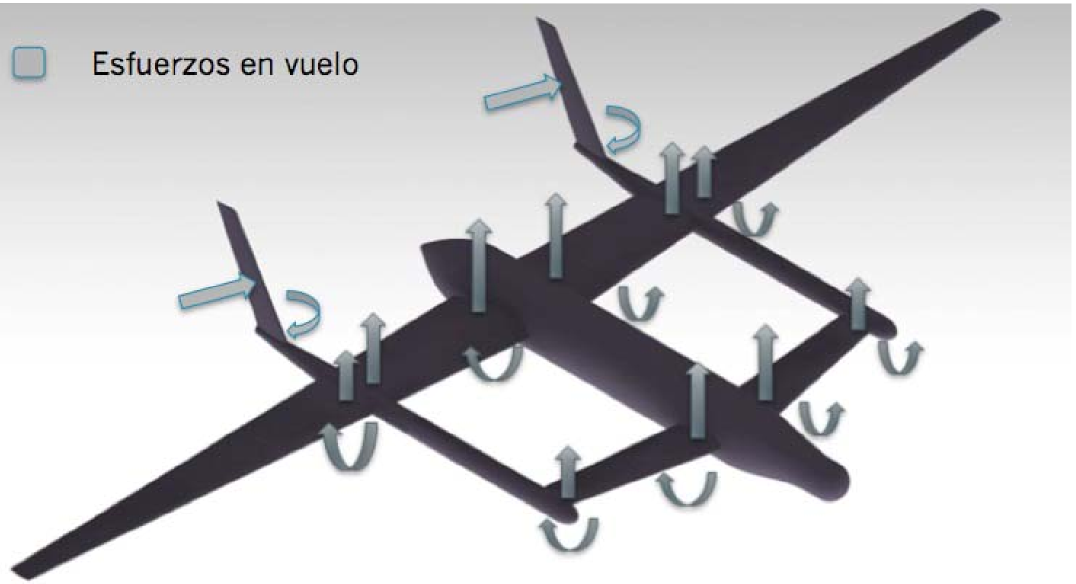
VN and VM are static ground reactions. The airplane is in the three point attitude. Pivoting is assumed to take place about one main landing gear unit.

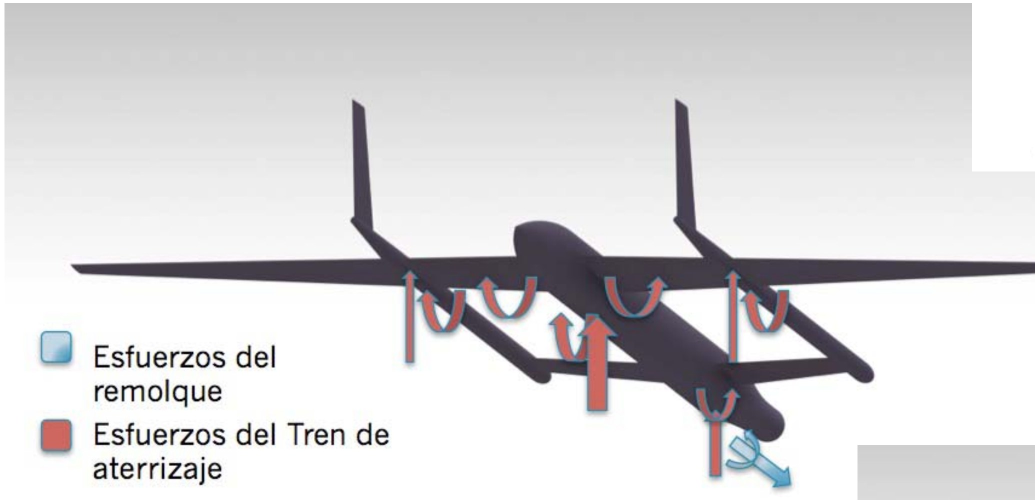
Landing gear loads

Towing



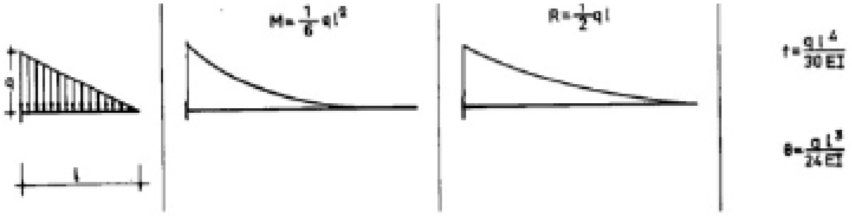
Ejemplos Esfuerzos - I

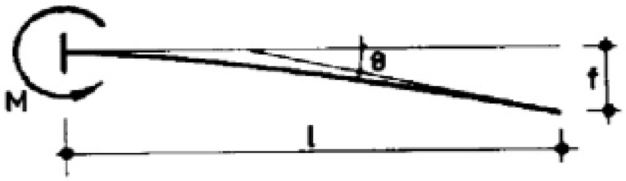


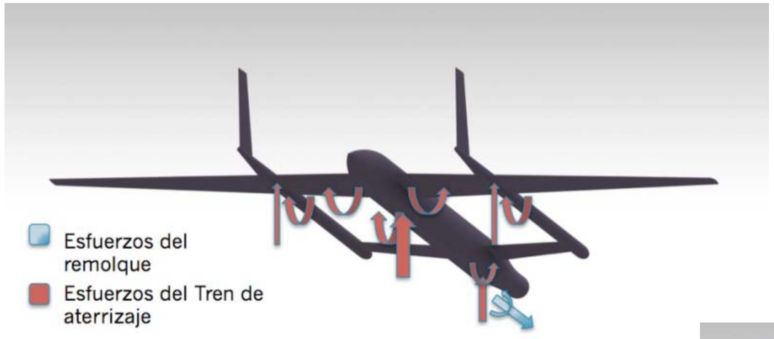


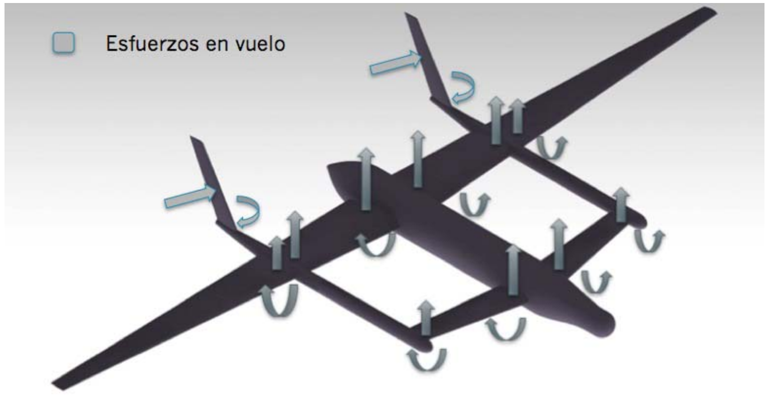
Ejemplos Esfuerzos - I

- Teoría de Resistencia de materiales.
  - Modelos viga empotrada por uno de sus extremos





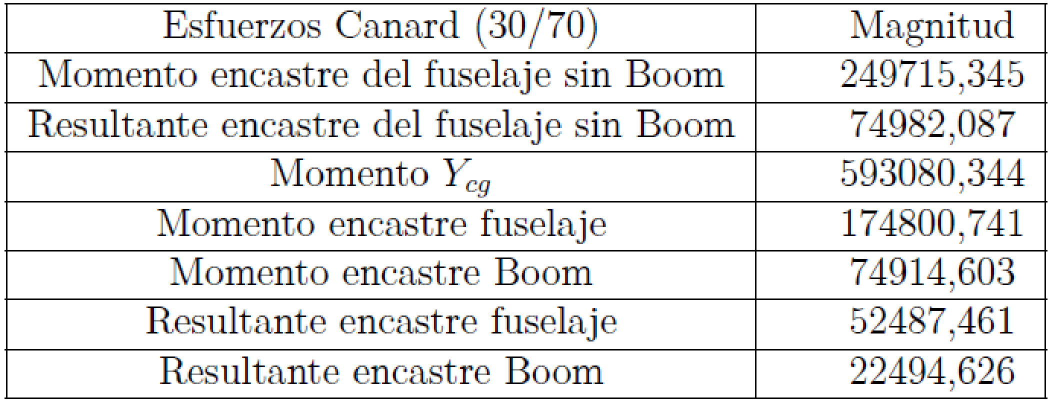




Ejemplos Esfuerzos - I

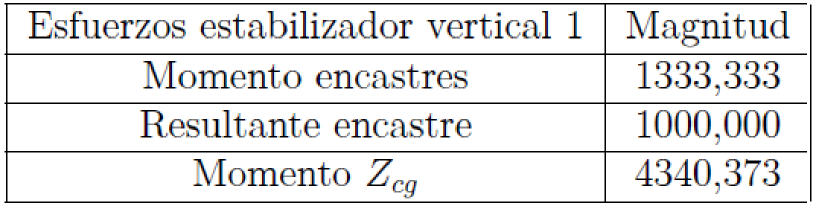
- Canard: Distribución *30 - 70* de los esfuerzos totales calculados con el modelo de la viga empotrada:
    - Ejemplo: *Boom* soporta el 30% de los esfuerzos y el encastre, junto al fuselaje soporta el 70% restante.
- Ala: Distribución es de 60% para el encastre junto al fuselaje, el 25% para el encastre de la unión *Boom - Fuselaje* y el 15% restante para el encastre que soporta el resto del *Ala*.
- *Vertical* y de un motor: Esfuerzos calculados de una manera tradicional, obteniéndose sus esfuerzos asociados mediante brazos y fuerzas
- Tren de aterrizaje: modelo para cuando se encuentra estacionada la aeronave y otro para cuando está en fase de rotación tanto en el despegue como en el aterrizaje. Para el caso de estacionamiento en tierra, se ha calculado también de una manera tradicional mediante fuerzas y brazos de momentos, repartiendo el 10% del peso al tren delantero, 80% al tren principal y 5% a cada uno de los dos trenes laterales.
- En cuanto a la rotación se ha tomado un factor de carga de 1,3 con una sustentación del 60% del peso, un ángulo de rotación de 15 grados y un ángulo de empuje de motor de 0 grados.

