Flight Vehicle Design

16BTAR5E07

16BTAR_E07 FLIGHT VEHICLE DESIGN 3 0 0 3 100

OBJECTIVES:
An understanding and experience of design of an aerospace system, mission, or vehicle and Identifying Engineering Problems

UNIT-I REQUIREMENTS OF FLIGHT VEHICLE:

Type, role, mission.Payload, performance and other requirements. Study of comparable aircraft - principal design and constructional and performance. Data collection and statistical analysis.

UNIT-II CONCEPTUAL SKETCH AND FIRST ESTIMATE OF WEIGHT

Conceptual sketch of candidate design- alternative configurations. First estimate of take off weight.Airfoil and wing geometry selection. Estimate of thrust to weight ratio and wing loading.

UNIT-III FUSELAGE AND CONTROL SURFACES

Sizing of Fuselage and control surfaces. And drawing of the configuration. Weight balance

UNIT-IV PERFORMANCE AND STABILITY ESTIMATE

Performance and stability estimate. Load estimates-Air load distribution on the wing. Preliminary structural Layout.

UNIT-VFLIGHT CONTROL SYSTEM

Flight control system, Landing Gear and subsystem, Propulsion and Fuel system integration, Air pressurization and air conditioning system, Electrical & Avionic system

TEXT BOOKS

S.NO.	AUTHOR(S)	TITLE OF THE BOOK	PUBLISHER	YEAR OF PUBLICATION
1.	Raymer, Daniel P.	Aircraft Design: Conceptual Approach	AIAA Educational Series	2013
2.	Torenbeek E	Synthesis of Subsonic Airplane Design	Delft University Press	1986

REFERENCES BOOKS:

S.NO.	AUTHOR(S)	TITLE OF THE BOOK	PUBLISHER	YEAR OF PUBLICATION
1.	Egbert Torenbeek	Advanced Aircraft Design: Conceptual Design, Technology and Optimization of Subsonic Civil Airplanes	John Wiley & Sons	2013
2.	Bruhn. E.H,	Analysis and Design of Flight Vehicles Structures,	tri -state off set company	1965
3.	Scheler.E.E and Dunn L.G,	Airplane Structural Analysis and Design	John Wiley & Sons	1963

WEB REFERENCES:

highered.mheducation.com/.../6eCh10**FlightVehicleS**tructuresAndMateri

https://courses.cit.cornell.edu/mae5070/Introduction.pdf

https://courses.cit.cornell.edu/mae5070/Caughey_2011_04.pdf
https://www.cranfield.ac.uk/courses/.../aerospace-**vehicle-design**.html
en.wikipedia.org/wiki/Flying_car_(aircraft)

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FACULTY OF ENGINERRING
DEPARTMENT OF MECHANICAL ENGINEERING (Aerospace)

COURSE PLAN

Subject Name : **FLIGHT VEHICLE DESIGN**
Subject Code : **16BTAR5E07** **(Credits - 3)**
Name of the Faculty : **ARUN PRAKASH.J**
Designation : **ASSISTANT PROFESSOR**
Year/Semester/Section : **III Year/V SEM**
Branch : **B.Tech Aerospace Engineering**

Sl. No.	No. of Periods	Topics to be Covered	Support Materials
UNIT – I : REQUIREMENTS OF FLIGHT VEHICLE			
1.	1	Introduction to the course	
2.	1	Types of Flight Vehicles	T [1] ,R [1] ,R [2]
3.	1	Classifications based on role, mission and Payload	T [1] ,R [1] ,R [2]
4.	1	Flight performance and other requirements.	T [1] ,R [1] ,R [2]
5.	1	Study of comparable aircraft	T [1] ,R [1] ,R [2]
6.	2	Principal design	T [1] ,R [1] ,R [2]
7.	1	Constructional performance.	T [1] ,R [1] ,R [2]
8.	1	Data collection	T [1] ,T [2]] ,R [1]
9.	1	Statistical analysis.	T [1] ,T [2]] ,R [1]
Total No. of Hours Planned for Unit - I			**10**

Sl. No.	No. of Periods	Topics to be Covered	Support Materials
UNIT – II : CONCEPTUAL SKETCH AND FIRST ESTIMATE OF WEIGHT			
10.	1	Conceptual Design Process	T [3] ,R [1] ,R [2]
11.	1	Sizing from a Conceptual Sketch	T [3] ,R [1] ,R [2]
12.	1	Configuration Layout	T [3] ,R [1] ,R [2]

13.	1	Special Considerations in Configuration Layout	
14.	1	Alternative configurations	T [3] ,R [1] ,R [2]
15.	1	First estimate of takeoff weight	T [3] ,R [1] ,R [2]
16.	1	Airfoil geometry selection	T [3] ,R [1] ,R [2]
17.	1	Wing geometry selection	T [3] ,R [1] ,R [2]
18.	1	Estimate of thrust to weight ratio	T [3] ,R [1] ,R [2]
19.	1	Wing loading.	T [3] ,R [1] ,R [2]
Total No. of Hours Planned for Unit - II			**9**

Sl. No.	No. of Periods	Topics to be Covered	Support Materials
UNIT – III : FUSELAGE AND CONTROL SURFACES			
20.	1	Sizing of Fuselage	T [3] ,R [1] ,R [2]
21.	1	Crew Station, Passengers, and Payload considerations	T [3] ,R [1] ,R [2]
22.	1		T [3] ,R [1] ,R [2]
23.	1		T [3] ,R [1] ,R [2]
24.	1	Sizing of control surfaces	T [3] ,R [1] ,R [2]
25.	1	Final configuration diagram.	T [3] ,R [1] ,R [2]
26.	1	Structures and Loads	T [3] ,R [1] ,R [2]
27.	1	Aircraft Weights	T [3] ,R [1] ,R [2]
28.	1	Weight balance	T [3] ,R [1] ,R [2]
Total No. of Hours Planned for Unit - III			**9**

Sl. No.	No. of Periods	Topics to be Covered	Support Materials
UNIT – IV : PERFORMANCE AND STABILITY ESTIMATE			
29.	1	Performance estimate for Aircraft	T [3] ,R [1] ,R [2]
30.	1	Aerodynamics of Aircraft	T [3] ,R [1] ,R [2]
31.	1	Propulsion System of Aircraft	T [3] ,R [1] ,R [2]
32.	1	Performance Measures of Merit	T [3] ,R [1] ,R [2]
33.	1	Stability estimate for Aircraft	T [3] ,R [1] ,R [2]
34.	1	Handling Qualities	T [3] ,R [1] ,R [2]
35.	1	Load estimates-	T [3] ,R [1] ,R [2]
36.	1	Air load distribution on the wing.	T [3] ,R [1] ,R [2]
37.	1	Preliminary structural Layout.	T [3] ,R [1] ,R [2]
Total No. of Hours Planned for Unit - IV			**9**

Sl. No.	No. of Periods	Topics to be Covered	Support Materials

UNIT – V : FLIGHT CONTROL SYSTEM			
38.	1	Flight control system Design	T [3] ,R [1] ,R [2]
39.	1	Propulsion and Fuel System Integration	T [3] ,R [1] ,R [2]
40.	1	Landing Gear	T [3] ,R [1] ,R [2]
41.	1	Landing Gear Subsystems	T [3] ,R [1] ,R [2]
42.	1	Air pressurization System	T [1], T [2], R [1]
43.	1	Air conditioning system	T [1], T [2], R [1]
44.	1	Electrical System	T [1], T [2], R [1]
45.	1	Avionics system	T [1], T [2], R [1]
46.	1	Conceptual Design Examples	T [1], T [2], R [1]
47.	1	Previous Year Question paper Discussion	
Total No. of Hours Planned for Unit - V			**9+1**

TOTAL PERIODS : 47

TEXT BOOKS

T [1] – Aircraft Design: Conceptual Approach- Raymer, Daniel P.
T [2] - Synthesis of Subsonic Airplane Design - Torenbeek E
T [3] - Flight without Formulae – Kermode A.C.

REFERENCES

R [1] - Advanced Aircraft Design: Conceptual Design, Technology and Optimization of Subsonic Civil Airplanes – Torenbeek E
R [2] - Airplane Structural Analysis and Design – Scheler.E.E and Dunn L.G,

JOURNALS

J [1] - Aerospace Science and Technology - Journal - Elsevier
J [2] –Journal of Aerospace Engineering | ASCE Library
J [3] –The Aeronautical Journal - Royal Aeronautical Society

UNIT	Total No. of Periods Planned	Lecture Periods	Tutorial Periods
I	10	10	-
II	9	9	-
III	9	9	-
IV	9	9	-
V	9+1	9	-
TOTAL	47	46	-

I. CONTINUOUS INTERNAL ASSESSMENT : 40 Marks

(Internal Assessment Tests: 30, Attendance: 5, Assignment/Seminar: 5)

II.	**END SEMESTER EXAMINATION**	**: 60 Marks**
	TOTAL	**: 100 Marks**

FACULTY	**COORDINATOR/ AERO**	**HOD / MECH**	**DEAN / FOE**

UNIT I

Introduction

Design

Design is the creation of a plan or convention for the construction of an object, system or measurable human interaction (as in architectural blueprints, engineering drawings, business processes, circuit diagrams, and sewing patterns). Design has different connotations in different fields (see design disciplines below). In some cases, the direct construction of an object (as in pottery, engineering, management, coding, and graphic design) is also considered to use design thinking.

