CHAPTER 7

Special consideration in configuration lay-out

7.1. Introduction

After dimensions of the major components have been obtained the subsequent steps in the design process are as follows.

(i) Development of a smooth, producible and aerodynamically efficient external geometry. The methods to obtain smooth external geometry are called lofting.

(ii) Installation of internal features such as crew station, payload, landing gear and various system.

(iii) Integration of propulsion system.

iv) Working out details such as wetted area, cross sectional areas, volume etc.

The final layout is a compromise between aerodynamic, structural, and functional requirements. Producibility, maintainability, and environmental considerations also affect the layout.

We briefly discuss these considerations in this chapter. The material is based on Chapter 8 of Ref.1.11 and chapter 4 of Ref.1.13.

It may be added that various aspects of lofting and ways to obtain areas and volumes etc., are discussed in chapter 7 of Ref.1.11 .

7.2. Aerodynamic considerations

A poorly designed external shape of the airplane could result in undesirable flow separation resulting in low lift to drag ratio and , large transonic and supersonic wave drag.

Based on section 8.2 of Ref.1.11, the following remarks can be made.

(i) Minimization of wetted area is an important consideration as it directly affects skin friction drag and in turn parasite drag. One way to achieve this is to have smallest fuselage diameter and low fineness ratio. However proper space for payload, ease of maintenance and tail arm also needs to be considered.

(ii) To prevent flow separation, the deviation of fuselage shape from free stream direction should not exceed 10-12 degree.

(iii) Proper fillets should be used at junctions between

a) wing and fuselage

b) fuselage and tails

c) wing and pylons

(iv) Base area viz. unfaired, rearward facing blunt surface should be minimum.

(v) Canard, if used, should be located such that its wake does not enter the engine inlet as it may cause engine stalling.

(vi) Area ruling: The transonic wave drag is reduced with a smooth distribution of the area of cross section of the airplane in planes perpendicular to the flow direction. In this context it may be added that the area of cross section of the fuselage generally varies smoothly. However when the wing is encountered there is an abrupt change in the cross sectional area. This is alleviated by reduction in area of cross section of fuselage in the region where wing is located. Such a fuselage shape is called the coke-bottle shape. Figure 7.1 illustrates this method. Figure 7.2 shows the wave drags of a) a body of revolution b) a wing body combination without area ruling and c) a wing body combination with area ruling. Fig.7.3 presents a practical application of this principle.