Esfuerzos Superficies



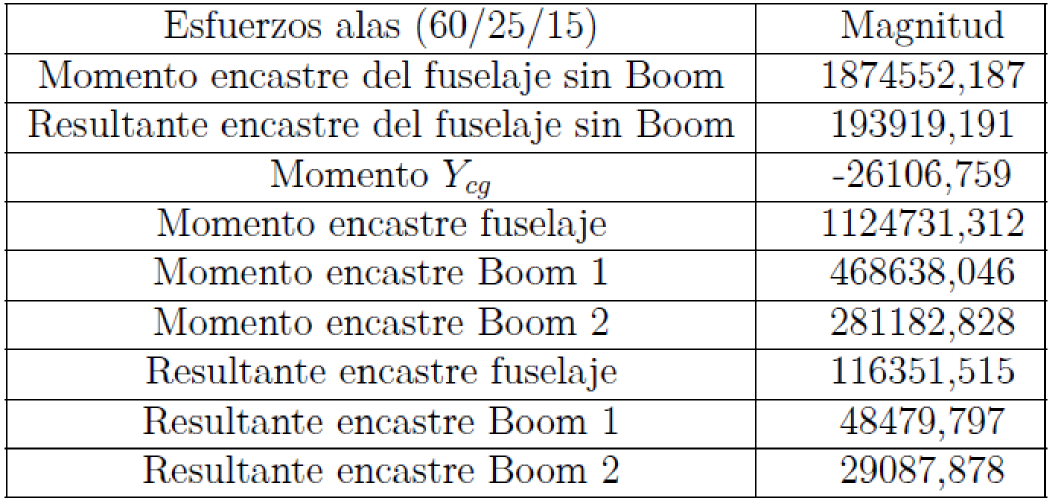
Esfuerzos Canard (30/70)	Magnitud
Momento encastre del fuselaje sin Boom	249715,345
Resultante encastre del fuselaje sin Boom	74982,087
Momento Y_{cg}	593080,344
Momento encastre fuselaje	174800,741
Momento encastre Boom	74914,603
Resultante encastre fuselaje	52487,461
Resultante encastre Boom	22494,626

Tabla 4: Esfuerzos en el Canard



Esfuerzos estabilizador vertical 1	Magnitud
Momento encastres	1333,333
Resultante encastre	1000,000
Momento Z_{cg}	4340,373

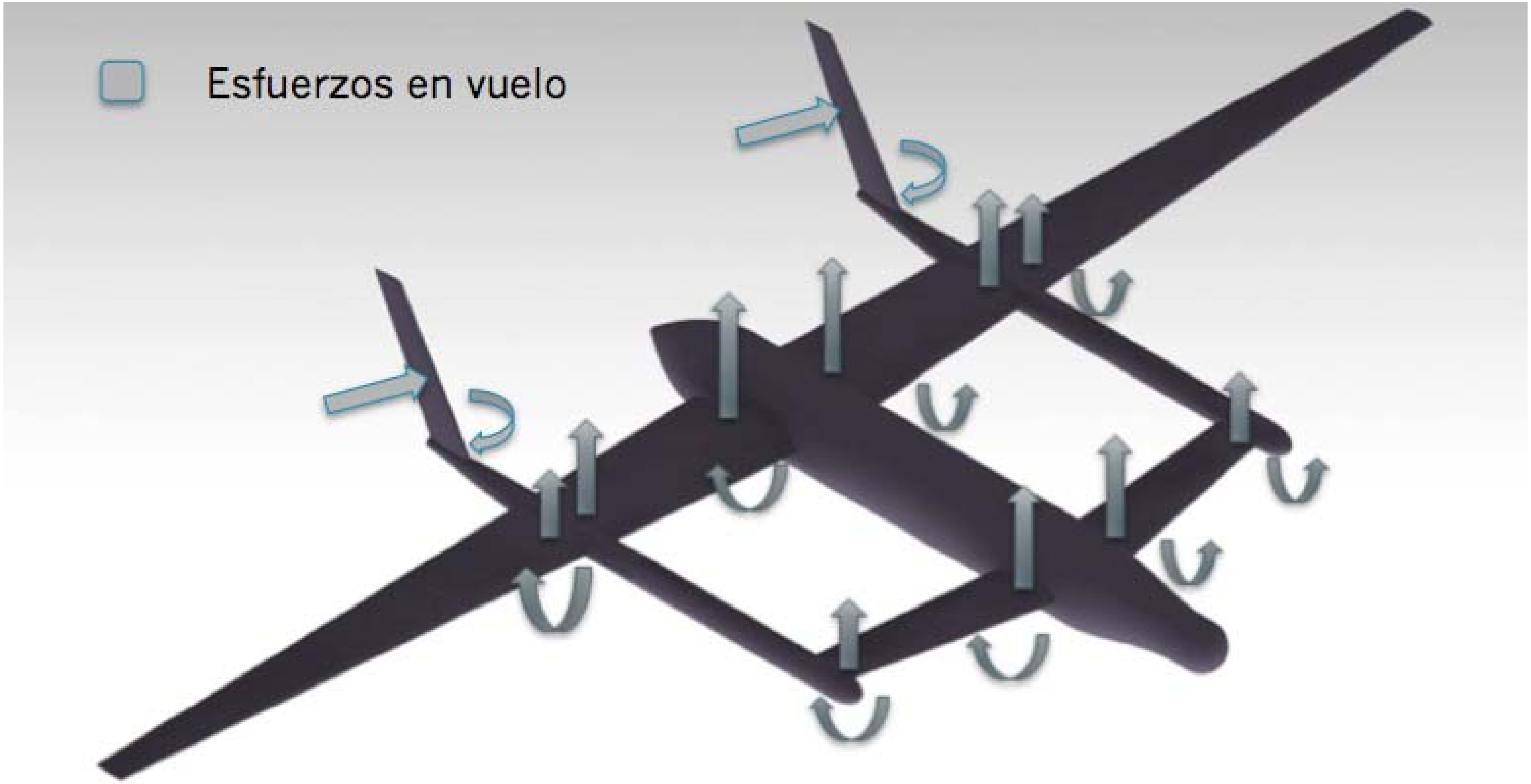
Tabla 6: Esfuerzos en el estabilizador vertical



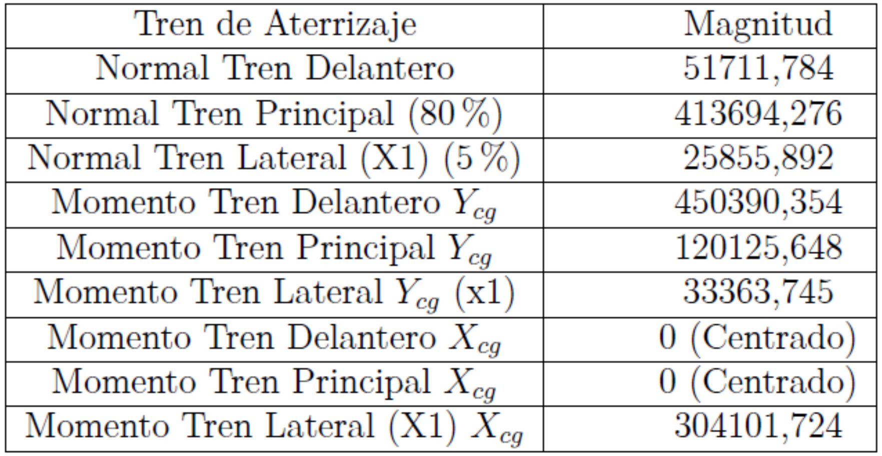
Esfuerzos alas (60/25/15)	Magnitud
Momento encastre del fuselaje sin Boom	1874552,187
Resultante encastre del fuselaje sin Boom	193919,191
Momento Y_{cg}	-26106,759
Momento encastre fuselaje	1124731,312
Momento encastre Boom 1	468638,046
Momento encastre Boom 2	281182,828
Resultante encastre fuselaje	116351,515
Resultante encastre Boom 1	48479,797
Resultante encastre Boom 2	29087,878

Tabla 5: Esfuerzos en el ala

Ejemplo Esfuerzos

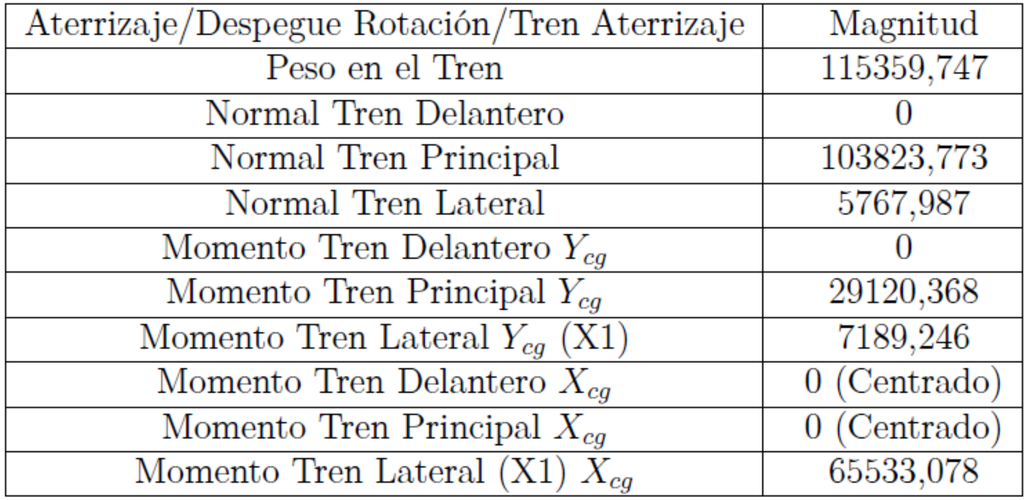


Esfuerzos Tren y Motor



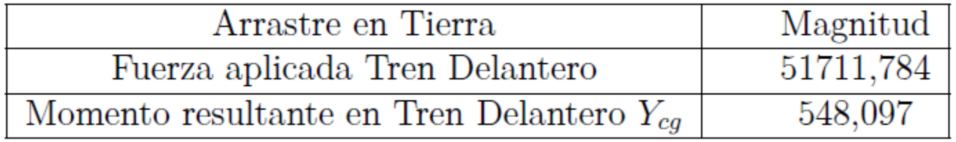
Tren de Aterrizaje	Magnitud
Normal Tren Delantero	51711,784
Normal Tren Principal (80 %)	413694,276
Normal Tren Lateral (X1) (5 %)	25855,892
Momento Tren Delantero Y_{cg}	450390,354
Momento Tren Principal Y_{cg}	120125,648
Momento Tren Lateral Y_{cg} (x1)	33363,745
Momento Tren Delantero X_{cg}	0 (Centrado)
Momento Tren Principal X_{cg}	0 (Centrado)
Momento Tren Lateral (X1) X_{cg}	304101,724