Another definition for design is "a roadmap or a strategic approach for someone to achieve a unique expectation. It defines the specifications, plans, parameters, costs, activities, processes and how and what to do within legal, political, social, environmental, safety and economic constraints in achieving that objective."

Aircraft design process

The aircraft design process is the engineering design process by which aircraft are designed. These depend on many factors such as customer and manufacturer demand, safety protocols, physical and economic constraints etc. For some types of aircraft the design process is regulated by national airworthiness authorities. This article deals with powered aircraft such as airplanes and helicopter designs.

Aircraft design is a compromise between many competing factors and constraints and accounts for existing designs and market requirements to produce the best aircraft.

Flight performance and other requirements.

These requirements set up numerical values for the main performance characteristics of the designed airplane.

These are usually

- Flight velocity and altitude,
- Design range,
- Rate of climb, Steady Climbing and Descending Flight . .
- Level Turning Flight
- Gliding Flight
- Operating Envelope
- Take-off and landing characteristics,
- Design and operating g-loads (load factor)
- Other Fighter Performance Measures of Merit

The numerical values of performance characteristics should be based on statistics and take into account the forecasted development for such airplane type.

It can be aided by making diagrams that show the relations between parameters: velocity - range, flight altitude - range and etc., and also diagrams that show the change of performance characteristics for prototype airplanes according to their time of production.

The forecasting of parameter values should be executed by finding the trend functions and their extrapolation for the next few years.

For PR the numerical values of each performance parameter should be set up within the range "from-to", or below the upper limit "no more than", or above the lower limit "no less than". It‟s not recommended to set up the certain value for a parameter.

Topics to be considered

1. Introduction to aerodynamics
2. Atmosphere through which aircraft flies
3. Useful equations
4. Airflow behavior past a body; viscosity and boundary layer concepts introduced to explain drag
5. Aircraft motion and the forces acting on it
6. Aerofoil definition and classification
7. Definition of relevant aerodynamic coefficients (e.g., CL, CD)
8. Lift generation, aerodynamic center, and center of pressure
9. Types of stall
10. Comparison of aerofoils and selection of appropriate choice
11. Introduction to high-lift devices
12. Transonic effects (area rule)
13. Wing aerodynamics (3D geometry)
14. Aspect ratio correction (2D to 3D)
15. Wing planform reference area definition, dihedral angle
16. Mean aerodynamic chord
17. Compressibility effect
18. Wing stall and twist
19. Influence of wing area and span on aerodynamics
20. Finalizing wing design parameters
21. Empennage, tail volume definition, canard
22. Fuselage
23. Undercarriage
24. Nacelle and intake
25. Speed and dive brakes

Various types of aircraft configurations.

This classification is based on the following features of the configuration.

a) Shape, number and position of wing.

b) Type of fuselage.

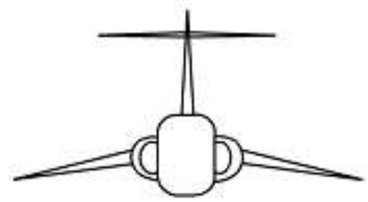
c) Location of horizontal tail.

d) Location and number of engines.

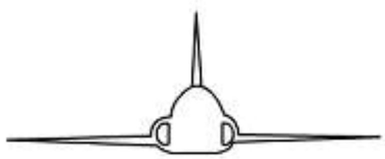
The different types of configurations are :

(a) Semi-cantilever monoplane

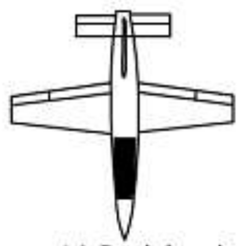
(b) Catilever high wing monoplane



(c) Cantilever midwing monoplane

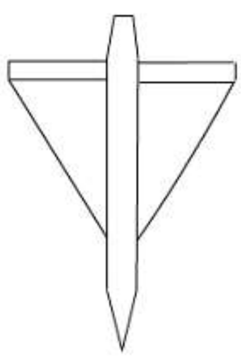


(d) Cantilever low wing monoplane

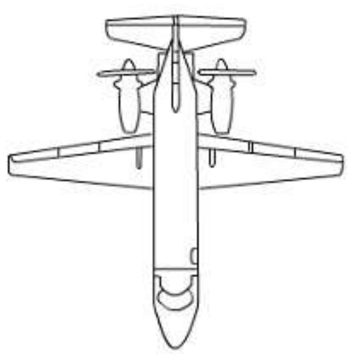


(e) Straight wing monoplane

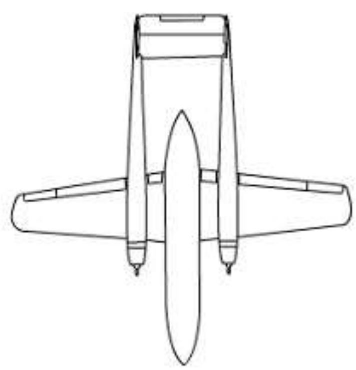
(f) Swept wing monoplane



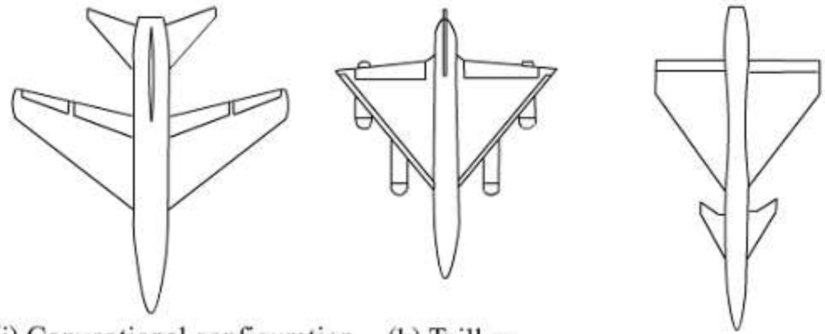
(g) Cropped delta wing monoplane



(h) Conventional single fuselage



(i) Pod and boom configuration



(j) Conventional configuration (tail behind wing) (k) Tailless configuration (l) Canard configuration

Classification of airplanes based on wing configuration

Early airplanes had two or more wings e.g. the Wright airplane (Fig.1.3) had two wings braced with wires. Presently only single wing is used. These airplanes are called monoplanes. When the wing is supported by struts the airplane is called semicantilever monoplane (Fig.1.2a). Depending on the location of the wing on the fuselage, the airplane is called high wing, mid-wing and low wing configuration (Fig.1.2b, c and d). Further, if the wing has no sweep the configuration is called straight wing monoplane (Fig.1.2e). The swept wing and delta wing configurations are shown in Figs.1.2f and g.

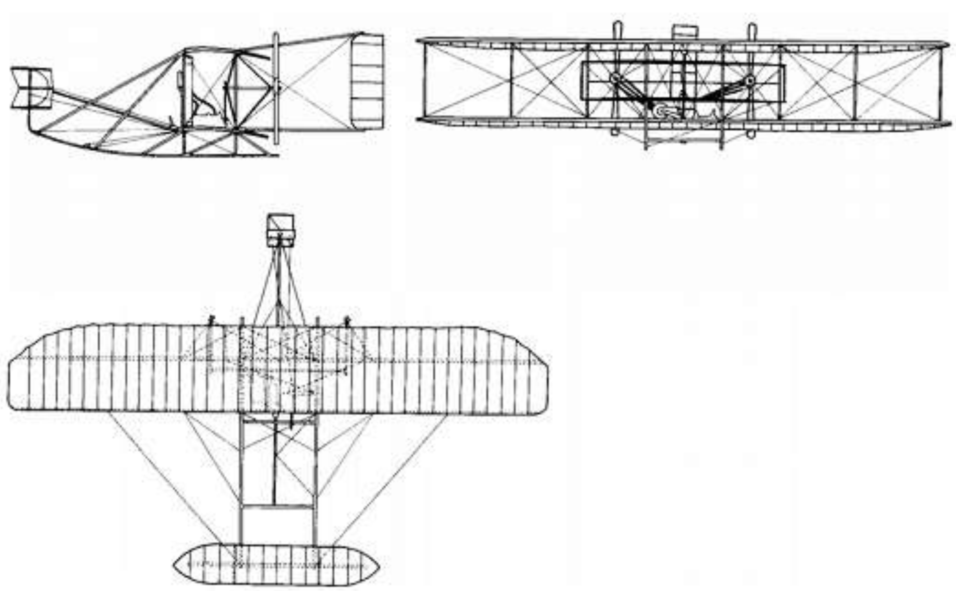


Fig.1.3 Wright flyer

Classification of airplanes based on fuselage

Generally airplanes have a single fuselage with wing and tail surfaces mounted on the fuselage (Fig.1.2 h). In some cases the fuselage is in the form of a pod. In such a case, the horizontal tail is placed between two booms emanating from the wings (Fig.1.2i). These airplanes generally have two vertical tails located on the booms. The booms provide required tail arm for the tail surfaces. Some airplanes with twin fuselage had been designed in the past. However, these configurations are not currently favoured.

Classification of airplanes based on horizontal stabilizer

In a conventional configuration, the horizontal stabilizer is located behind the wing (Fig.1.2j). In some airplanes there is no horizontal stabilizer and the configuration is called tailless design (Fig.1.2k). In these airplanes, the functions of elevator and aileron are performed by ailevons located near the wing tips. When both ailevons (on left and right wings) move in the same direction, they function as elevators and when the two ailevons move in opposite direction, they function as ailerons. In some airplanes, the control in pitch is obtained by a surface located ahead of the wing. This configuration is called canard configuration (Fig.1.2l). In conventional configuration the horizontal tail has a negative lift and the total lift produced by the wing is more than the weight of the airplane. In canard configuration, the lift on the canard is in the upward direction and lift produced by the wing is less than the weight of the aircraft. However, the canard has destabilizing contribution to the longitudinal stability.