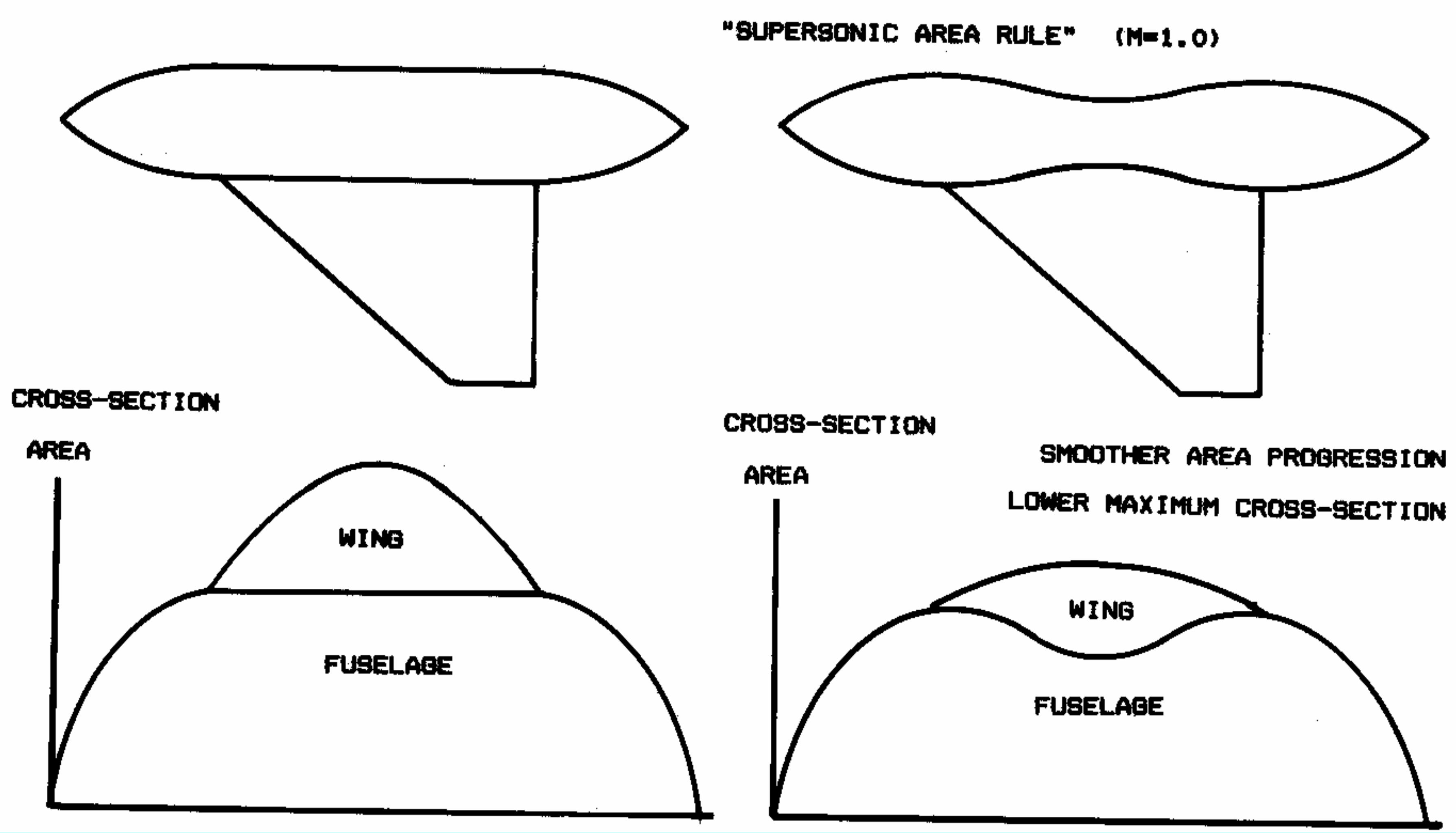
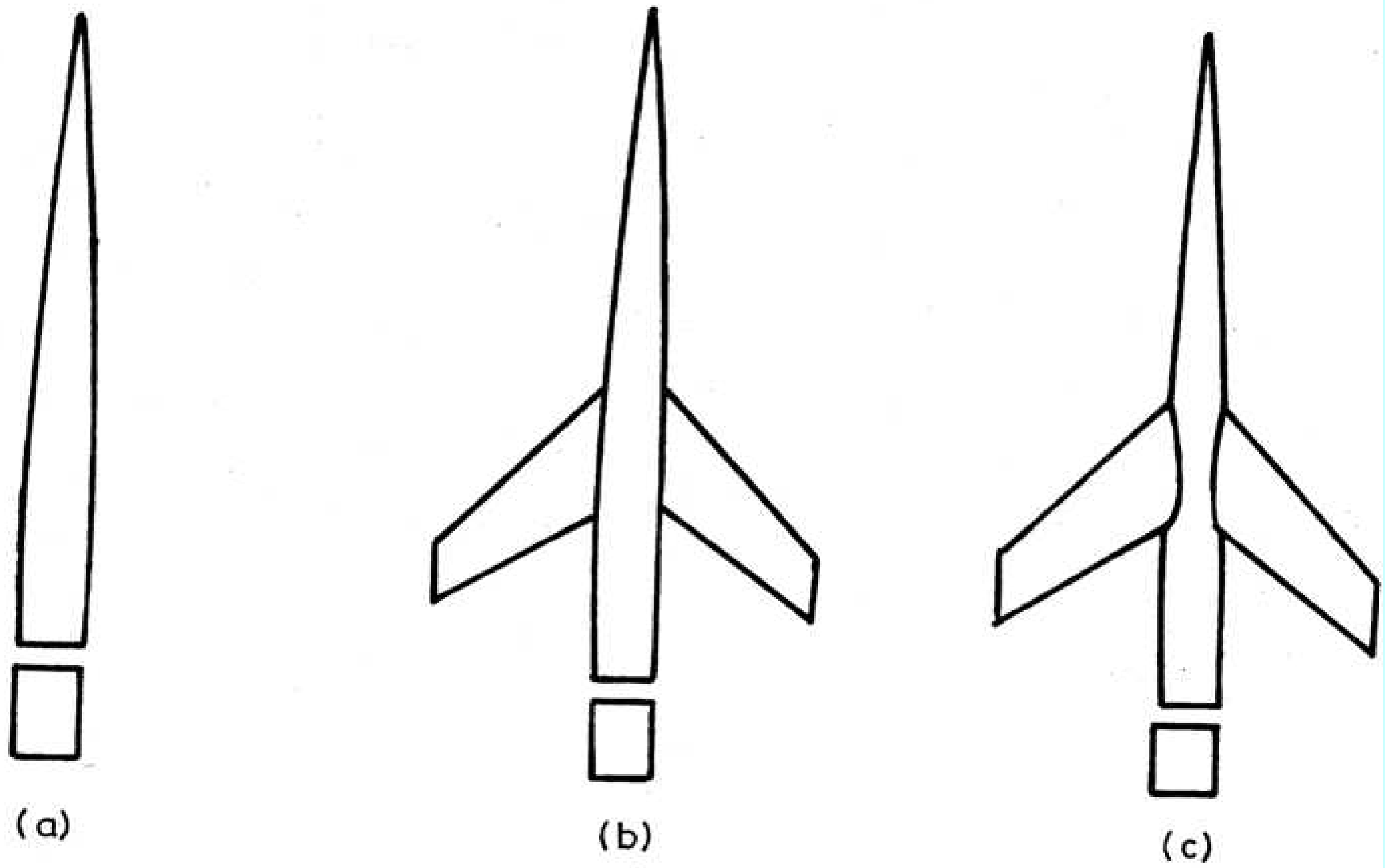


Fig 7.1 Design for low wave drag
(Adapted from Ref.1.11, chapter 8)