Tabla 7: Esfuerzos en el tren principal



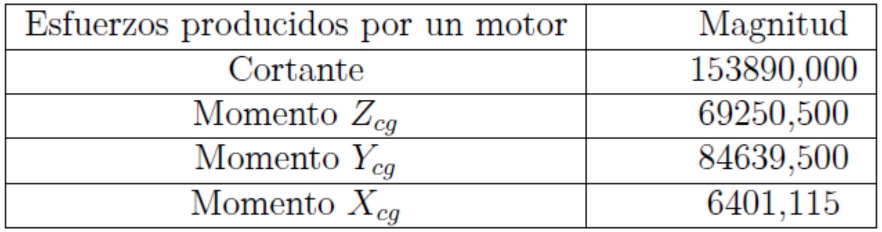
Aterrizaje/Despegue Rotación/Tren Aterrizaje	Magnitud
Peso en el Tren	115359,747
Normal Tren Delantero	0
Normal Tren Principal	103823,773
Normal Tren Lateral	5767,987
Momento Tren Delantero Y_{cg}	0
Momento Tren Principal Y_{cg}	29120,368
Momento Tren Lateral Y_{cg} (X1)	7189,246
Momento Tren Delantero X_{cg}	0 (Centrado)
Momento Tren Principal X_{cg}	0 (Centrado)
Momento Tren Lateral (X1) X_{cg}	65533,078

Tabla 8: Esfuerzos en Aterrizaje/Despegue Rotación/Tren Aterrizaje



Arrastre en Tierra	Magnitud
Fuerza aplicada Tren Delantero	51711,784
Momento resultante en Tren Delantero Y_{cg}	548,097

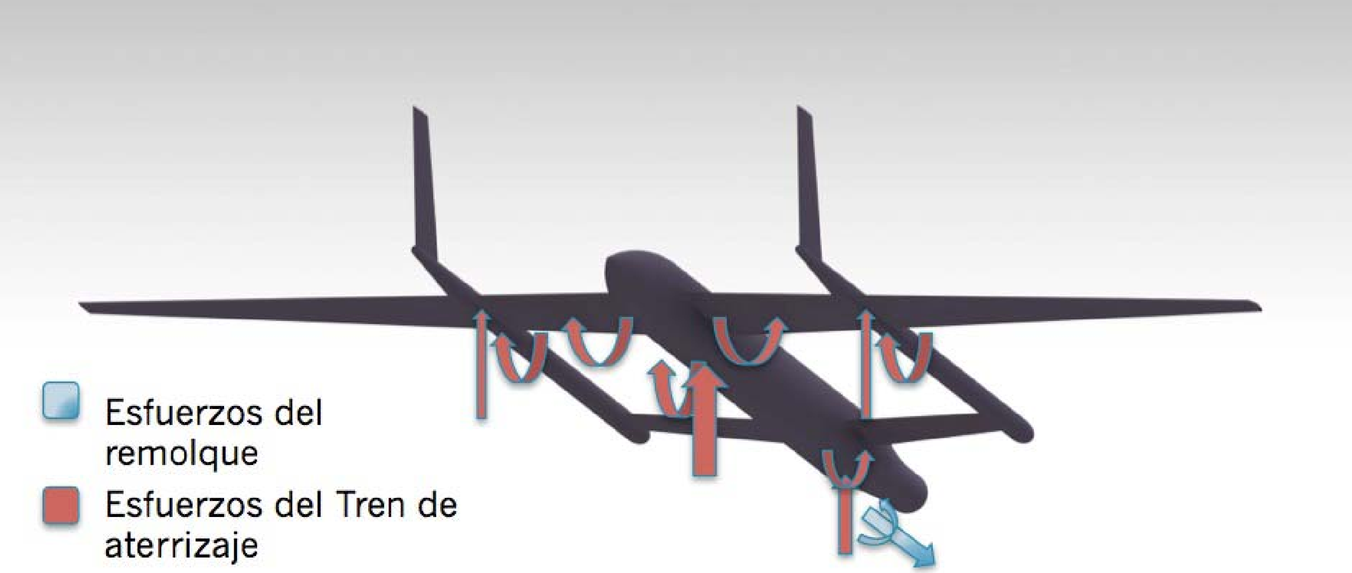
Tabla 9: Esfuerzos en Arrastre en Tierra



Esfuerzos producidos por un motor	Magnitud
Cortante	153890,000
Momento Z_{cg}	69250,500
Momento Y_{cg}	84639,500
Momento X_{cg}	6401,115

Tabla 10: Esfuerzos producidos por un motor

Ejemplo Esfuerzos



🟦 Esfuerzos del remolque

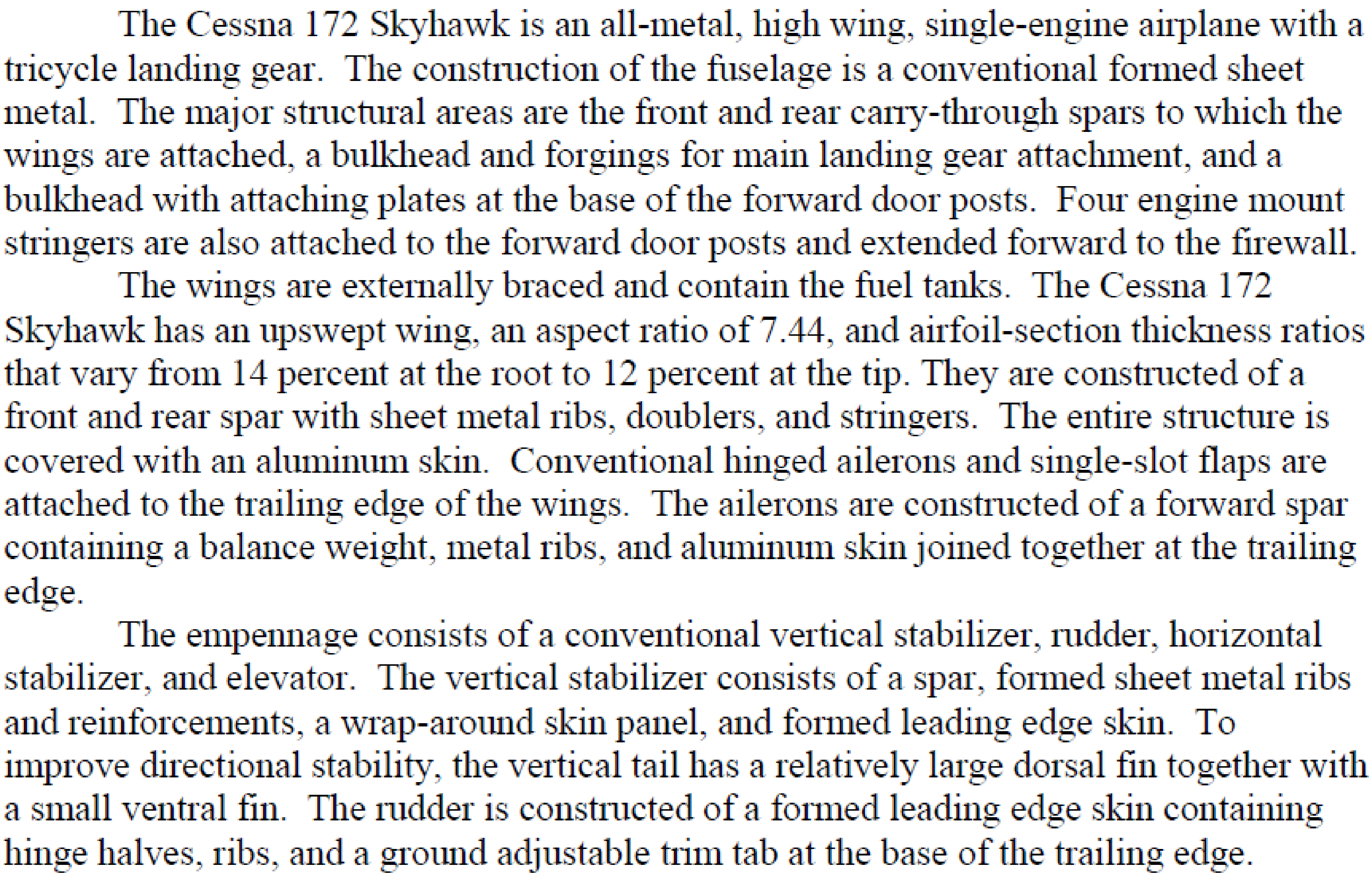
🟥 Esfuerzos del Tren de aterrizaje

🟦 Esfuerzos producidos por los motores

Cálculo Requisitos Estructurales

- Estudio de las cargas de un aeronave: Ejemplo Cessna 172 Skyhawk
  - Structural Design Loads
  - Wing Torsion
  - Wing Skin and Spar Web Thickness
  - Wing Bending Flexure
  - Combined Flexure and Torsion