Classification of airplanes based on number of engines and their location

Airplanes with one, two, three or four engines have been designed. In rare cases, higher number of engines are also used. The engine, when located in the fuselage, could be in the nose or in the rear portion of the fuselage. When located outside the fuselage the engines are enclosed in nacelles, which could be located on the wings or on the rear fuselage (see section 6.6 for further details). In case of airplanes with engine-propeller combination, there are two configurations – tractor propeller and pusher propeller. In pusher configuration the propeller is behind the engine (Fig.1.2h). In tractor configuration the propeller is ahead of the engine(Fig.1.4).

Requirements for Military Aircrafts.

Military aircraft, any type of aircraft that has been adapted for military use. Aircraft have been a fundamental part of military power since the mid-20th century. Generally speaking, all military aircraft fall into one of the following categories: fighters, which secure control of essential airspaces by driving off or destroying enemy aircraft; bombers, which are larger, heavier, and less-maneuverable craft designed to attack surface targets with bombs or missiles; ground-support, or attack, aircraft, which operate at lower altitudes than bombers and air-superiority fighters and attack tanks, troop formations, and other ground targets; transport and cargo planes, big-bodied craft with large amounts of interior space for carrying weapons, equipment, supplies, and troops over moderate or long distances; helicopters, which are rotary-winged aircraft used for ground support, for transporting assault troops, and for short-distance transport and surveillance; and unmanned aerial vehicles, which are remotely controlled or autonomously guided aircraft that carry sensors, target designators, electronic transmitters, and even offensive weapons.

Combat aircraft

Combat aircraft, or "Warplanes", are divided broadly into multi-role, fighters, bombers, attackers, and electronic warfare support.

Variations exist between them, including fighter-bombers, such as the MiG-23 ground-attack aircraft and the Soviet Ilyushin Il-2 Sturmovik. Also included among combat aircraft are long-range maritime patrol aircraft, such as the Hawker Siddeley Nimrod and the S-3 Viking that are often equipped to attack with anti-ship missiles and anti-submarine weapons.

Fighter aircraft

The primary role of fighters is destroying enemy aircraft in air-to-air combat, as part of both offensive and defensive counter air operations. Many fighters also possess a degree of ground attack capability, allowing them to perform surface attack and close air support missions. In addition to their counter air duties they are tasked to perform escort mission for bombers or other aircraft. Fighters are capable of carrying a variety of weapons, including machine guns, cannons, rockets, guided missiles, and bombs. Many modern fighters can attack enemy fighters from a great distance, before the enemy even sees or detects them. Examples of fighters include the F-22 Raptor, F-15 Eagle, and Su-27.

Bomber aircraft

Bombers are normally larger, heavier, and less maneuverable than fighter aircraft. They are capable of carrying large payloads of bombs, torpedoes or cruise missiles. Bombers are used almost exclusively for ground attacks and not fast or agile enough to take on enemy fighters head-to-head. A few have a single engine and require one pilot to operate and others have two or more engines and require crews of two or more. A limited number of bombers, such as the B-2 Spirit, have stealth capabilities that keep them from being detected by enemy radar. An example of a conventional modern bomber would be the B-52 Stratofortress. An example of a World War II bomber would be a B-17 Flying Fortress. Bombers include light bombers, medium bombers, heavy bombers, dive bombers, and torpedo bombers.

Attack aircraft

Attack aircraft can be used to provide support for friendly ground troops. Some are able to carry conventional or nuclear weapons far behind enemy lines to strike priority ground targets. Attack helicopters attack enemy armor and provide close air support for ground troops. An example historical ground-attack aircraft is the Soviet Ilyushin Il-2 Shturmovik. Several types of transport airplanes have been armed with sideways firing weapons as gunships for ground attack. These include the AC-47and AC-130 aircraft.

Electronic warfare aircraft

An electronic warfare aircraft is a military aircraft equipped for electronic warfare (EW) - i.e. degrading the effectiveness of enemy radar and radio systems. They are generally modified versions of other pre-existing aircraft. A recent example would be the Boeing EA-18G Growler, which is a modified version of the Boeing F/A-18F Super Hornet.

Maritime patrol aircraft

A maritime patrol aircraft fixed-wing military aircraft designed to operate for long durations over water in maritime patrol roles—in particular anti-submarine, anti-ship and search and rescue. Some patrol aircraft were designed for this purpose, like the Kawasaki P-1. Many others are modified designs of pre-existing aircraft, such as the Boeing P-8 Poseidon, which is based on the Boeing 737-800 airliner.

Multirole combat aircraft

Many combat aircraft today have a multirole ability. Normally only applying to fixed-wing aircraft, this term signifies that the plane in question can be a fighter or a bomber, depending on what the mission calls for. An example of a multirole design is the F-15E Strike Eagle, F/A-18 Hornet, F-35 Lightning II. A World War II example would be the P-38 Lightning.

Non-combat aircraft

Non-combat roles of military aircraft include search and rescue, reconnaissance, observation/surveillance, Airborne Early Warning and Control, transport, training, and aerial refueling.

Many civil aircraft, both fixed wing and rotary wing, have been produced in separate models for military use, such as the civilian Douglas DC-3 airliner, which became the military C-47 Sky train, and British "Dakota" transport planes, and decades later, the USAF's AC-47 aerial gunships. Even the fabric-covered two-seat Piper J3 Cub had a military version. Gliders and balloons have also been used as military aircraft; for example, balloons were used for observation during the American Civil War and during World War I, and military gliders were used during World War II to deliver ground troops in airborne assaults.

Military transport aircraft

Military transport (logistics) aircraft are primarily used to transport troops and war supplies. Cargo can be attached to pallets, which are easily loaded, secured for flight, and quickly unloaded for delivery. Cargo also may be discharged from flying aircraft on parachutes, eliminating the need for landing. Also included in this category are aerial tankers; these planes can refuel other aircraft while in flight. An example of a transport aircraft is the C-17 Globemaster III. A World War II example would be the C-47. An example of a tanker craft would be the KC-135 Strato tanker. Helicopters and gliders can transport troops and supplies to areas where other aircraft would be unable to land.

Calling a military aircraft a "cargo plane" is incorrect, because military transport planes also carry paratroopers and other soldiers.

Airborne early warning and control

An airborne early warning and control (AEW&C) system is an airborne radar system designed to detect aircraft, ships and ground vehicles at long ranges and control and command the battle space in an air engagement by directing fighter and attack aircraft strikes. AEW&C units are also used to carry out surveillance, including over ground targets and frequently perform C2BM (command and control, battle management) functions similar to an Airport Traffic Controller given military command over other forces. Used at a high altitude, the radars on the aircraft allow the operators to distinguish between friendly and hostile aircraft hundreds of miles away.

AEW&C aircraft are used for both defensive and offensive air operations, and are to the NATO and USA forces trained or integrated Air Forces what the Command Information Center is to a Navy Warship, plus a highly mobile and powerful radar platform. The system is used offensively to direct fighters to their target locations, and defensively in order to counterattacks by enemy forces, both air and ground. So useful is the advantage of command and control from a high altitude, the United States Navy operates AEW&C aircraft off its Supercarriers to augment and protect its carrier Command Information Centers (CICs).

AEW&C is also known by the older terms "airborne early warning" (AEW) and "airborne warning and control system" (AWACS) although AWACS is the name of a specific system currently used by NATO and the USAF and is often used in error to describe similar systems.

Reconnaissance and surveillance aircraft

Reconnaissance aircraft are primarily used to gather intelligence. They are equipped with cameras and other sensors. These aircraft may be specially designed or may be modified from a basic fighter or bomber type. This role is increasingly being filled by satellites and unmanned aerial vehicles (UAVs).

Surveillance and observation aircraft use radar and other sensors for battlefield surveillance, airspace surveillance, maritime patrol and artillery spotting. They include modified civil aircraft designs, moored balloons and UAVs.

Experimental aircraft

Experimental aircraft are designed in order to test advanced aerodynamic, structural, avionic, or propulsion concepts. These are usually well instrumented, with performance data telemetered on radio-frequency data links to ground stations located at the test ranges where they are flown. An example of an experimental aircraft is the Bristol 188.

Parameters to be considered for the design

These requirements give the general idea for creation of a new airplane. They define the airplane type and class, the airplane functions and main parameters and characteristics. This group includes the following airplane design properties:

1. Airplane type.
2. The main tasks fulfilled by an airplane.
3. The variants of operation for an airplane and its possible modifications.
4. The content of payload
5. Airplane crew.
6. Degree of automation of the main flight stages.
7. Conditions of stationing, airfield class, runway types.
8. The equipment necessary for handling freights/payload.
9. The opportunity for personnel and material airdrops.
10. The opportunity of autonomous maintenance at unprepared airfield.
11. Armament.
12. Mission tactics and combined arms requirements, time to prepare for the next sortie.
13. ECM and other defense.

The example of using the paired comparison method for ranking requirements for the military transport airplane is given below. The approximate list of the main requirements for this airplane (in random order):

1. High cruise speed.
2. Time necessary for loading and unloading freights.
3. The possibility for transportation and air-dropping of light- and mid-weight infantry equipment.
4. Good taking-off and landing performance and the opportunity to operate from unpaved runways.
5. High fuel efficiency.
6. The opportunity for autonomous maintenance at unprepared airfields.
7. The convenience of maintenance and repair.