C_{Dwave}=0.0035 0.0085 0.0045

Fig 7.2 Reduction in wave drag due to area-rule

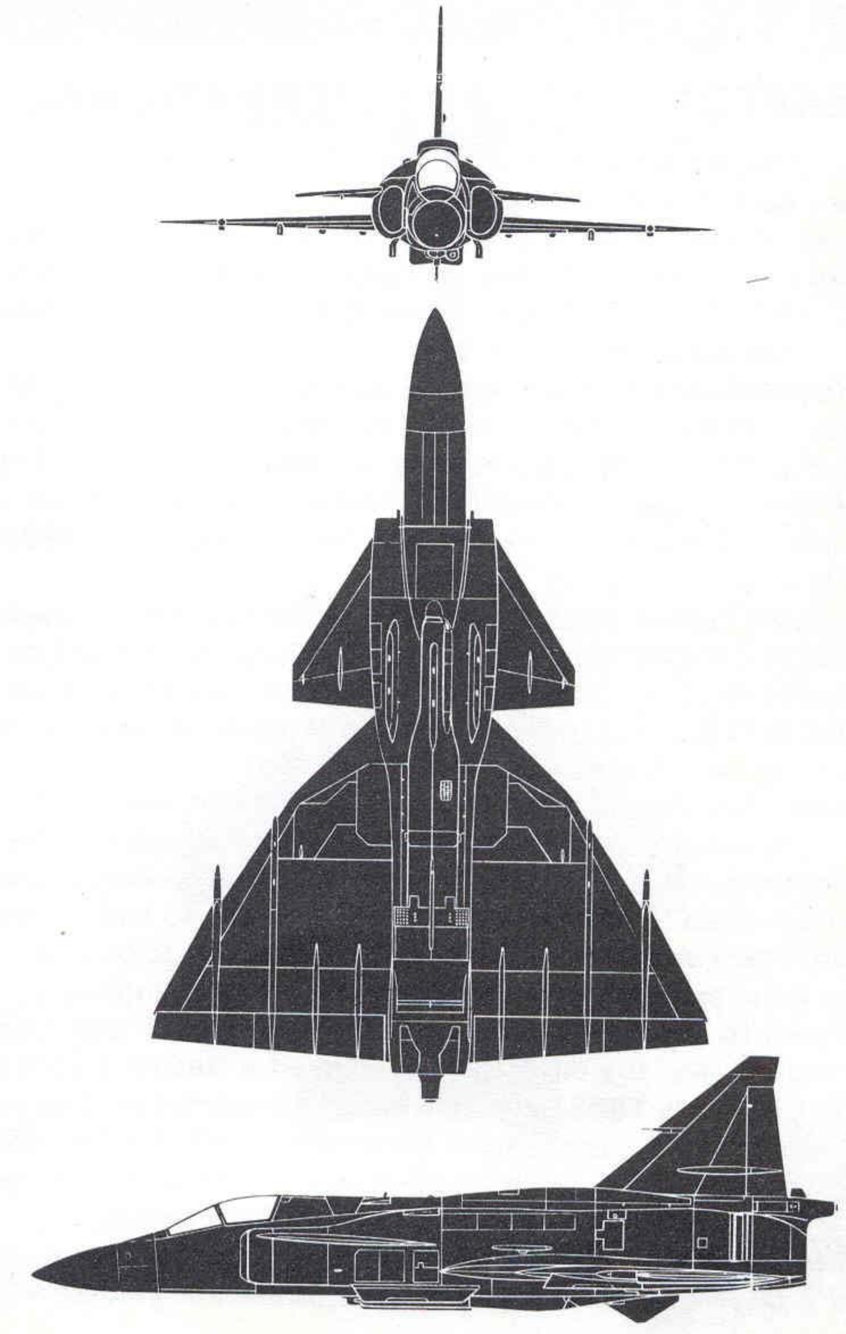


Fig 7.3 **SAAB VIGGEN** (Adapted from Ref.7.1, p.189)

7.3. Structural considerations

Primary concern in the design process is to obtain an airplane with low structural weight. This is achieved by provision of efficient load path i.e. structural elements by which the opposing forces are connected.

It may be recalled that the structural members are of the following types.