General information Cessna 172 Skyhawk - I

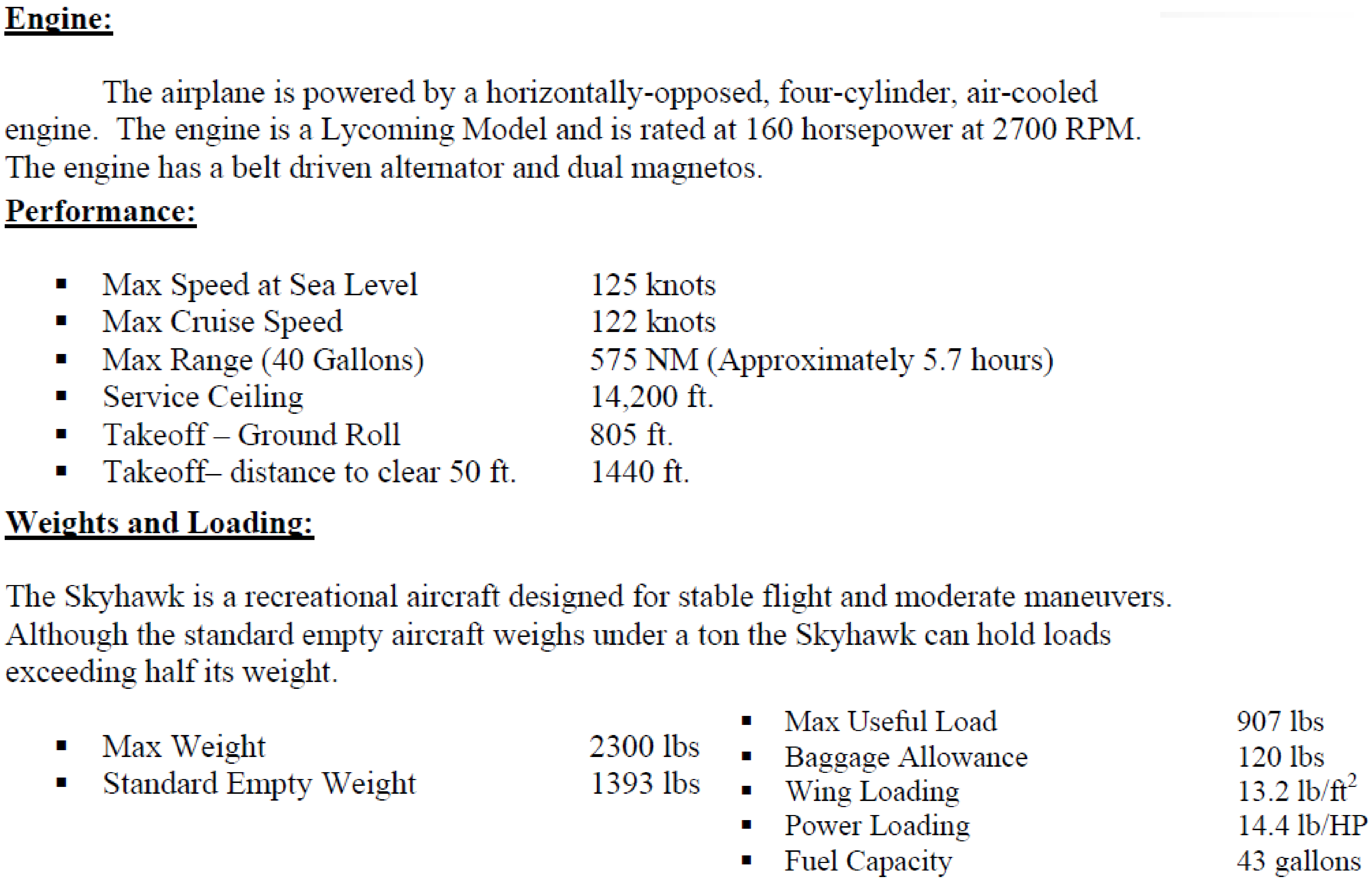


The Cessna 172 Skyhawk is an all-metal, high wing, single-engine airplane with a tricycle landing gear. The construction of the fuselage is a conventional formed sheet metal. The major structural areas are the front and rear carry-through spars to which the wings are attached, a bulkhead and forgings for main landing gear attachment, and a bulkhead with attaching plates at the base of the forward door posts. Four engine mount stringers are also attached to the forward door posts and extended forward to the firewall.

The wings are externally braced and contain the fuel tanks. The Cessna 172 Skyhawk has an upswept wing, an aspect ratio of 7.44, and airfoil-section thickness ratios that vary from 14 percent at the root to 12 percent at the tip. They are constructed of a front and rear spar with sheet metal ribs, doublers, and stringers. The entire structure is covered with an aluminum skin. Conventional hinged ailerons and single-slot flaps are attached to the trailing edge of the wings. The ailerons are constructed of a forward spar containing a balance weight, metal ribs, and aluminum skin joined together at the trailing edge.

The empennage consists of a conventional vertical stabilizer, rudder, horizontal stabilizer, and elevator. The vertical stabilizer consists of a spar, formed sheet metal ribs and reinforcements, a wrap-around skin panel, and formed leading edge skin. To improve directional stability, the vertical tail has a relatively large dorsal fin together with a small ventral fin. The rudder is constructed of a formed leading edge skin containing hinge halves, ribs, and a ground adjustable trim tab at the base of the trailing edge.

General information Cessna 172 Skyhawk - II



Engine:

The airplane is powered by a horizontally-opposed, four-cylinder, air-cooled engine. The engine is a Lycoming Model and is rated at 160 horsepower at 2700 RPM. The engine has a belt driven alternator and dual magnetos.

Performance:

Max Speed at Sea Level	125 knots
Max Cruise Speed	122 knots
Max Range (40 Gallons)	575 NM (Approximately 5.7 hours)
Service Ceiling	14,200 ft.
Takeoff – Ground Roll	805 ft.
Takeoff– distance to clear 50 ft.	1440 ft.

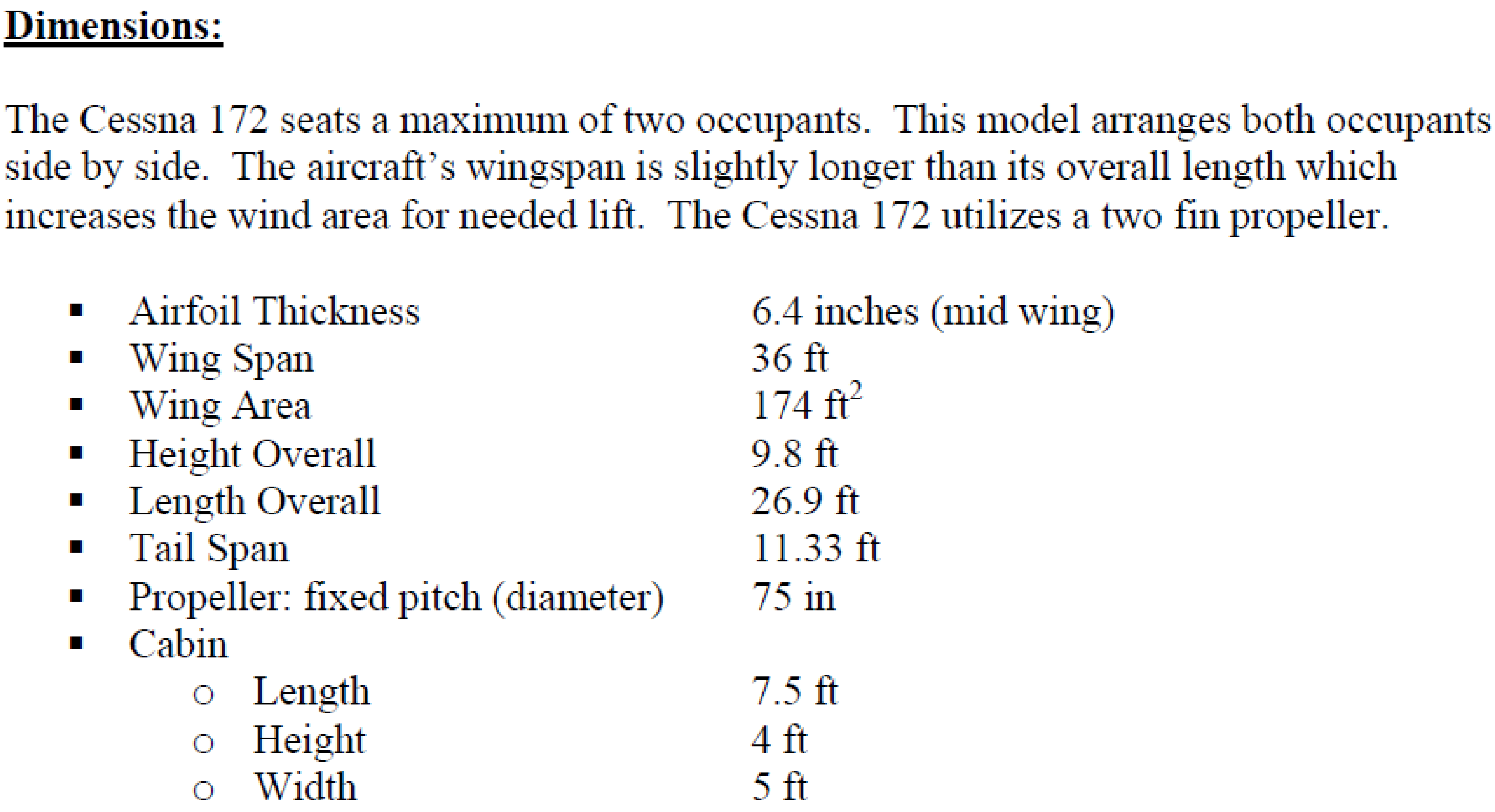
Weights and Loading:

The Skyhawk is a recreational aircraft designed for stable flight and moderate maneuvers. Although the standard empty aircraft weighs under a ton the Skyhawk can hold loads exceeding half its weight.

Max Weight	2300 lbs
Standard Empty Weight	1393 lbs

Max Useful Load	907 lbs
Baggage Allowance	120 lbs
Wing Loading	13.2 lb/ft^2
Power Loading	14.4 lb/HP
Fuel Capacity	43 gallons

General information Cessna 172 Skyhawk - II

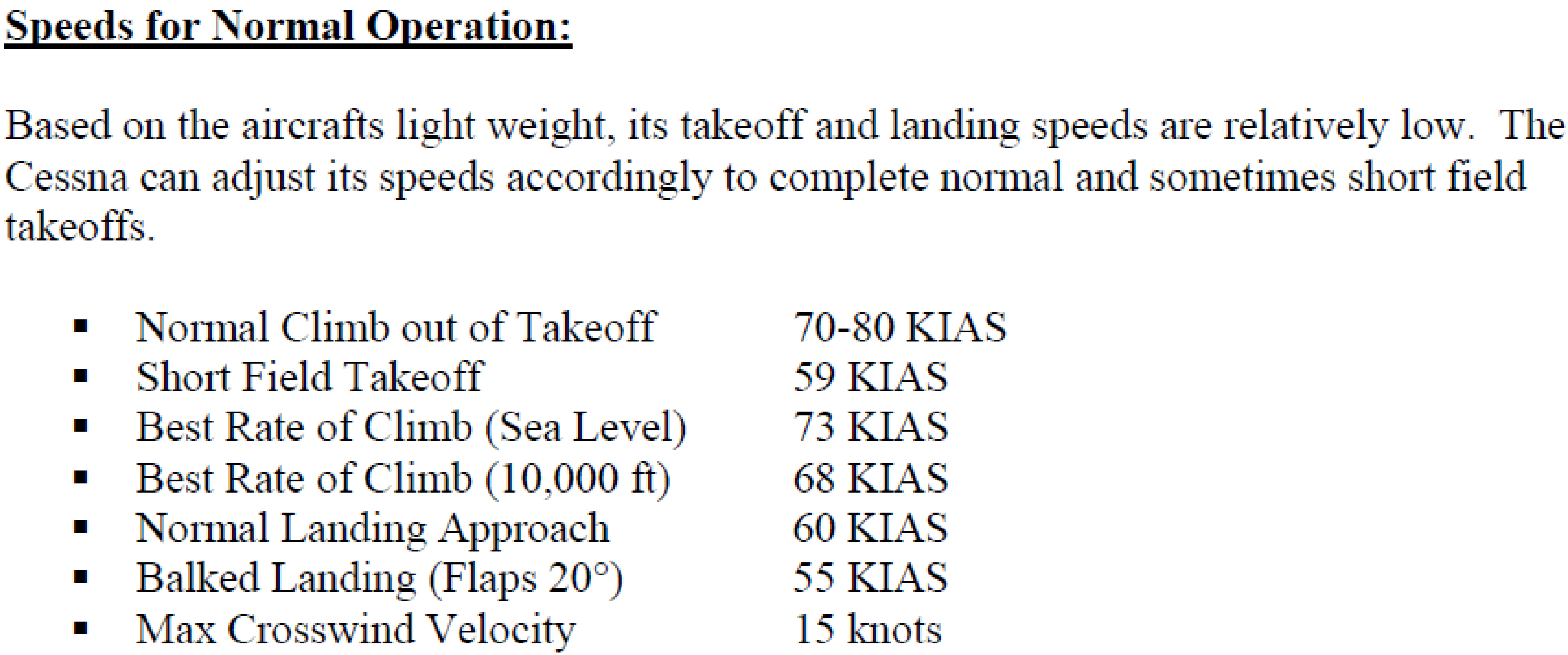


Dimensions:

The Cessna 172 seats a maximum of two occupants. This model arranges both occupants side by side. The aircraft's wingspan is slightly longer than its overall length which increases the wind area for needed lift. The Cessna 172 utilizes a two fin propeller.