Considering each pair of requirements one after another, you should give the comparative evaluation of importance using the mentioned above three-point scale.

a) Requirement "1" - Requirement "2".

Decreasing the time of loading and unloading is more important than decreasing the time of the cruise flight (achieved by high cruise speed). Thus the requirement "2" gets 2 points, the requirement "1" gets 0.

b) Requirement "1" - Requirement "3".

The necessity of transportation and air-dropping personnel and equipment is more important than the increased flight velocity. Thus, the requirement "3" gets 2 points; the requirement "1" gets 0.

c) Requirement "1" - Requirement "7".

These two requirements are approximately equal in importance, that's why they get 1 point each.

The results of ranking requirements

№	1	2	3	4	5	6	7	score	rank
1	☼	0	0	0	0	1	1	2	7
2	2	☼	1	1	2	2	2	10	1
3	2	1	☼	1	1	1	1	7	3
4	2	1	1	☼	2	2	1	9	2
5	2	0	1	0	☼	0	0	3	6
6	1	0	1	0	2	☼	2	6	4
7	1	0	1	2	2	0	☼	6	5

If two requirements got the equal number of points, their ranks are defined by comparing them one more time (requirements 6 and 7).

The ranked results enable to make the list of requirements in the decreasing order of their importance.

1. Time necessary for loading and unloading freights.
2. Good taking-off and landing performance and the opportunity to operate from unpaved runways.
3. The possibility for transportation and air-dropping of light- and mid-weight infantry equipment.
4. The opportunity for autonomous maintenance at unprepared airfields.
5. The convenience of maintenance and repair.
6. High fuel efficiency.
7. High cruise speed.

Choosing the scheme parameters

The sequence for choosing the airplane scheme is the following:

1. Estimate the layout of crew, payload and fuel.
2. Choose the lifting system configuration for cruise, take-off and landing stages.
3. Choose the balancing scheme.
4. Choose the parameters for wing, empennage, fuselage, control units and lift augmentation devices.
5. Choose the scheme and parameters for the landing gear.
6. Choose the type of engines, their number and placement on the airplane.
7. Estimate the approximate values of aerodynamic performance, power-plant performance and specific wing load.
8. Draw a three-projection and/or axonometric design drawing of the airplane general view.

The choice of less important parameters of can be biased in the following way:

— Listing the airplane properties and characteristics that are influenced by the chosen parameter;

— Picking out two-three characteristics from the list that correspond to PR and have the highest rank in the ranked list of requirements (see section 2);

— According to statistics, the parameter value is chosen that satisfies these requirements in the best way.

Consider the example of applying this method for choosing wing aspect ratio λ.

2. Figuring out the main characteristics, depending on the airplane type:

— for passenger, transport and other long-range airplanes they are range (provides the lower limit for λ), wing mass and stiffness (provide the upper limit for λ);

— for short range airplanes of the same type the lower limit is defined by the take-off and landing characteristics and the upper limit is defined by wing mass;

— for fighters the lower limit is defined by take-off and landing or maneuvering characteristics and the upper limit is defined by maximum velocity.

3. Choice of the numerical value for wing aspect ratio λ can be made with the help of statistical diagrams $\lambda(L_p)$, $\lambda(V_{кр})$, etc.

PHASES OF AIRCRAFT DESIGN

Conceptual Design

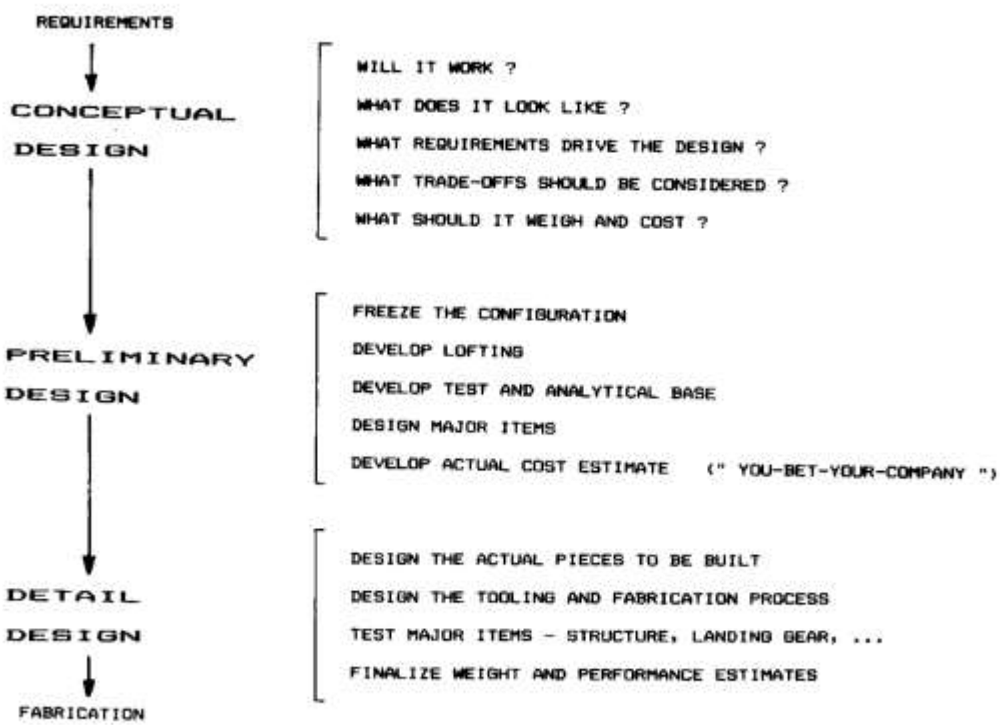
Aircraft design can be broken into three major phases, as depicted in Fig. 2.2. Conceptual design is the primary focus of this book. It is in conceptual design that the basic questions of configuration arrangement, size and weight, and performance are answered.

The first question is, "Can an affordable aircraft be built that meets the requirements?" If not, the customer may wish to relax the requirements.

Conceptual design is a very fluid process. New ideas and problems emerge as a design is investigated in ever-increasing detail. Each time the latest design is analyzed and sized, it must be redrawn to reflect the new gross weight, fuel weight, wing size, engine size, and other changes. Early wind-tunnel tests often reveal problems requiring some changes to the configuration. The steps of conceptual design are described later in more detail.

Preliminary Design

Preliminary design can be said to begin when the major changes are over. The big questions such as whether to use a canard or an aft tail have been resolved. The configuration arrangement can be expected to remain about as shown on current drawings, although minor revisions may occur. At some point late in preliminary design, even minor changes are stopped when a decision is made to freeze the configuration.



Three phases of aircraft design.

During preliminary design the specialists in areas such as structures, landing gear, and control systems will design and analyze their portion of the aircraft. Testing is initiated in areas such as aerodynamics, propulsion, structures, and stability and control. A mockup may be constructed at this point.

A key activity during preliminary design is "lofting." Lofting is the mathematical modeling of the outside skin of the aircraft with sufficient accuracy to insure proper fit between its different parts, even if they are designed by different designers and possibly fabricated in different locations. Lofting originated in shipyards and was originally done with long flexible rulers called "splines." This work was done in a loft over the shipyard; hence the name.

The ultimate objective during preliminary design is to ready the company for the detail design stage, also called full-scale development. Thus, the end of preliminary design usually involves a full-scale development proposal. In today's environment, this can result in a situation jokingly referred to as "you-bet-your-company." The possible loss on an overrun contract or from lack of sales can exceed the net worth of the company! Preliminary design must establish confidence that the airplane can be built on time and at the estimated cost.