a) Struts which take tension

b) Columns which take compressive load

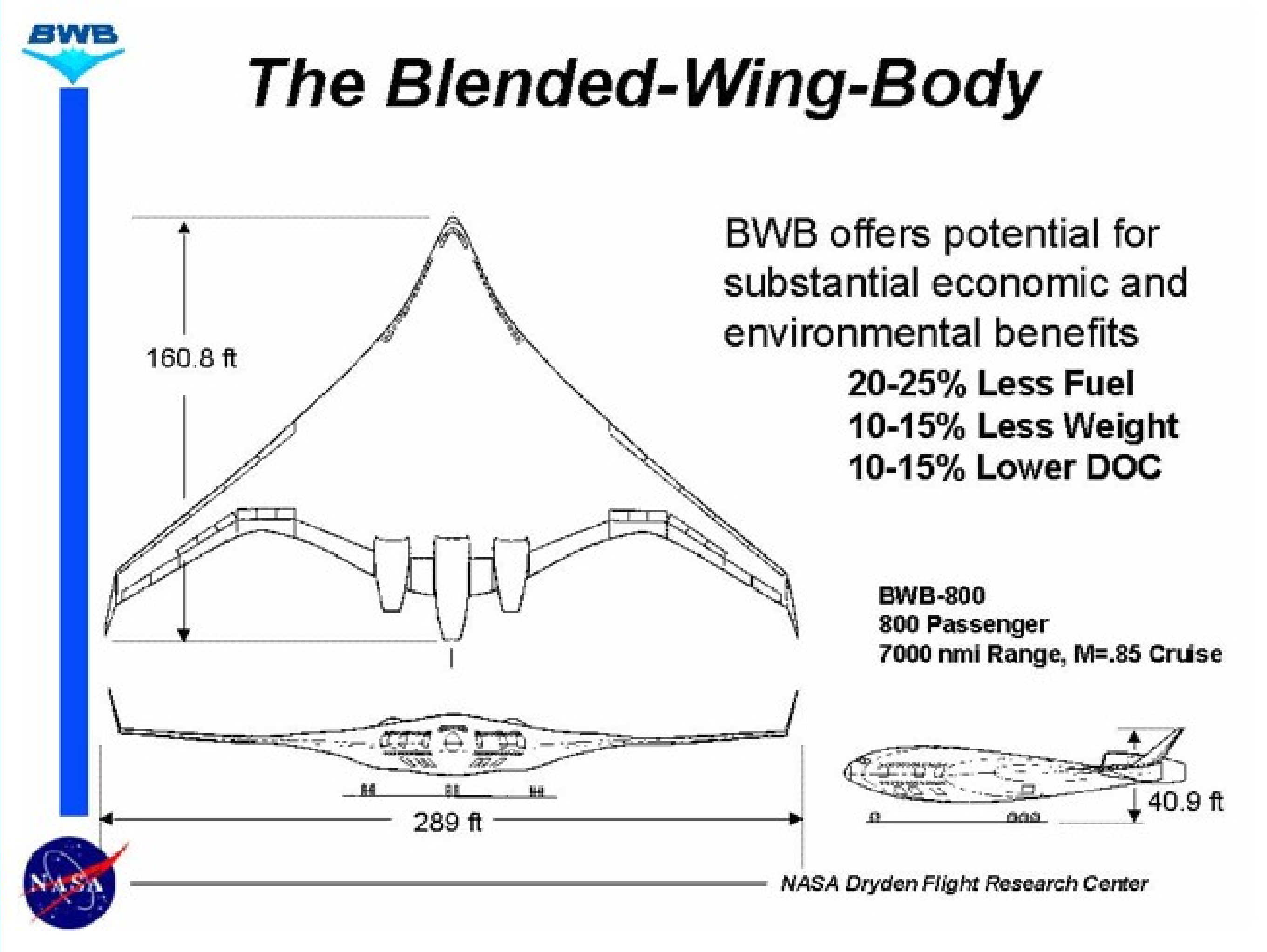
c) Beams which transfer normal loads

d) Shafts which transmit torsion

e) Levers which transfer the load along with change of direction.

The most efficient way of transmitting the load is when the force is transmitted in an axial direction.

In the case of airplane the lift acts vertically upwards and the weights of various components and the payload act vertically downwards. In this situation the sizes and weights of structural members are minimized or the structure is efficient if opposing forces are aligned with each other. This has led to the flying wing or blended wing-body concept (Fig.7.4) in which the structural weight is minimized as the lift is produced by the wing and the entire weight of the airplane is also in the wing.



The Blended-Wing-Body

BWB offers potential for substantial economic and environmental benefits

- **20-25% Less Fuel**
- **10-15% Less Weight**
- **10-15% Lower DOC**

BWB-800
800 Passenger
7000 nmi Range, M=.85 Cruise

NASA Dryden Flight Research Center

Fig.7.4 Blended-wing-body concept
(Source: NASA Website)

However in a conventional airplane the payload and systems are in the fuselage. The wing produces the lift and as a structural member it behaves like a beam. Hence to reduce the structural weight the fuel tanks, engines and landing gears are located on the wing, as they act as relieving load.

Reduction in number of cutouts and access holes, consistent with maintenance requirements , also reduces structural weight.

Remark :

Equation 5.1 shows that the weight of the wing is reduced with high thickness ratio, low aspect ratio, no sweep and high taper ratio. Some of these requirements are in conflict with aerodynamic considerations.

This has led to different wing geometries for airplanes with different flight Mach number. For example, low speed airplanes have moderate aspect ratio, high thickness ratio, taper ratio between 0.3 to 0.5 and no sweep. High subsonic jet airplanes have moderate aspect ratio, moderate thickness ratio, moderate sweep and taper ratio around 0.2. Supersonic airplanes have highly swept or delta wings. For efficient performance at various flight Mach numbers, variable sweep has also been used.

7.4 Crashworthiness:

During a crash, parts of airplane would break loose and fly forward. Hence heavy items should not be located behind and above the passengers.

Landing gear and engine nacelles may get ripped away during a crash. Hence, they should be located such that they do not rip open fuel tanks. Lower portion of fuselage should be such that it does not dig into ground.

See also Ref.1.11, sec 8.9 and Ref.1.13, chapters 4 and 5. In the case of passenger airplanes emergency exits and evacuation system need to be provided.