▪ Airfoil Thickness	6.4 inches (mid wing)
▪ Wing Span	36 ft
▪ Wing Area	174 ft^2
▪ Height Overall	9.8 ft
▪ Length Overall	26.9 ft
▪ Tail Span	11.33 ft
▪ Propeller: fixed pitch (diameter)	75 in
▪ Cabin	
○ Length	7.5 ft
○ Height	4 ft
○ Width	5 ft

General information Cessna 172 Skyhawk - III

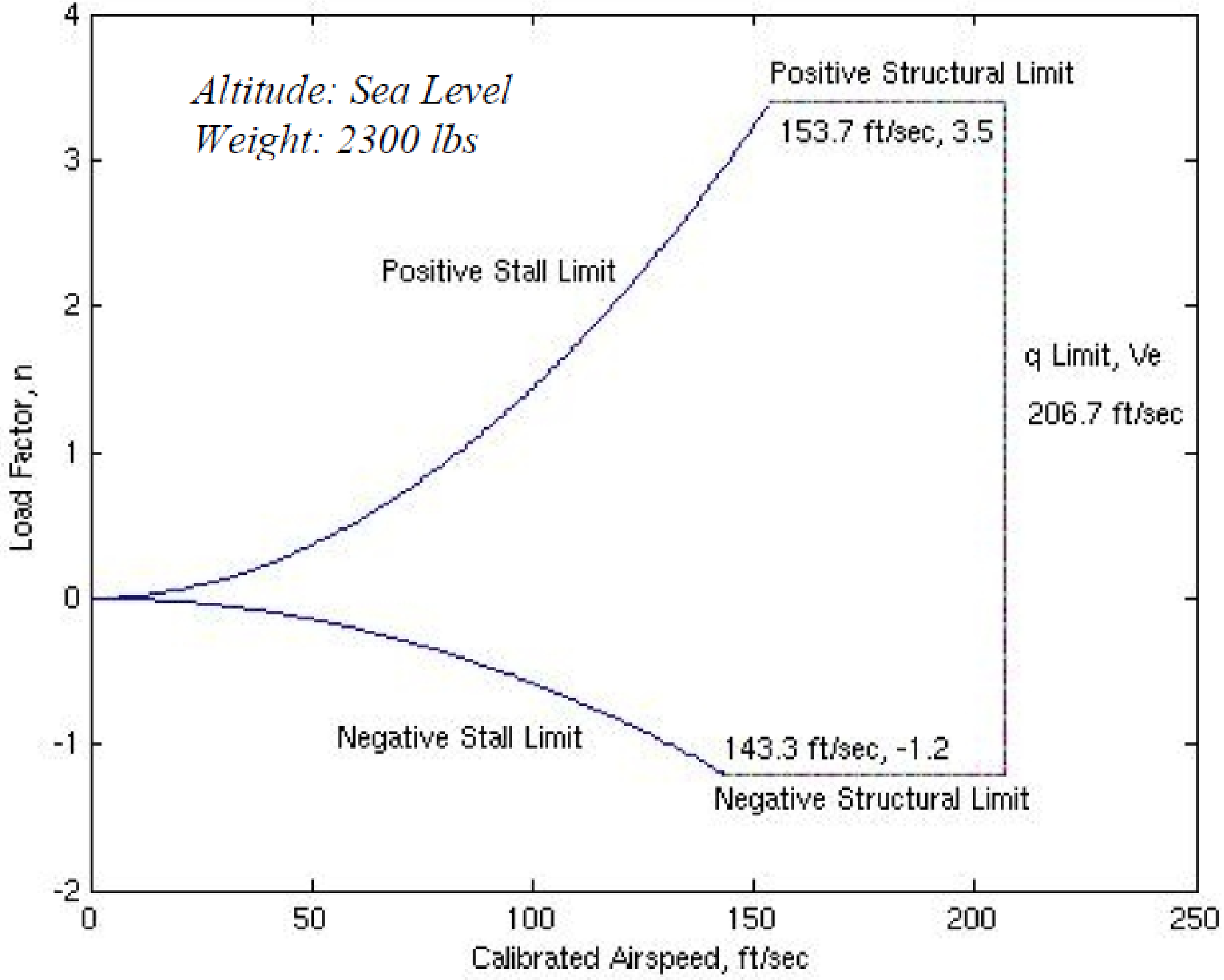


Speeds for Normal Operation:

Based on the aircrafts light weight, its takeoff and landing speeds are relatively low. The Cessna can adjust its speeds accordingly to complete normal and sometimes short field takeoffs.

Normal Climb out of Takeoff	70-80 KIAS
Short Field Takeoff	59 KIAS
Best Rate of Climb (Sea Level)	73 KIAS
Best Rate of Climb (10,000 ft)	68 KIAS
Normal Landing Approach	60 KIAS
Balked Landing (Flaps 20°)	55 KIAS
Max Crosswind Velocity	15 knots

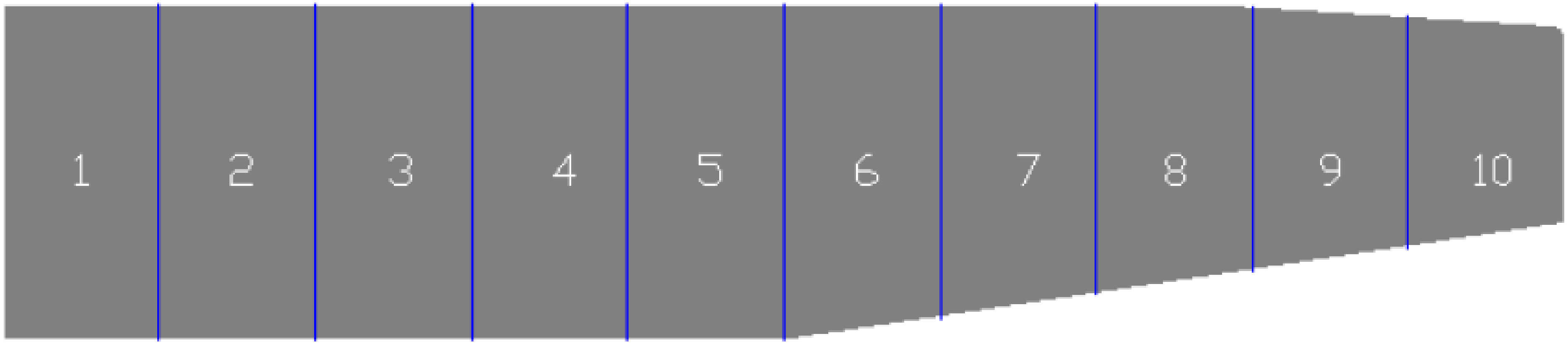
V-n Diagram


Altitude: Sea Level
Weight: 2300 lbs
Positive Structural Limit
153.7 ft/sec, 3.5
Positive Stall Limit
q Limit, Ve
206.7 ft/sec
Negative Stall Limit
143.3 ft/sec, -1.2
Negative Structural Limit
Load Factor, n
Calibrated Airspeed, ft/sec
4
3
2
1
0
-1
-2
0
50
100
150
200
250

Structural Design Loads - I

Computing shear force and bending moment for the Skyhawk provides a detailed model of the stresses acting on the each wing. These forces are created from total lift force and the wing and fuel weight. To accurately represent the shape of the wing it is separated into ten sections as seen in Figure 2. Each section has both an elliptical and trapezoidal chord length. The average chord length and area of each section is then used to calculate the Shear Force and Bending Moment on each section of the wing. Total Force is computed from the difference between each sections lift force subtracted by the total weight force. Bending Moment is computed using the Total Force on the wing section.

Figure 2



Structural Design Loads - II

Calculating total lift for each wing:

Total Lift = n_{max}*TOGW*FS / 2

Total Lift = 5347.5 lbs

FS = 1,5

The average chord distance for each section:

$C_{avg} = C_{trapezoidal} + C_{elliptical} / 2$ *(Eqn. 1.1)*

$C_{trapezoidal} = C_r [1-2/y * (1-\lambda)]$ *(Eqn. 1.2)*

$C_{elliptical} = (4S / \Pi b) * \mathrm{sqrt}[1- (2y/b)^2]$ *(Eqn. 1.3)*

*C_{avg} is found along with the area of each section. After, solving for **f**, the force coefficient, the lift force on each strip is established.*

Each separate force; lift, fuel, and wing weight have different coefficients. They are:

f_{lift} = LIFT / Wing Area (half) *(Eqn. 2.1)*

f_{fuel} = Fuel weight / Wing Area (half) *(Eqn. 2.2)*

f_{wing} = Wing weight / Wing Area (half) *(Eqn. 2.3)*

❖ Note: Wing weight = 7.5% of empty weight.
Density of gasoline = 803 kg/m^3

Structural Design Loads - III

Table 1

C(y)elip [ft]	y distance [ft]	C(y)trap [ft]	C(y) avg [ft]	Area of Section [ft^2]
6.150	0.000	5.330	5.740	10.242
6.120	1.800	5.160	5.640	9.984
5.910	3.600	4.996	5.453	9.723
5.870	5.400	4.830	5.350	9.450
5.640	7.200	4.660	5.150	9.059
5.330	9.000	4.500	4.915	8.586
4.920	10.800	4.330	4.625	8.010
4.390	12.600	4.160	4.275	7.306
3.690	14.400	3.995	3.843	6.388
2.680	16.200	3.830	3.255	4.577
0.000	18.000	3.660	1.830	0.000
			Total Area:	83.323

- Table 1 represents the calculations necessary to solve for average chord length for each section (refer to the equations 1.1-1.3). An average is taken between the elliptical and trapezoidal chord lengths. The area of each section is then computed. Checking the calculated values with *Figure 2* proves the accuracy of the values.