Detail Design

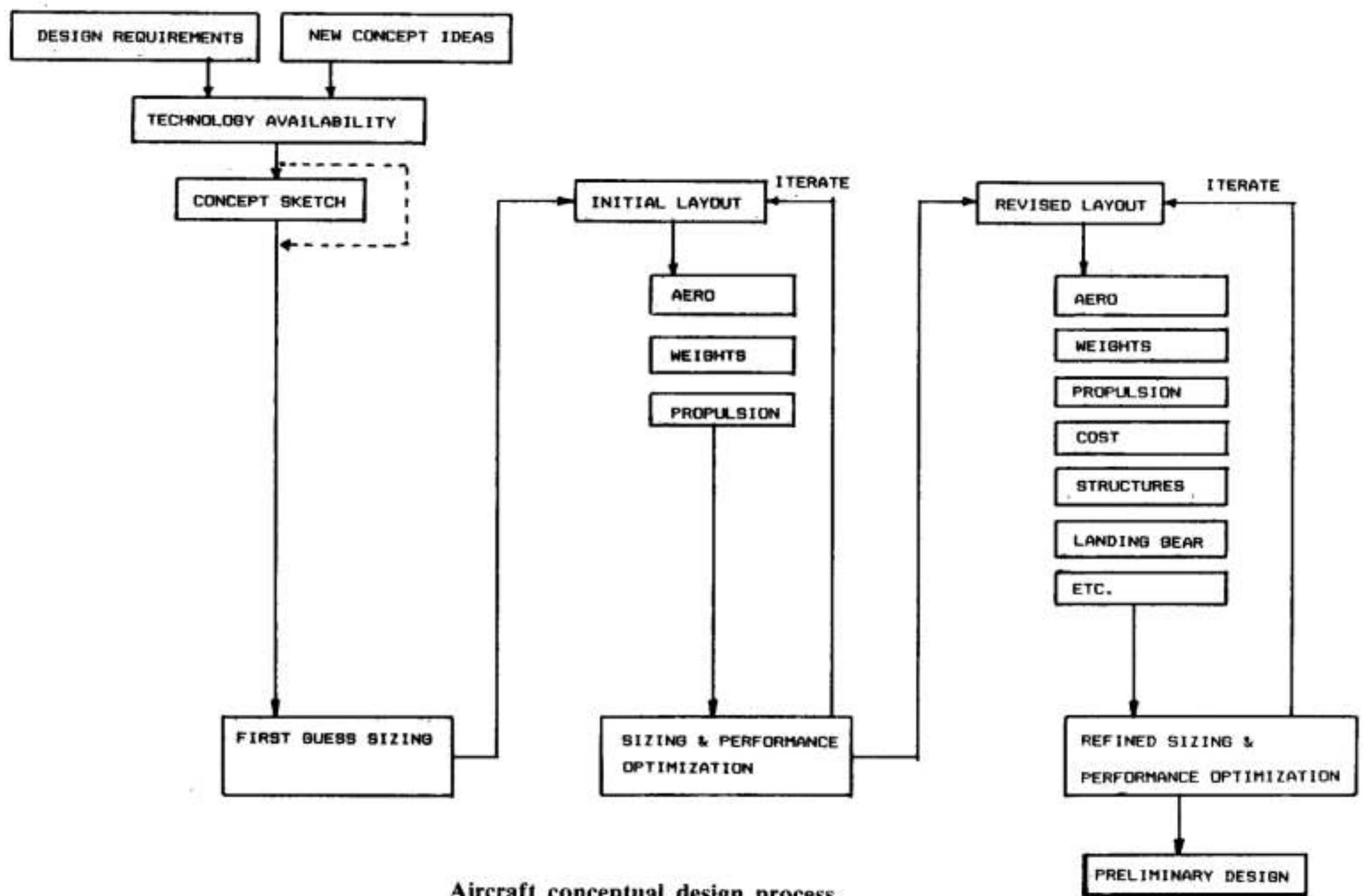
Assuming a favorable decision for entering full-scale development, the detail design phase begins in which the actual pieces to be fabricated are designed. For example, during conceptual and preliminary design the wing box will be designed and analyzed as a whole. During detail design, that whole will be broken down into individual ribs, spars, and skins, each of which must be separately designed and analyzed.

Another important part of detail design is called production design. Specialists determine how the airplane will be fabricated, starting with the smallest and simplest subassemblies and building up to the final assembly process. Production designers frequently wish to modify the design for ease of manufacture; that can have a major impact on performance or weight. Compromises are inevitable, but the design must still meet the original requirements.

It is interesting to note that in the Soviet Union, the production design is done by a completely different design bureau than the conceptual and preliminary design, resulting in superior producibility at some expense in performance and weight.

During detail design, the testing effort intensifies. Actual structure of the aircraft is fabricated and tested. Control laws for the flight control system are tested on an "iron-bird" simulator, a detailed working model of the actuators and flight control surfaces. Flight simulators are developed and flown by both company and customer test-pilots.

Detail design ends with fabrication of the aircraft. Frequently the fabrication begins on part of the aircraft before the entire detail-design effort is completed. Hopefully, changes to already-fabricated pieces can be avoided.



Aircraft conceptual design process.

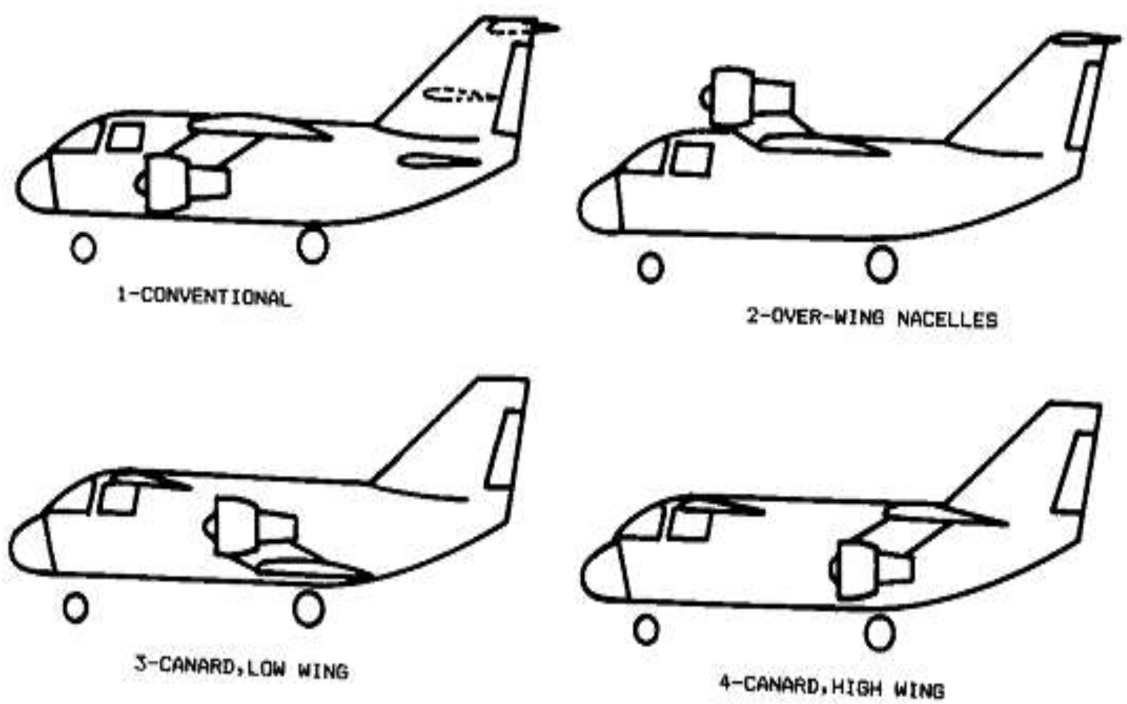
DESIGN EXAMPLE: ASW AIRCRAFT

ASW Requirements

Figure 3.8 illustrates the mission requirement for a hypothetical antisubmarine warfare (ASW) aircraft. The key requirement is the ability to loiter for three hours at a distance of 1500 n.mi. from the takeoff point. While loitering on-station, this type of aircraft uses sophisticated electronic equipment to detect and track submarines. For the sizing example, this equipment is assumed to weigh 10,000 lb. Also, a four-man crew is required, totalling 800 lb. The aircraft must cruise at 0.6 Mach number.

Conceptual Sketches

Figure shows four conceptual approaches considered by the designer in response to these mission requirements. Concept one is the conventional



ASW concept sketches.

approach, looking much like the Lockheed S-3A that currently performs a similar mission. The low horizontal tail position shown in solid line would offer the lightest structure, but may place the tail in the exhaust stream of the engines, so other positions for the horizontal tail are shown in dotted lines.

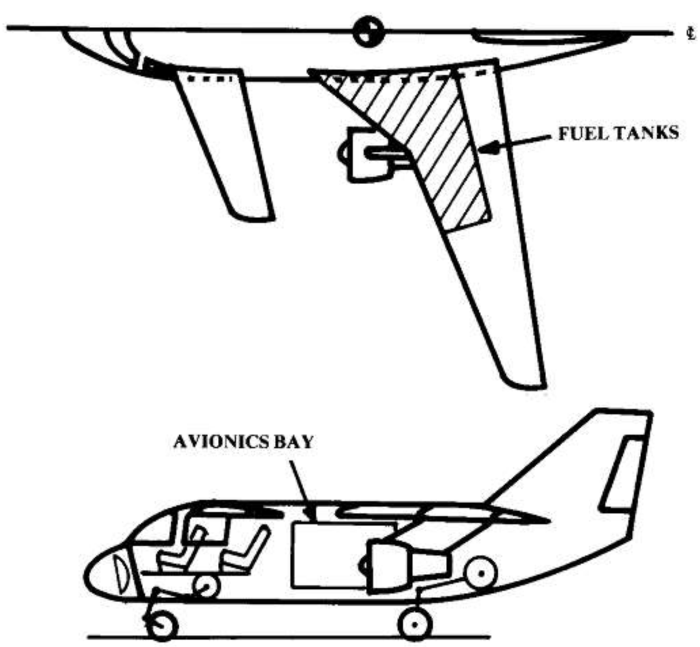
The second concept is much like the first except for the engine location. Here the engines are shown mounted over the wing. This provides extra lift due to the exhaust over the wings, and also provides greater ground clearance for the engines, which reduces the tendency of the jet engines to suck up debris. However, the disadvantage of this concept is the difficulty in reaching the engines for maintenance work.

Concepts three and four explore the canarded approach. Canards offer the potential for reduced trim drag and may provide a wider allowable range for the center of gravity. In concept three, the wing is low and the engines are mounted over the wing as in concept two. This would allow the main landing gear to be stowed in the wing root.

In concept four, the wing is high with the engines mounted below. This last approach offers better access to the engines, and for this reason was selected for further development.

Figure 3.10 is a conceptual sketch prepared, in more detail, for the selected concept. Note the locations indicated for the landing-gear stowage, crew station, and fuel tanks.

This points out a common problem with canard aircraft, the fuel tank locations. The fuel tanks should be placed so that the fuel is evenly dis-



Completed ASW sketch.

tributed about the aircraft center of gravity (estimated location shown by the circle with two quarters shaded). This is necessary so that the aircraft when loaded has nearly the same center of gravity as when its fuel is almost gone. However, the wing is located aft of the center of gravity whenever a canard is used, so the fuel located in the wing is also aft of the center of gravity.