7.5 Producibility or manufacturing considerations:

The cost of an airplane is generally proportional to its weight. However, factors like material chosen, fabrication processes (machining, forging, molding, welding, finishing etc.), tooling required and assembly man-hours also influence the cost. Hence ease of fabrication is an important consideration in design of an airplane.

Some of the suggestions(Ref.1.11,chapter 8) are :

(i) There should be commonality of parts e.g. left and right landing gear, left and right halves of tail, ailerons etc., should be identical.

(ii) Forgings are expensive and should be reduced in number.

(iii) Installations of internal components, hydraulic lines, electrical wiring, cooling ducts need careful layout to avoid excessive cost.

(iv) For convenience an airplane is built from sub-assemblies. This needs incorporation of suitable subdivisions and allocation of parts to different sub-assemblies. This requires an adequate knowledge of structural design, fabrication techniques and principles of operation of major subsystems.

(v) Use of CAD/CAM techniques require standardization of drawings and processes.

(vi) Components made of FRP materials are lighter but need altogether different manufacturing techniques than the metal components.

7.6 Maintainability

Airplane being a costly vehicle the general policy is to carry out periodical maintenance and not wait for break down. Different parts of the airplane have different service life. Hence, inspection and maintenance are carried out after a specified number of hours of flight. To carry out these, proper access doors need to be provided. However, such cutouts increase structural weight and a proper compromise is required. Civil airplanes also require ground servicing, the lay out of the airplane should enable low turn-around time for items like re-fuelling, fresh water replenishment, re-supply of food, toilet servicing, cabin cleaning and cargo/baggage handling (see Fig.7.5).

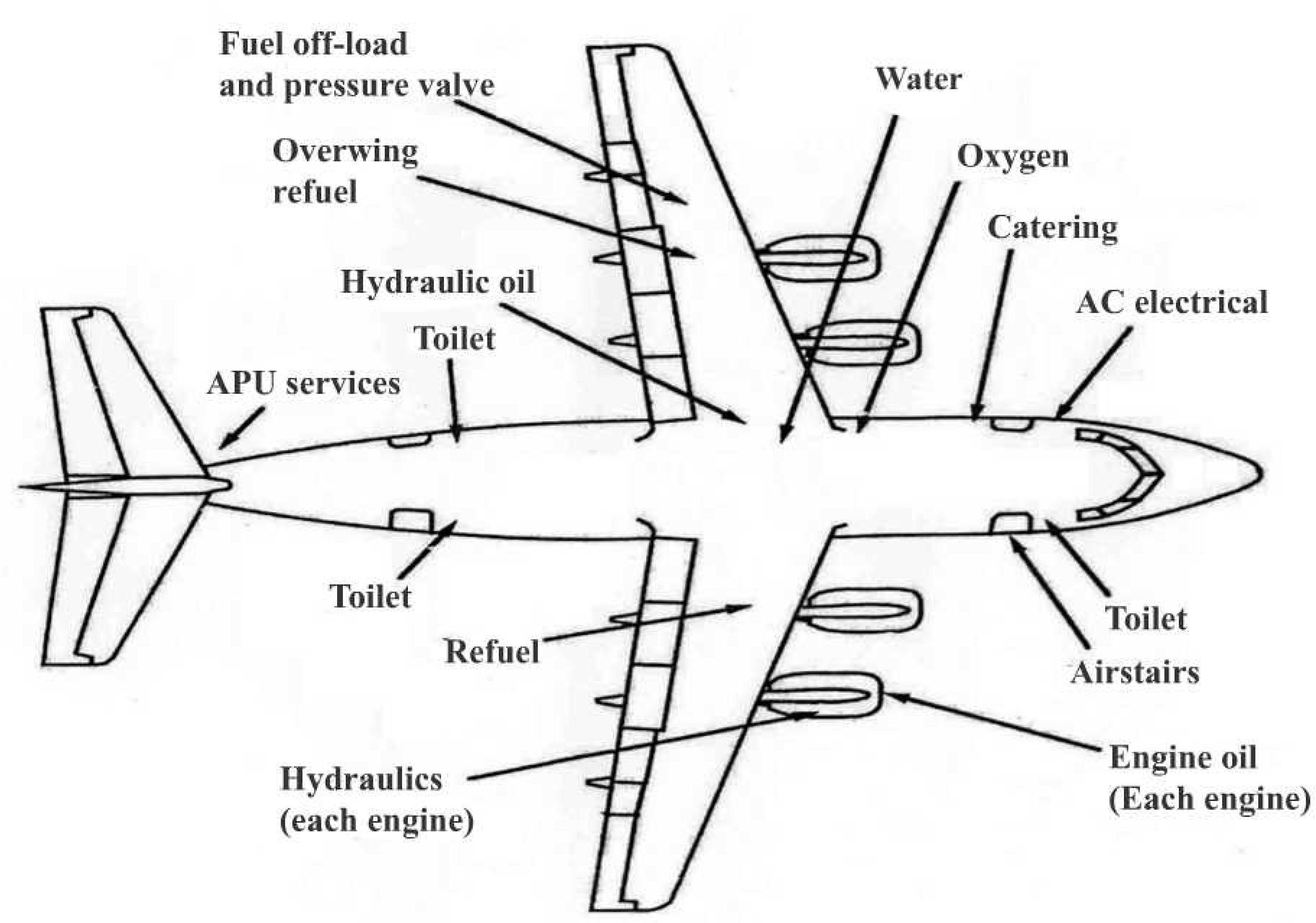


Fig.7.5 Ground service requirements
(Adapted from Ref.1.13, chapter 3)