Structural Design Loads - IV

Lift force on each strip:

$L_{force} = A_{strip} * f$ *(Eqn. 2.4)*

Total force on each strip:

$\text{Total Force} = L_{force} - [\, f_{fuel} * \text{Area} - f_{wing} * \text{Area} \,]$ *(Eqn. 3.1)*

Shear Force on each strip:

$\Sigma_i \text{ Total Force}_i$ *(Eqn. 4.1)*

Using the total force the Bending Moment is worked out:

$BM = \Sigma_i \, Total\ Force_i * \text{y distance (from fuselage)}$ *(Eqn. 5.1)*

Structural Design Loads - V

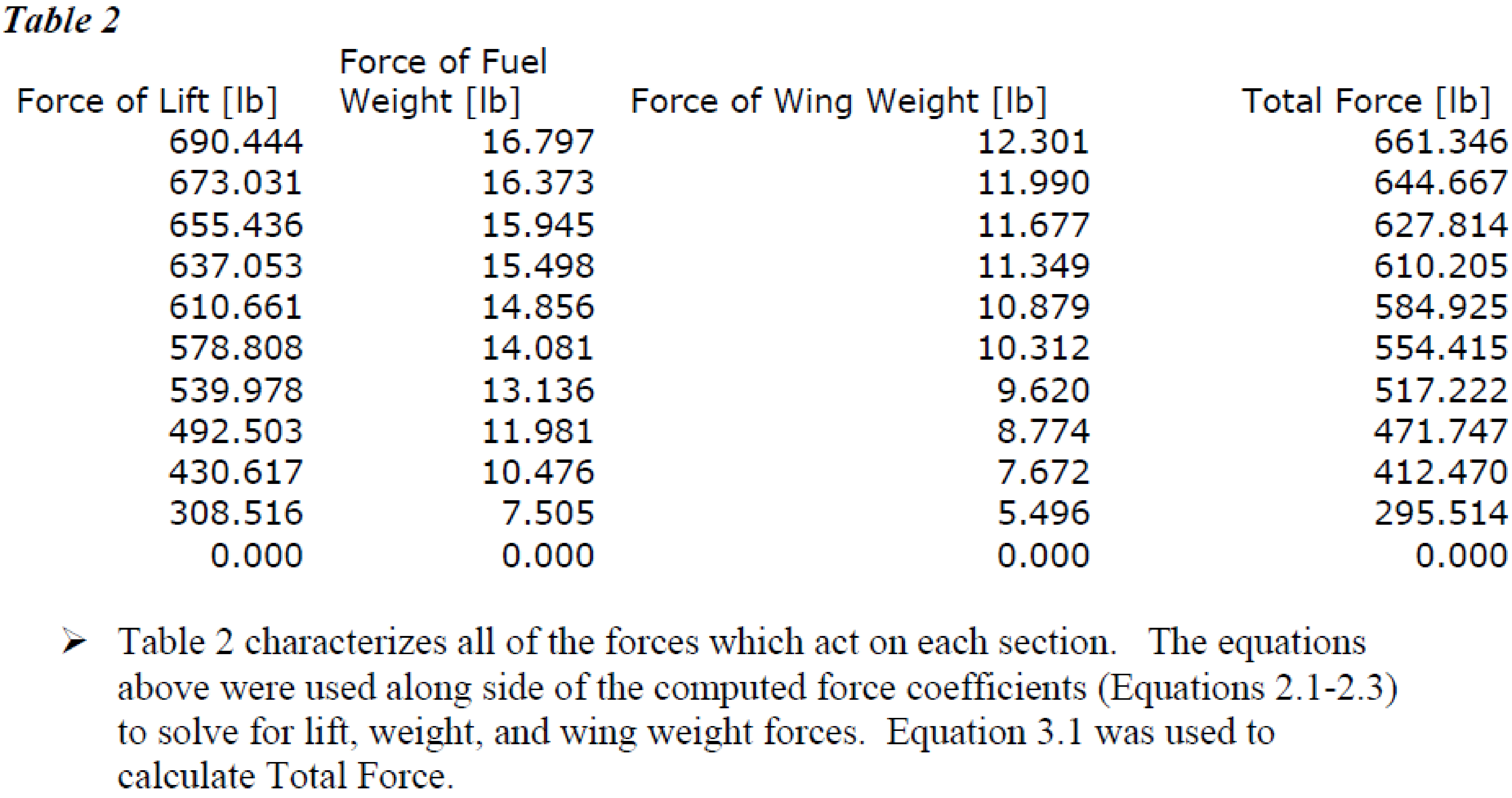


Table 2

Force of Lift [lb]	Force of Fuel Weight [lb]	Force of Wing Weight [lb]	Total Force [lb]
690.444	16.797	12.301	661.346
673.031	16.373	11.990	644.667
655.436	15.945	11.677	627.814
637.053	15.498	11.349	610.205
610.661	14.856	10.879	584.925
578.808	14.081	10.312	554.415
539.978	13.136	9.620	517.222
492.503	11.981	8.774	471.747
430.617	10.476	7.672	412.470
308.516	7.505	5.496	295.514
0.000	0.000	0.000	0.000

- Table 2 characterizes all of the forces which act on each section. The equations above were used along side of the computed force coefficients (Equations 2.1-2.3) to solve for lift, weight, and wing weight forces. Equation 3.1 was used to calculate Total Force.

Structural Design Loads - VI

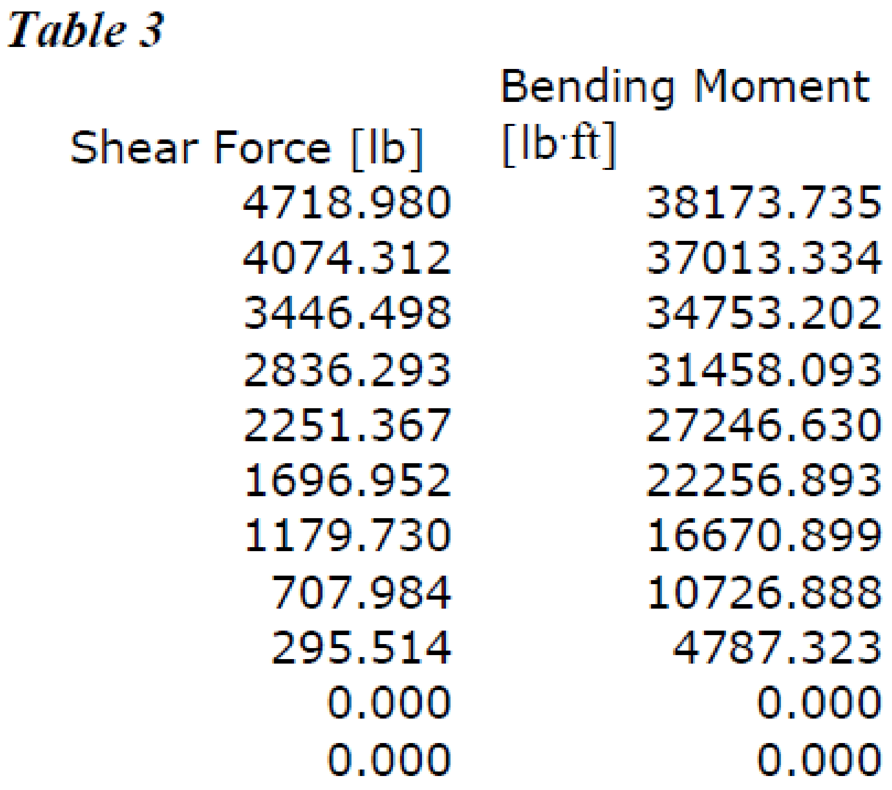


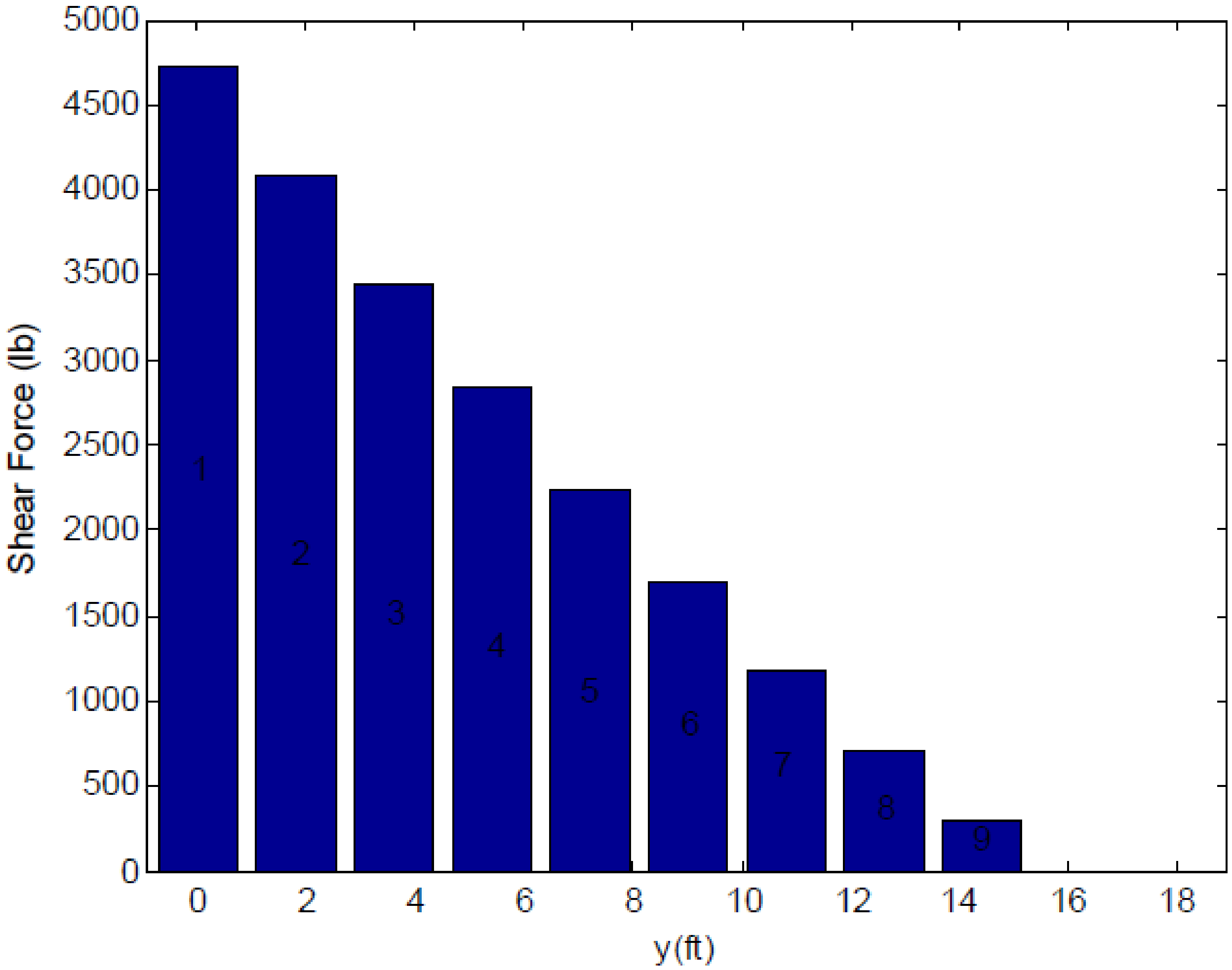
Table 3

Shear Force [lb]	Bending Moment [lb·ft]
4718.980	38173.735
4074.312	37013.334
3446.498	34753.202
2836.293	31458.093
2251.367	27246.630
1696.952	22256.893
1179.730	16670.899
707.984	10726.888
295.514	4787.323
0.000	0.000
0.000	0.000

- Table 3 corresponds to the Shear and Bending Moments for each section of the wing. These equations can be found from above, Equations 4.1 & 5.1.