ASW sizing calculations

Mission Segment Weight Fractions

1) Warmup and takeoff	$W_1/W_0 = 0.97$	(Table 2)
2) Climb	$W_2/W_1 = 0.985$	(Table 2)
3) Cruise	$R = 1500\text{nm} = 9{,}114{,}000$ ft	
	$C = 0.5$ 1/hr $= 0.0001389$ 1/s	
	$V = 0.6\text{M} \times (994.8$ ft/s$) = 569.9$ ft/s	
	$L/D = 16 \times 0.866 = 13.9$	
	$W_3/W_2 = e^{[-RC/VL/D]} = e^{-0.16} = 0.852$	
4) Loiter	$E = 3$ hours $= 10{,}800$ s	
	$C = 0.4$ 1/hr $= 0.0001111$ 1/s	
	$L/D = 16$	
	$W_4/W_3 = e^{[-EC/L/D]} = e^{-0.075} = 0.9277$	
5) Cruise (same as 3)	$W_5/W_4 = 0.852$	
6) Loiter	$E = ⅓$ hours $= 1200$ s	
	$C = 0.0001111$ 1/s	
	$L/D = 16$	
	$W_6/W_5 = e^{-0.0083} = 0.9917$	
7) Land	$W_7/W_6 = 0.995$	(Table 2)

$$W_7/W_0 = (0.97)(0.985)(0.852)(0.9277)(0.852)(0.9917)(0.995) = 0.635$$

$$W_f/W_0 = 1.06(1 - 0.6505) = 0.387$$

$$W_e/W_0 = 0.93 W_0^{-0.07} \qquad \text{(Table 1)}$$

$$W_0 = \frac{10{,}800}{1 - 0.387 - \dfrac{W_e}{W_0}} = \frac{10{,}800}{0.613 - 0.93\ W_0^{-0.07}}$$

W_0 Guess	W_e/W_0	W_0 Calculated
50,000	0.4361	61,057
60,000	0.4305	59,191
59,200	0.4309	59,328
59,300	0.4309	59,311
59,310	0.4309	59,309.6

Aircraft based on the wing position and wing geometry

The wing configuration of a fixed-wing aircraft (including both gliders and powered aeroplanes or airplanes) is its arrangement of lifting and related surfaces.

Aircraft designs are often classified by their wing configuration. For example, the Supermarine Spitfire is a conventional low wing cantilever monoplane of straight elliptical planform with moderate aspect ratio and slight dihedral.

Many variations have been tried. Sometimes the distinction between them is blurred, for example the wings of many modern combat aircraft may be described either as cropped compound deltas with (forwards or backwards) swept trailing edge, or as sharply tapered swept wings with large leading edge root extensions (or LERX). Some are therefore duplicated here under more than one heading. This is particularly so for variable geometry and combined (closed) wing types.

Most of the configurations described here have flown (if only very briefly) on full-size aircraft. A few significant theoretical designs are also noted.

Note on terminology: Most fixed-wing aircraft have left hand and right hand wings in a symmetrical arrangement. Strictly, such a pair of wings is called a wing plane or just plane. However, in certain situations it is common to refer to a plane as a wing, as in "a biplane has two wings", or to refer to the whole thing as a wing, as in "a biplane wing has two planes". Where the meaning is clear, this article follows common usage, only being more precise where needed to avoid real ambiguity or incorrectness.

Number and position of main planes

Fixed-wing aircraft can have different numbers of wings:

Monoplane: one wing plane. Since the 1930s most aeroplanes have been monoplanes. The wing may be mounted at various positions relative to the fuselage:

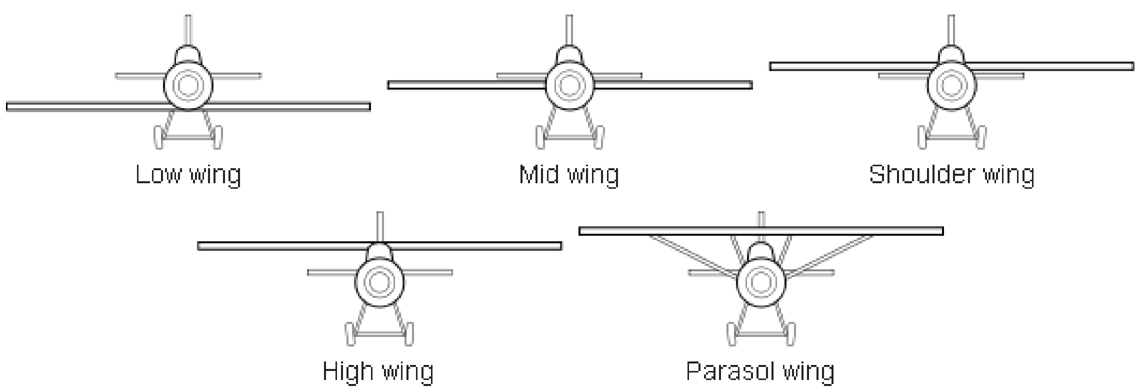
Low wing: mounted near or below the bottom of the fuselage.

Mid wing: mounted approximately halfway up the fuselage.

Shoulder wing: mounted on the upper part or "shoulder" of the fuselage, slightly below the top of the fuselage. A shoulder wing is sometimes considered a subtype of high wing.

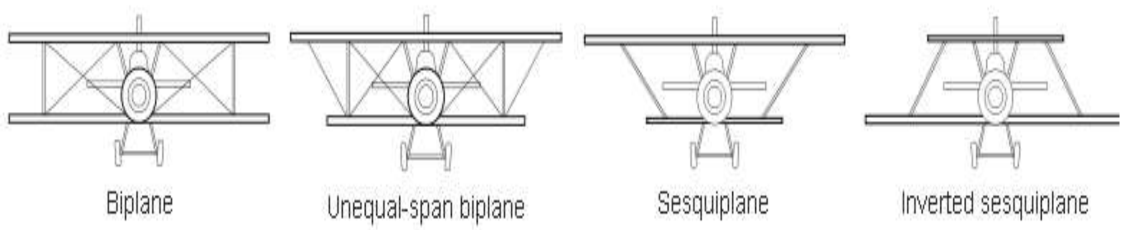
High wing: mounted on the upper fuselage. When contrasted to the shoulder wing, applies to a wing mounted on a projection (such as the cabin roof) above the top of the main fuselage.

Parasol wing: raised clear above the top of the fuselage, typically by cabane struts, pylon(s) or pedestal(s).



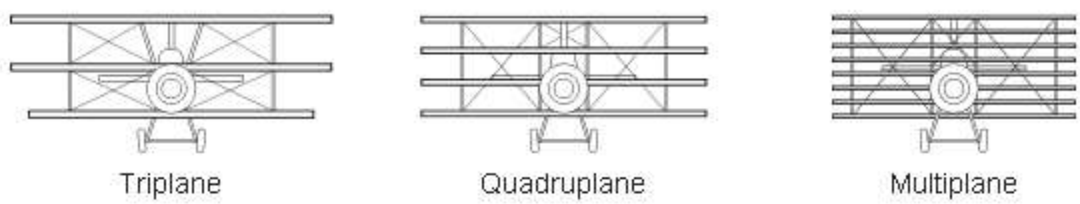
A fixed-wing aircraft may have more than one wing plane, stacked one above another:

- Biplane: two wing planes of similar size, stacked one above the other. The biplane is inherently lighter and stronger than a monoplane and was the most common configuration until the 1930s. The very first Wright Flyer I was a biplane.
    - Unequal-span biplane: a biplane in which one wing (usually the lower) is shorter than the other, as on the Curtiss JN-4 Jenny of the First World War.
    - Sesquiplane: literally "one-and-a-half planes" is a type of biplane in which the lower wing is significantly smaller than the upper wing, either in span or chord or both. The Nieuport 17 of World War I was notably successful.
    - Inverted sesquiplane: has a significantly smaller upper wing. The Fiat CR.1 was in production for many years.

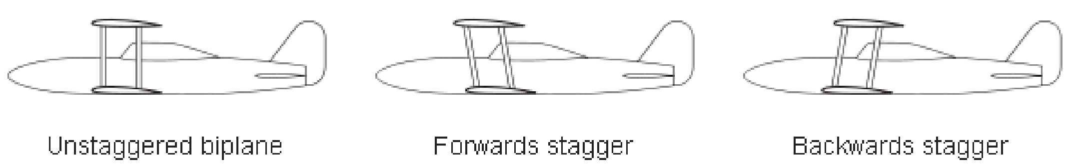


- Triplane: three planes stacked one above another. Triplanes such as the Fokker Dr.I enjoyed a brief period of popularity during the First World War due to their manoeuvrability, but were soon replaced by improved biplanes.
- Quadruplane: four planes stacked one above another. A small number of the Armstrong Whitworth F.K.10 were built in the First World War but never saw service.

- Multiplane: many planes, sometimes used to mean more than one or more than some arbitrary number. The term is occasionally applied to arrangements stacked in tandem as well as vertically. The 1907 Multiplane of Horatio Frederick Phillips flew successfully with two hundred wing foils. See also the tandem wing, below.