7.7 Environmental consideration

In recent years the factors like aircraft noise, emissions and ecological effects have acquired due importance and begun to influence airplane layout. Based on Ref.1.13,chapter 4 the following remarks can be made

7.7.1 Aircraft Noise

Noise during the arrival and departure of the airplane affects the community around the airport. In 1994 , ICAO (International Civil Aviation Organization) and later FAR (Federal Aviation Regulation) prescribed limits on noise level at three different points near the airport (see Ref.1.13,chapter 4 for details).

The noise is generated by the following parts.

a) The engines ,
b) Parts of the airframe like control surfaces, high lift devices which significantly change the airflow direction.
c) Projections in airflow like landing gear and spoilers.

Considerable research has been carried out to reduce the engine noise. High by-pass ratio engines with lobed nozzle have significantly lowered the noise level.

Noise level inside the cabin has to be minimal. This is achieved by suitable noise insulation.

Further the clearance between cabin and the propeller should not be less than the half of the radius of the propeller.

7.7.2 Emissions :

Combustion of the fuel in an engine produces carbon dioxide, water vapor, various oxides of Nitrogen (NOx), carbon monoxide, unburnt hydrocarbons and sulphur dioxide (SO_2). The components other than carbon dioxide and water vapor are called pollutants. ICAO has prescribed acceptable limits of pollutants (grams of pollutant per kg of fuel burnt) . The thrust setting changes during the flight and hence the emission levels have to be controlled during landing, take-off and climb segment up to 3000 ft (1000m) . At high altitudes the NOx components may deplete ozone layer. Hence supersonic airplanes may not be allowed to fly above 50000 ft (15 km) altitude. It may be noted that cruising altitude for Concorde was 18 km. Improvements in engine design have significantly reduced the level of pollutants.

The amount of pollution caused by air transport is negligible as compared to that caused by road transport, energy generation and industry.

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However the aircraft industry has always been responsive to the ecological concerns and newer technologies have emerged in the deign of engine and airframe.

7.8. Considerations for military airplanes

These airplanes need special considerations like radar, infrared and visual detectability and vulnerability.

7.8.1 Radar detectability :

A radar installation consists of a transmitter antenna that sends a directed beam of electromagnetic wave and receiver antenna which picks up the faint radio waves that bounce off the object. The extent to which an object returns electromagnetic energy is a measure of its "Radar cross section (RCS)". Following may be remarked.

(i) Radar signal strength is inversely proportional to the 4th power of distance of the target. It takes substantial reduction in RCS to obtain operational benefit.

(ii) RCS depends on "look angle" i.e. the direction from threat radar.

(iii) Following factors contribute to RCS .

(a) Flat surfaces perpendicular to incoming radar beams for example flat sides of fuselage.

(b) Leading edges.

(c) Inlet and exhaust cavities of engine.

(d) Discontinuities in surface.

(iv) Stealth technology :

The ways to reduce RCS are referred to as stealth technology. This calls for proper shaping of the airplane,- buried engines (no nacelles), -flying wing; intakes on top of the airplane, exhaust with 2 –D nozzles. Use of radar beam absorbing materials like composites and special paints also reduces RCS (see Fig.1.10 for B-2 stealth bomber)

7.8.2 Infrared detectability:

Guidance of air-to-air and ground-to-air missiles is many times based on seeking source of infrared (IR) radiation. Following are the sources of IR

(i) Engine exhaust

(ii) Hot parts of airplane. Heating being caused by aerodynamic heating, at high speeds.

(iii) Solar IR radiation reflected by skin and cockpit.

The Radiation from engine exhaust can be reduced in the following manner.

(i) Having bypass engine

(ii) Increased mixing and lower temperature by using 2-D nozzle.

7.8.3 Visual detectability:

Visual detection depends on the size of the airplane and color. Aircraft can also be detected in night by glow of engine exhaust. Camouflage schemes are used to avoid detection.

7.8.4 Vulnerability:

Vulnerable area or component is that which when struck by a weapon will cause the aircraft to be lost. Following considerations reduce vulnerability .

(i) Fuel should not be stored over or around engines and inlet ducts.

(ii) Hydraulic lines and reservoirs should be away from engine.

(iii) Engine bays, fuel bays & weapons bay should have fire suppressing systems.

(iv) In twin- engined airplane there should be enough separation between engines to prevent damage to the engine which is not damaged.

(v) Critical components, crew & passengers should not be placed within 5 degrees arc of propeller disc.

(vi) There could be redundancy in important systems like hydraulic, electrical, flight control and fuel systems.

See Ref 7.2 for further details on combat survivability.

7.9 V-n diagram

The discussion in subsequent chapters would involve the load factor ($n=L/w$) . This factor has different values in different flights and a discussion on it is presented with the help of a diagram called V-n diagram. A brief discussion is as follows.