Structural Design Loads - VII

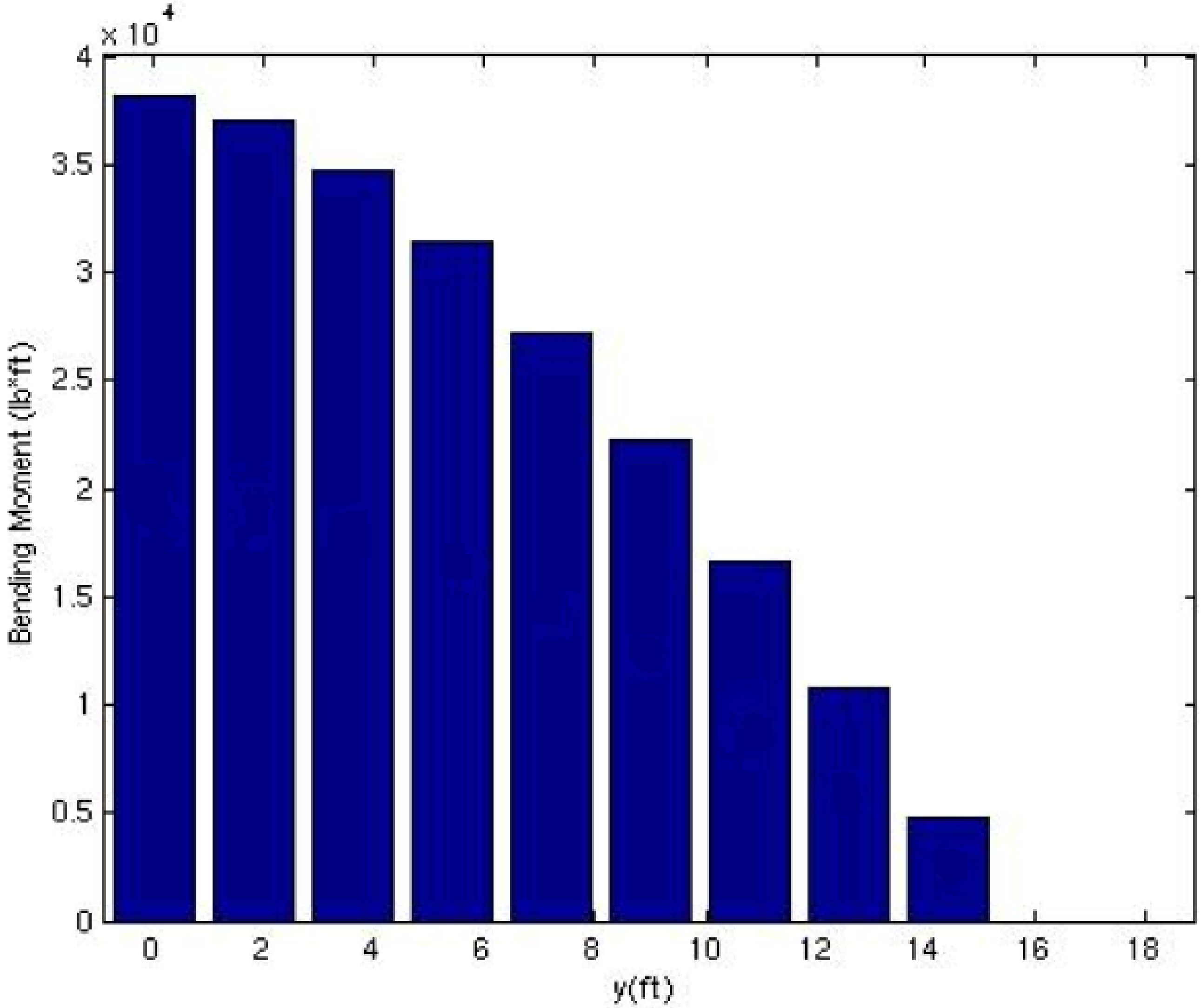
Figure 3



- Figure 3 represents the Shear Force versus the distance away from the fuselage. The Shear Force is the summation of Total Forces outboard of that section. The sections are labeled accordingly on the graph.

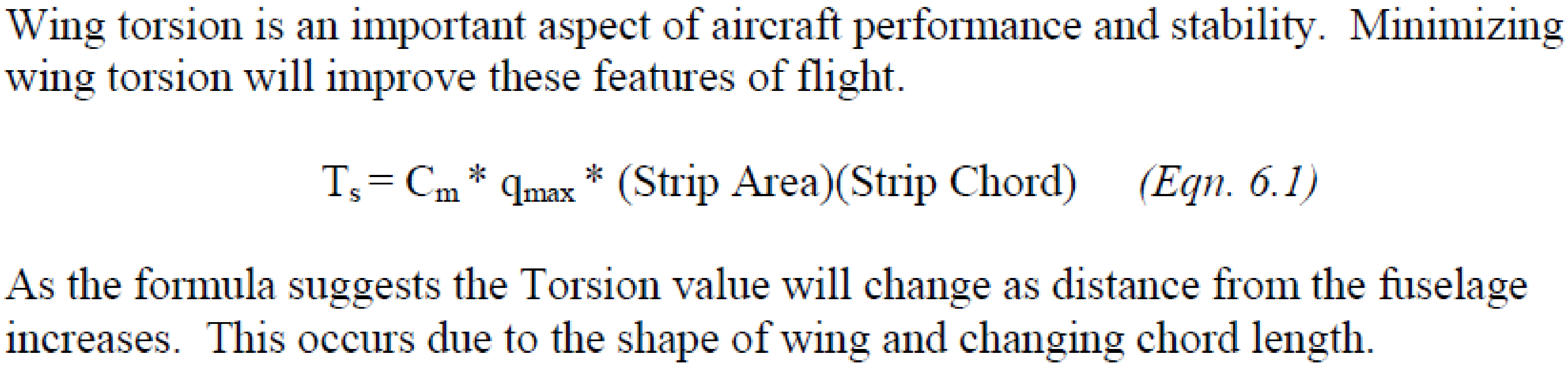
Structural Design Loads - VIII

- *Figure 4*



- Figure 4 represents the Bending Moment as the distance away from the fuselage increases. As with the Shear Force, Bending Moment is the summation of the bending moment's outboard of that specific section.

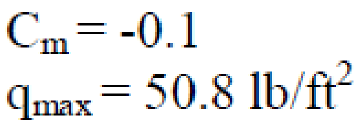
Wing Torsion - I



Wing torsion is an important aspect of aircraft performance and stability. Minimizing wing torsion will improve these features of flight.

$$T_s = C_m * q_{max} * (\text{Strip Area})(\text{Strip Chord}) \qquad \textit{(Eqn. 6.1)}$$

As the formula suggests the Torsion value will change as distance from the fuselage increases. This occurs due to the shape of wing and changing chord length.