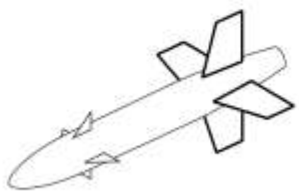
A staggered design has the upper wing slightly forward of the lower. Long thought to reduce the interference caused by the low pressure air over the lower wing mixing with the high pressure air under the upper wing; however the improvement is minimal and its primary benefit is to improve access to the fuselage. It is common on many successful biplanes and triplanes. Backwards stagger is also seen in a few examples such as the Beechcraft Staggerwing.



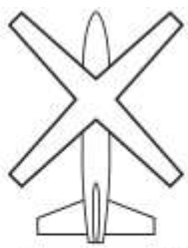
A tandem wing design has two wings, one behind the other: see Tailplanes and foreplanes below. Some early types had tandem stacks of multiple planes, such as the nine-wing Caproni Ca.60 flying boat with three triplane stacks in tandem.

A cruciform wing is a set of four individual wings arranged in the shape of a cross. The cross may take either of two forms:

- Wings equally spaced around the cross-section of the fuselage, lying in two planes at right angles, as on a typicalmissile.
- Wings lying together in a single horizontal plane about a vertical axis, as in the cruciform rotor wing or X-wing.



Cruciform wing weapon



Cruciform rotor wing or X wing rotor

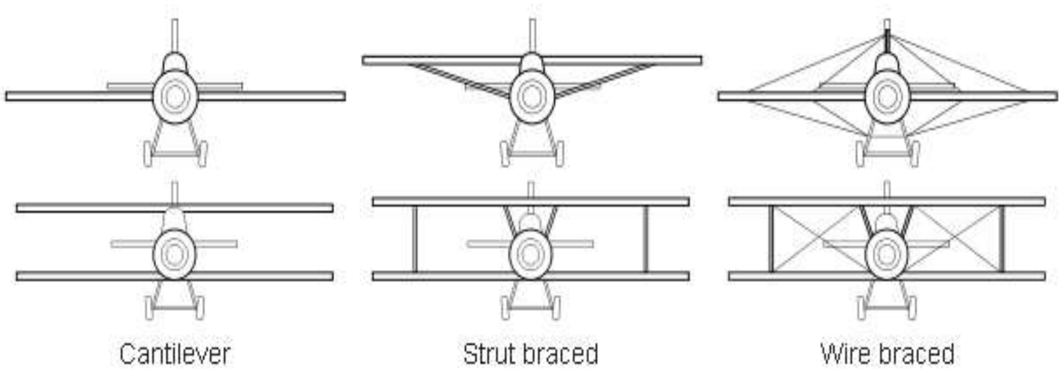
Wing support

To support itself a wing has to be rigid and strong and consequently may be heavy. By adding external bracing, the weight can be greatly reduced. Originally such bracing was always present, but it causes a large amount of drag at higher speeds and has not been used for faster designs since the early 1930s.

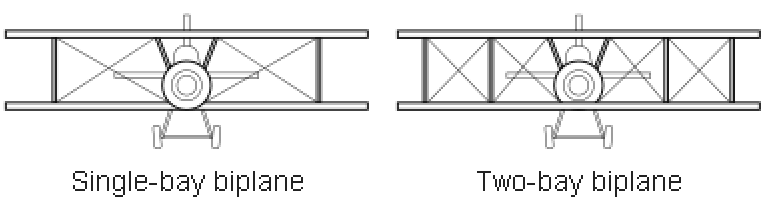
The types are:

- Cantilevered: self-supporting. All the structure is buried under the aerodynamic skin, giving a clean appearance with low drag.
- Braced: the wings are supported by external structural members. Nearly all multi-plane designs are braced. Some monoplanes, especially early designs such as the Fokker Eindecker, are also braced to save weight. Braced wings are of two types:

- Strut braced: one or more stiff struts help to support the wing, as on the Fokker D.VII. A strut may act in compression or tension at different points in the flight regime.
- Wire braced: alone (as on the Boeing P-26 Peashooter) or, more usually, in addition to struts, tension wires also help to support the wing. Unlike a strut, a wire can act only in tension.

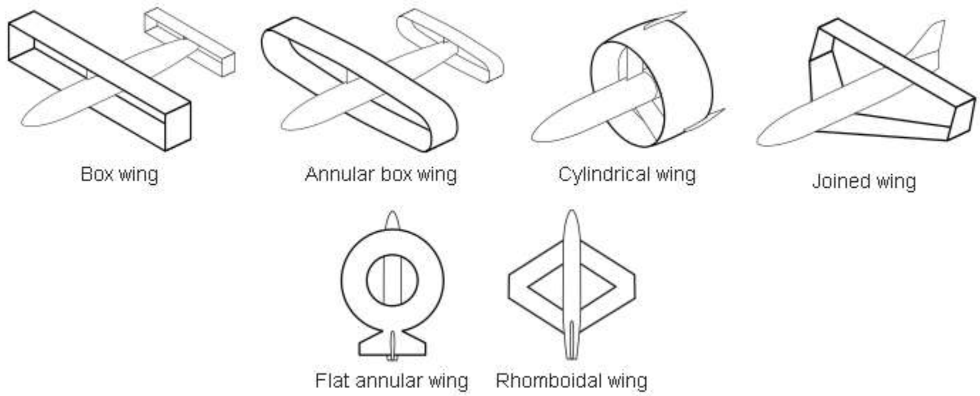


A braced multiplane may have one or more "bays", which are the compartments created by adding interplane struts; the number of bays refers to one side of the aircraft's wing panels only. For example, the de Havilland Tiger Moth is a single-bay biplane where the Bristol F.2 Fighter is a two-bay biplane.



Closed wing: two wing planes are merged or joined structurally at or near the tips in some way.[4] This stiffens the structure and can reduce aerodynamic losses at the tips. Variants include:

- Box wing: upper and lower planes are joined by a vertical fin between their tips. The first officially witnessed unaided takeoff and flight, Santos-Dumont´s 14-bis, used this configuration and some Dunne biplanes were of this type as well. Tandem box wings have also been studied (see Joined wing description below).
- Annular box wing: A type of box wing whose vertical fins curve continuously, blending smoothly into the wing tips. An early example was the Blériot III, which featured two annular wings in tandem.
- Annular (cylindrical): the wing is shaped like a cylinder. The Coléoptère had concentric wing and fuselage. It took off and landed vertically, but never achieved transition to horizontal flight. Examples with the wing mounted on top of the fuselage have been proposed but never built.
- Annular (planar): the wing is shaped like a disc with a hole in it. A number of Lee-Richards annular monoplanes flew shortly before the First World War.
- Joined wing: a tandem layout in which the front low wing sweeps back and/or the rear high wing sweeps forwards such that they join at or near the tips to form a continuous surface in a hollow diamond or triangle shape. The Ligeti Stratos is a rare example.
  - Rhomboidal wing: a joined wing consisting of four surfaces in a diamond arrangement. The Edwards Rhomboidal biplane of 1911 had both wings in the same plane and failed to fly.



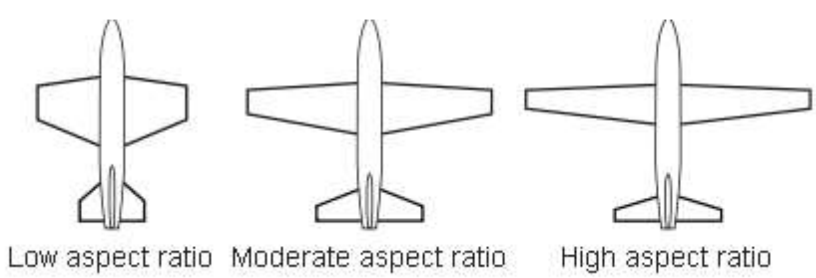
Aspect ratio

The aspect ratio is the span divided by the mean or average chord.[9] It is a measure of how long and slender the wing appears when seen from above or below.

- **Low aspect ratio**: short and stubby wing. More efficient structurally and higher instantaneous roll rate. They tend to be used by fighter aircraft, such as the Lockheed F-104 Starfighter, and by very high-speed aircraft including the North American X-15.

- **Moderate aspect ratio**: general-purpose wing, very widely used, for example on the Douglas DC-3 transport).

- **High aspect ratio**: long and slender wing. More efficient aerodynamically, having less induced drag. They tend to be used by high-altitude subsonic aircraft such as airliners like the Bombardier Dash 8 and by high-performance sailplanes such as the Glaser-Dirks DG-500.