The load factor of (n) is defined as the ratio of lift and weight i.e. $n= L/w$. In level flight $n=1$. However the value of 'n' during a maneuver is greater than one. Hence the structure of the airplane must be designed to withstand the permissible load factor. Further when an airplane encounters a gust of velocity V_{gu} (see Fig.7.6) the angle of attack of the airplane would increase by $\Delta\alpha = V_{gu} /V$. This increase in angle of attack would increase lift (ΔL) by:

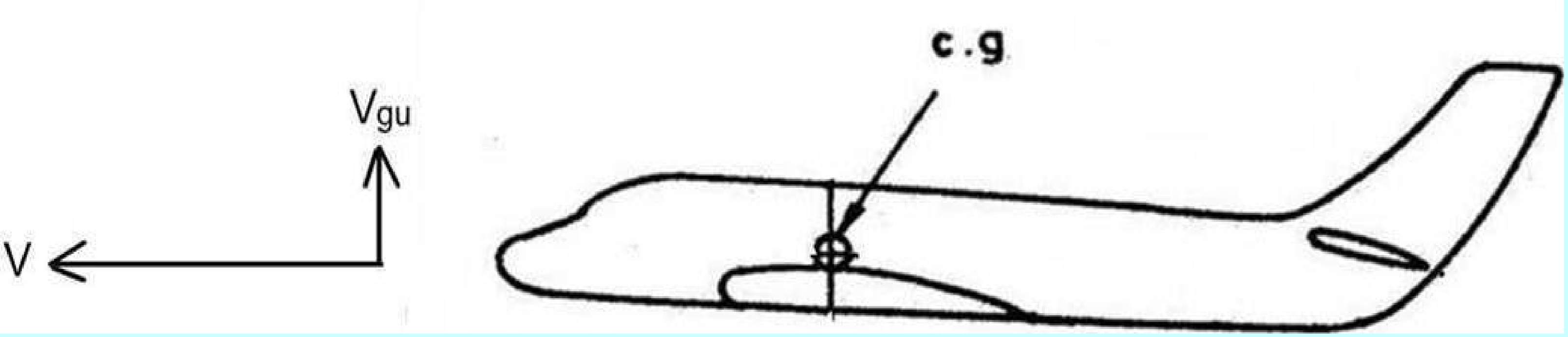

Fig. 7.6 Effect of gust

$\Delta L = \frac{1}{2} \rho V^2 S C_{L\alpha} \Delta\alpha = \frac{1}{2} \rho V^2 S C_{L\alpha} V_{gu}/V$

$= \frac{1}{2} \rho V S C_{L\alpha} V_{gu}$ (7.1)

Thus ΔL increases with V_{gu} and for a given V_{gu} they (ΔL & Δn) are higher at higher flight velocity. An airplane must be designed to withstand these gust loads also.

In aeronautical engineering practice the load factors due to maneuver and gust are indicated by a diagram called velocity-load factor diagram or V-n diagram . A typical V-n diagram is shown in Fig.7.7. This diagram can be explained as follows.

(i) The lift (L) produced by an airplane is given by $L = \frac{1}{2} \rho V^2 S C_L$. Noting that $C_L \leq C_{Lmax}$, we observe that at staling speeds (V_s), L=W and n=1. However if