$C_m = -0.1$ Coeficiente de momentos

$q_{max} = 50.8\ \text{lb/ft}^2$ Presión dinámica máxima

Wing Torsion - I

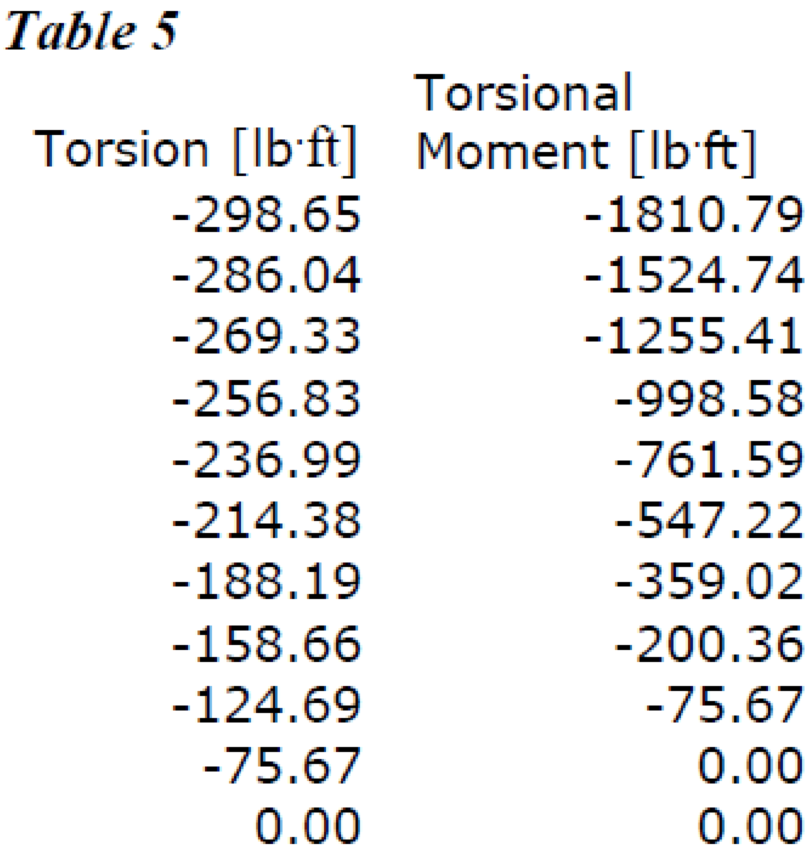


Table 5

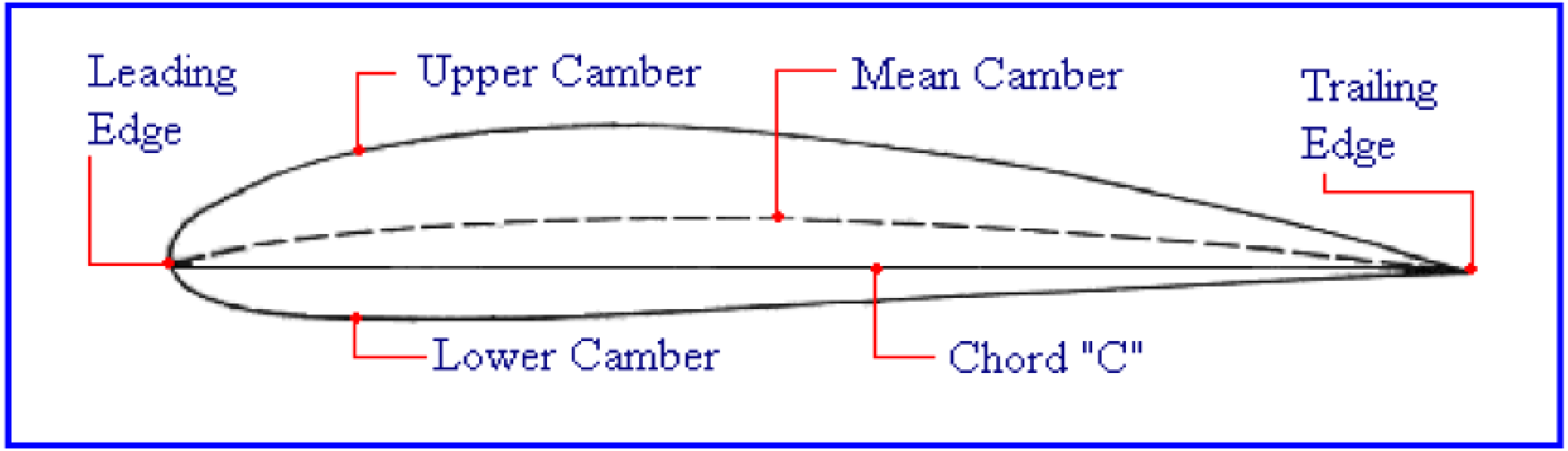
Torsion [lb·ft]	Torsional Moment [lb·ft]
-298.65	-1810.79
-286.04	-1524.74
-269.33	-1255.41
-256.83	-998.58
-236.99	-761.59
-214.38	-547.22
-188.19	-359.02
-158.66	-200.36
-124.69	-75.67
-75.67	0.00
0.00	0.00

- Table 5 symbolizes the Torsional Moments along the wing. The moments at each section were computed by summing the torsions outboard of that section.

Wing Skin and Spar Web Thickness - I

Solving for skin and spar web thickness requires the dimensions of the wing airfoil at root, mid-span, and tip. These airfoils will describe the areas of the wing cross section at each segment of the wing. Correctly assuming the wing airfoil decreases along with chord length then the area should as well. Based on the fact skin and spar web thickness is directly related to the cross sectional wing area and Torque solved for above, the thicknesses will decrease as predicted.

Figure 5



- Figure 5 embodies what a general wing cross section looks like. The airfoil height will decrease as distance from the fuselage increases.

Wing Skin and Spar Web Thickness - II

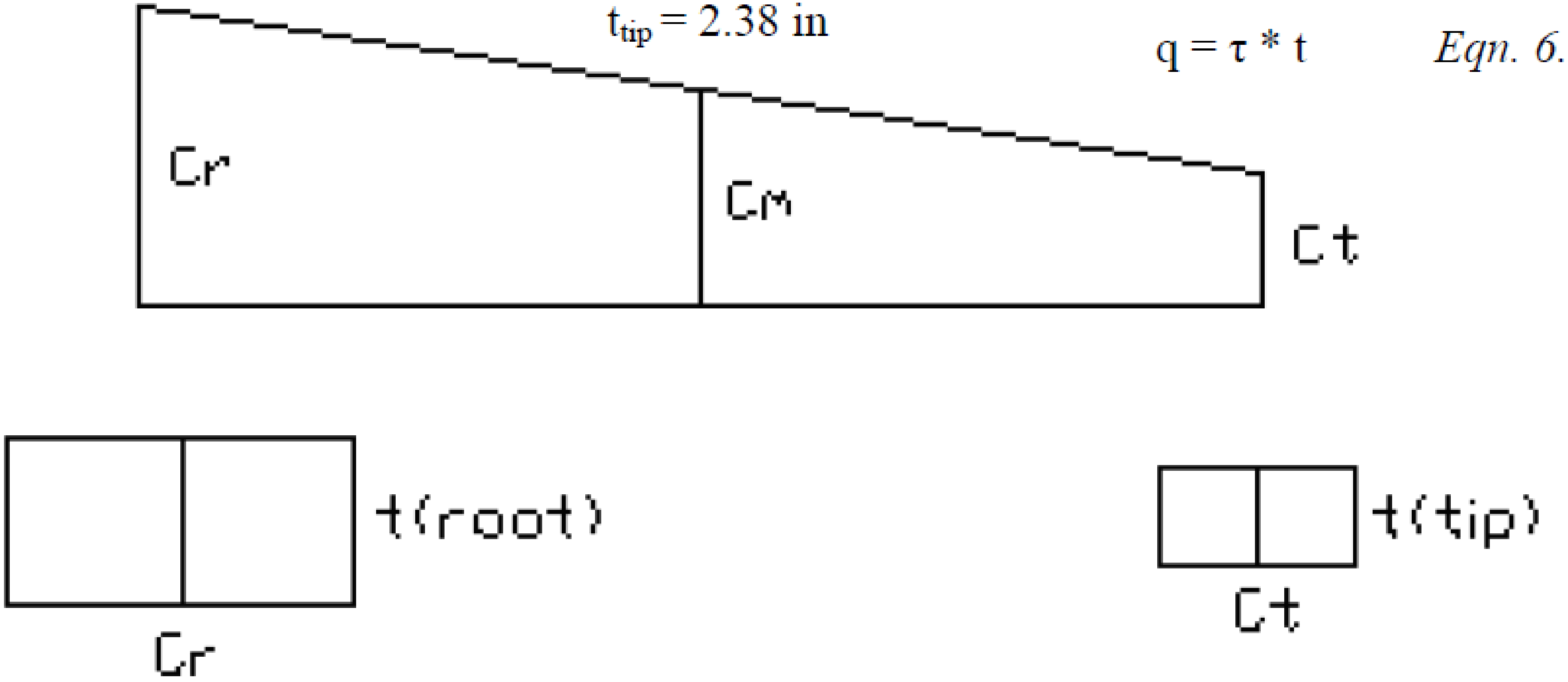
Figure 6

$\sigma_Y = 47{,}000$ psi
$t_{root} = 7.47$ in
$t_{mid} = 6.4$ in
$t_{tip} = 2.38$ in

Equations:

$T = 2Aq$ *Eqn. 6.1*

$q = \tau * t$ *Eqn. 6.2*



- Figure 6 represents the general diagram used to visualize the cross sections at root and tip. The same procedure was used for the mid-span section but was not included in the diagram.

Wing Skin and Spar Web Thickness - III

Solving for Area at each section of the wing:

$\sigma_Y = 47{,}000$ psi

$t_{root} = 7.47$ in

$t_{mid} = 6.4$ in

$t_{tip} = 2.38$ in

$A = C^*t$

$A_{root} = 3.57\ \text{ft}^2$ $A_{mid} = 2.57\ \text{ft}^2$ $A_{tip} = .363\ \text{ft}^2$

Solving q at each section of the wing using equation 6.1:

$q_{root} = 253.39$ lb/ft

$q_{mid} = 104.39$ lb/ft

$q_{tip} = 104.25$ lb/ft

Equations:

$T = 2Aq$ *Eqn. 6.1*

$q = \tau * t$ *Eqn. 6.2*

Using the torsional moment (Torque) solved above and the value of q, the thickness to prevent yielding can be computed using equation 6.2.

Wall thickness$_{(root)}$ = .0089 in

Wall thickness$_{(mid\text{-}span)}$ = .0037 in

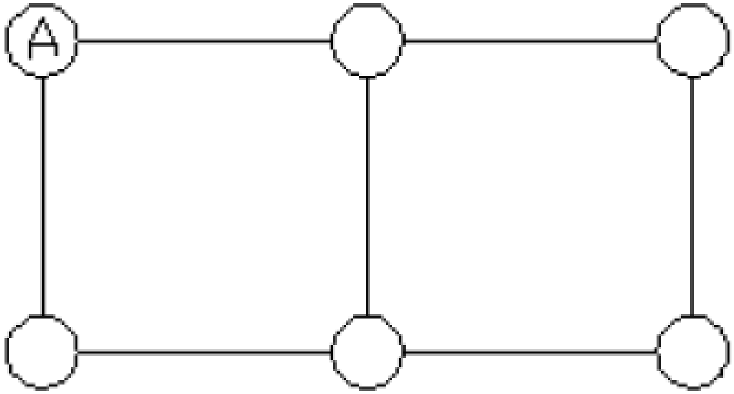
Wall thickness$_{(tip)}$ = .0036 in

Cuidado unidades ft & in!!!

Wing Bending (flexure) - I

To approximate the wing sections at root and mid-span the cross section is represented by a symmetric rectangle where A signifies the concentrated area at each spar cap. These concentrated areas are required to be a certain size which will prevent yielding.

Figure 7



- Figure 7 shows the cross section of the wing. At root and mid-span the concentrated area, A, along with the airfoil thickness or height t will change based on wing geometry.

Solving I_y in terms of A gives the following equation: $I_y = 6A(t/2)^2$

Wing Bending (flexure) - I

To solve for A such that there is no yielding:

$\sigma_{xx} = \sigma_Y = 47{,}000$ psi $\qquad \sigma_{xx} = M_y z / I_y \qquad$ Eqn. 6.3

Cuidado Bending moment el lb*ft!!!

Using equation 6.3 and the previously solved bending moment from step 2:

$t_{root} = 7.47$ in $\qquad z_{root} = t/2 = 3.735$ in

$t_{mid} = 6.4$ in $\qquad z_{mid} = 3.2$ in

$t_{tip} = 2.38$ in

Therefore to prevent yielding:

$A_{root} \leq 0.0362\ \text{in}^2 \qquad A_{mid} \leq 0.0302\ \text{in}^2$ ⇦ $I_y = 6A(t/2)^2$

To compute bending stress the known concentrated areas are used and substituted in to equation 6.3:

$I_{y(root)} = 3.034\ \text{in}^4 \qquad I_{y(mid)} = 1.843\ \text{in}^4$

$\sigma_{xx(root)} = 46{,}990.7$ psi $\qquad \sigma_{xx(mid)} = 46{,}993.1$ psi

Bibliografía

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- Design Philosophy, Design and Analysis of Aircraft Structures, Dr. Douglas S. Cairns, http://www.coe.montana.edu/me/faculty/cairns/Introduction%20to%20Aerospace-Web/04-DesignPhilosophy.pdf