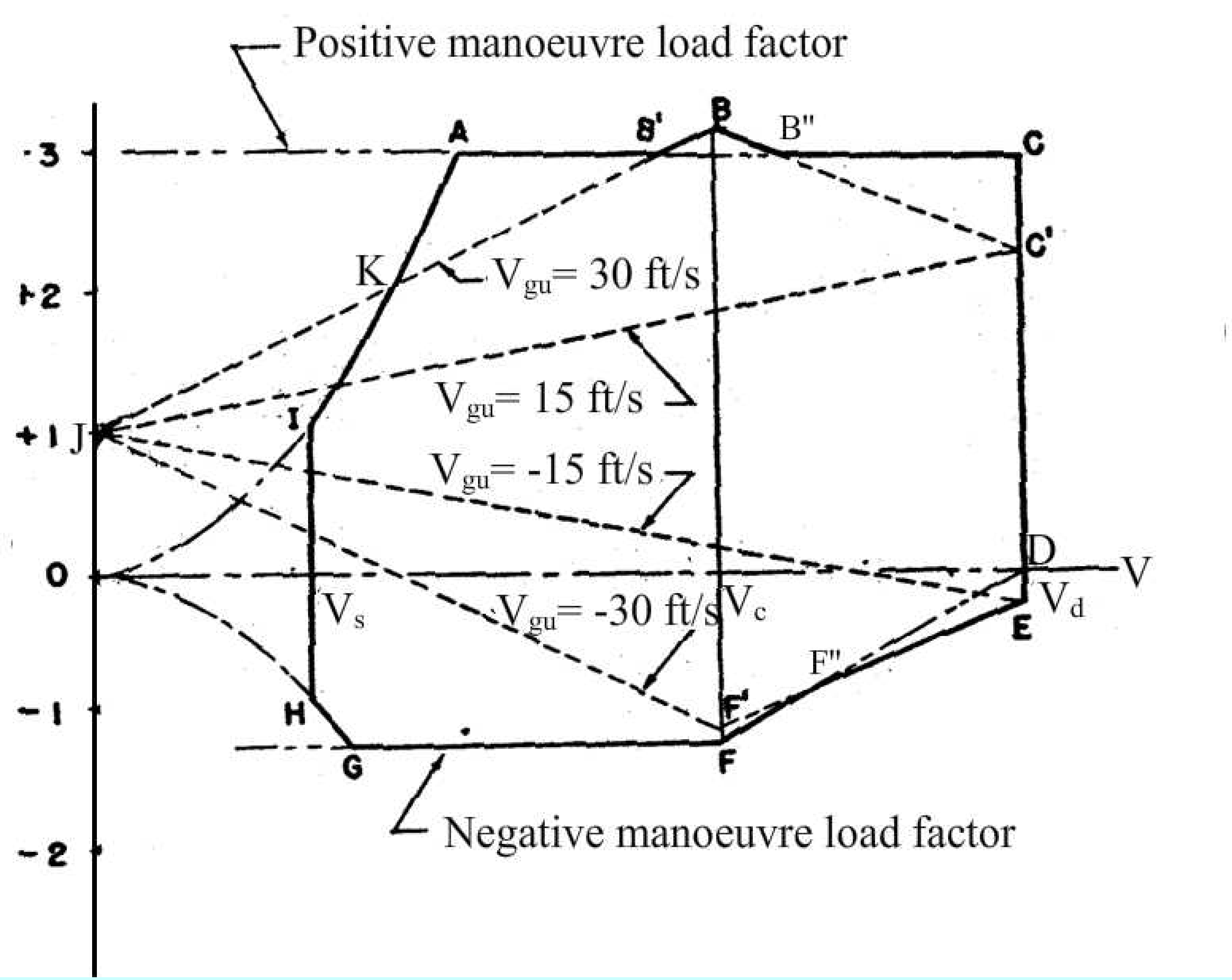

Fig.7.7 A typical V-n diagram
(Adapted from Ref.7.3 , chapter 2)

the airplane is flown with $C_L = C_{Lmax}$ at speeds higher than V_s, then L will be more than W and L or n would be proportional to V^2. This variation is a parabola and is shown by curve OIA in Fig.7.7. In an inverted flight the load factor will be negative and the V vs n curve in such a flight is indicated by the curve OHG in Fig.7.7. It may be mentioned that an airplane can fly only at $V \geq V_s$ and hence the portions IA and HG are shown by solid lines.

(ii) Higher the permissible load factor, heavier will be the airplane structure. Hence for actual airplanes the maneuver load factor is limited depending on its intended use. Federal Aviation Administration (FAA) and other agencies prescribe values of n_{max} for different categories of airplanes (see for example chapter 7 of Ref.4.2). Table 7.1 gives typical limit load factors. The limit load is the load that can be supported by the structure without yielding. The ultimate load factor, in aeronautical practice, is 1.5 times the limit load factor.

Type of airplane	$n_{positive}$	$n_{negative}$
General aviation- Normal	2.5 to 3.8	-1 to -1.5
General aviation- Aerobatic	6	-3
Transport	3 to 4	-1 to -2
Fighter	6.5 to 9	-3 to -6

Table 7. 1 Typical limit load factors

(Adapted from Ref.1.11 , chapter 14)

In Fig.7.7, $n_{positive}$ = 3 and $n_{negative}$ = -1.2 have been chosen; the actual values depend on the weight of the airplane and its category.

(iii) The positive maneuver load factor is prescribed to be constant upto the design diving speed (V_d); line AC in Fig.7.7. According to Ref.1.11, chapter 14, the design diving speed could be 40 to 50% higher than the cruising speed for subsonic airplanes. For supersonic airplanes the Mach number corresponding to V_d could be 0.2 faster than the maximum level flight Mach number.

The negative maneuver load factor is prescribed to be constant upto design cruising speed (line GF in Fig.7.7) and then increases linearly to zero at $V=V_d$ (line FD in Fig.7.7).

(iv) As per Eq.(7.1) the gust load factor varies linearly with velocity. It is prescribed that an airplane should be able to withstand V_{gu}=30 ft/s (9.1 m/s) upto V_c and V_{gu} = 15 ft/s (4.6 m/s) upto V_d (see lines JB', JC' , JF' and JE in Fig.7.7). It may be added that a gust in reality is not a sharp edged gust as shown in Fig.7.6 and the gust load factor is reduced by "Gust alleviation factor" (see Ref.1.11 chapter 14 for details).

(v) For safe operation the airplane must be designed to withstand load factors at all points of the gust and manouever load curves. It may be pointed out that angles of attack are different at various points of the V-n diagram and the structure analysis needs to take this into account. For example the angle of attack is positive and high at point A and it is positive and low at point C. At points G and E the angles of attack are negative.

(vi) The final V-n diagram , satisfying gust and manouever loads, is given by the solid line IAB’BB’’CEF’’FGHI. It may be pointed out that the gust load line JB’ is above the curve IA in the region IK. However along the curve IK the airplane is already operating at C_{Lmax} and any increase in angle of attack due to gust cannot increase C_L beyond C_{Lmax}.

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