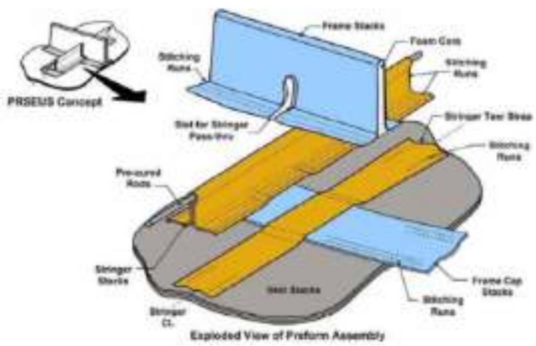


Measure of Merit for Aircraft Design Process

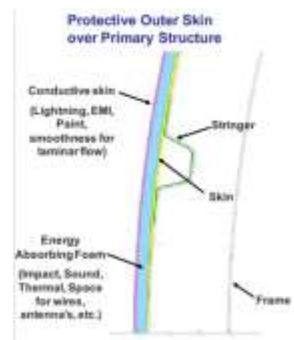
No.	Group	Design requirements and constraints
1	Standard, non-standard	(i) Standard and (ii) home-built (or garage-built)
2	General type	(i) Military (MIL-STD), (ii) civil – transport (FAR[a] 25), (iii) civil – GA (FAR 23), and (iv) very light aircraft (VLA), etc.
3	Maneuverability	(i) Normal or non-aerobatic, (ii) utility or semi-aerobatic, (iii) aerobatic or acrobatic, and (iv) highly maneuverable (e.g., fighters and anti-missile missiles)
4	GA mission	(i) General purpose, (ii) hang glider, (iii) sailplane or glider, (iv) agricultural, (v) utility, (vi) commuter, (vii) business, (viii) racer, (ix) sport, (x) touring, (xi) trainer, (xii) maneuver, and (xiii) model
5	Military mission	(i) Fighter, (ii) bomber, (iii) attack, (iv) interceptor, (v) reconnaissance, (vi) military transport, (vii) patrol, (viii) maritime surveillance, (ix) military trainer, (x) stealth, (xi) tanker, (xii) close support, (xiii) trainer, (xiv) anti-submarine, (xv) early warning, (xvi) airborne command, (xvii) communication relay, (xviii) target, (xix) missile, and (xx) rocket
6	Density	(i) Lighter-than-air craft (a. balloon, b. airship) and (ii) heavier-than-air craft
7	Pilot control	(i) Manned aircraft, (ii) unmanned aircraft, and (iii) remote control (RC)
8	Weight	(i) Model (less than 30 lb), (ii) ultralight aircraft (less than 300 kg), (iii) very light (less than 750 kg), (iv) light (less than 12 500 lb), (v) medium weight (less than 100 000 lb), and (vi) heavy or jumbo (above 100 000 lb)
9	Producibility	(i) Kit form, (ii) semi-kit form, and (iii) modular (conventional)
10	Take-off run	(i) Short take-off and landing (STOL) (runway less than 150 m), (ii) vertical take-off and landing (VTOL), and (iii) regular
11	Landing field	(i) Land-based, (ii) sea-based, (iii) ship-based, (iv) amphibian, and (v) shoulder-based
12	Stage	(i) Model, (ii) prototype, and (iii) operational
13	Term of use	(i) Long-term (regular) and (ii) experimental (X aircraft) or research
14	Payload	(i) Number of passengers, (ii) payload weight, and (iii) store, etc.
15	Aircraft subsystems	(i) Air condition, (ii) weather radar, and (iii) parachute, etc.
16	FAR and MIL requirements	(i) Number of crew, (ii) ejection seat, and (iii) reserve fuel, etc.
17	Performance	(i) Max speed, (ii) range, (iii) ceiling, (iv) rate of climb, (v) take-off run, and (vi) endurance, etc.
18	Maneuverability	(i) Turn radius, (ii) turn rate, and (iii) load factor

Future Trends in Civil Aircraft Design. (Journal Reference)

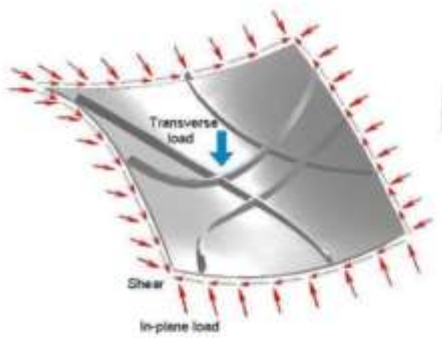
Figure 1. Conceptual illustration of fuel-efficient aircraft, including the truss-braced wing configuration (right), hybrid wing body configuration (center), and double-bubble configuration (left). Image credit: NASA.



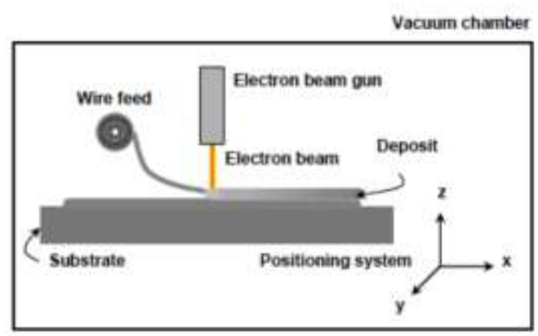
(a) Schematic of the Pultruded Rod Stitched Efficiency Unitized Structure concept for stitched composites.[11]



(b) Schematic of the Smoothing, Thermal, Absorbing, Reflective, Conductive, Cosmetic concept for multifunctional skins.[13]



(c) Diagram of a curvilinear stiffener structural concept.[10]



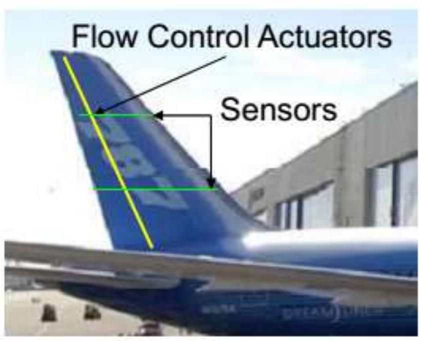
(d) Schematic of an electron beam freeform fabrication system for additive manufacturing.[14]

(e) Diagram of an aeroelastically tailored wing structural design with integrated structural controls.[14]

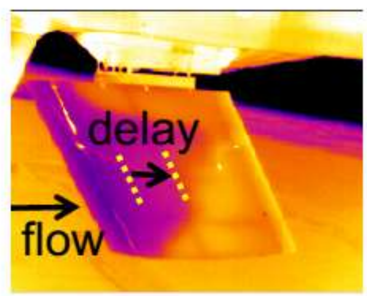
Figure 2. Concepts and technologies for the reduction of vehicle weight.

(a) Hybrid wing body configuration with reduced "wetted" area and elliptical span-wise lift distribution during cruise.[6]

(b) Truss-brased wing configuration with a large wing span and high aspect ratio wings.[5]

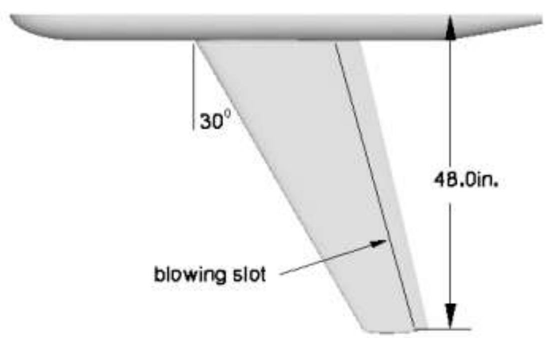


(c) Notional concept to augment rudder performance with active flow control.[16]



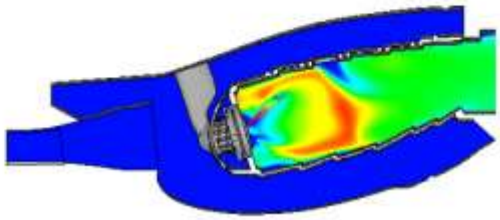
(d) Image showing the delay of transition from laminar to turbulent flow due to discrete roughness elements at low Mach and Reynolds number conditions.

(e) Elastically Shaped Aircraft Concept with Variable Camber Continuous Trailing Edge Flap.[18]

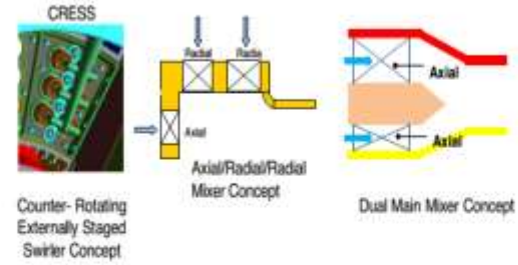


(f) Depiction of the Fundamental Aerodynamics Subsonic/Transonic-Modular Active Control semi-span model used to evaluate the effectiveness of circulation control for drag reduction during cruise conditions.[19]

Figure 3. Concepts and technologies to increase the ratio of lift over drag through the reduction of drag.

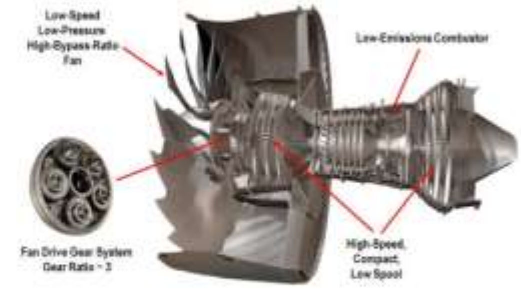


(a) Combustor concept utilizing Ceramic Matrix Composites and Environmental Barrier Coating systems for the combustion liner.[21]



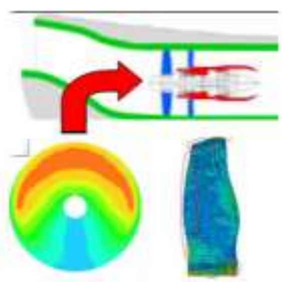
(b) Drawing of candidate lean burn injector/mixer concepts.[20]

(c) Open Rotor Propulsion Rig installed in a NASA low speed wind tunnel.[20]



(d) Diagram highlighting research technology areas for an ultra-high bypass ratio geared turbofan.[23]

(e) Embedded engines located on the aft of the double-bubble configuration for boundary layer ingestion.[6]



(f) Diagram depicting research to enable embedded systems, including an aeroelastic analysis of fan blades due to inlet distortion and composite fan blade design with aeroelastic tailoring.[10,24]

(g) Diagram of the turbo-electric distributed propulsion concept, as applied to a hybrid wing body configuration.[24]

Figure 4. Concepts and technologies for the reduction of thrust specific fuel consumption.

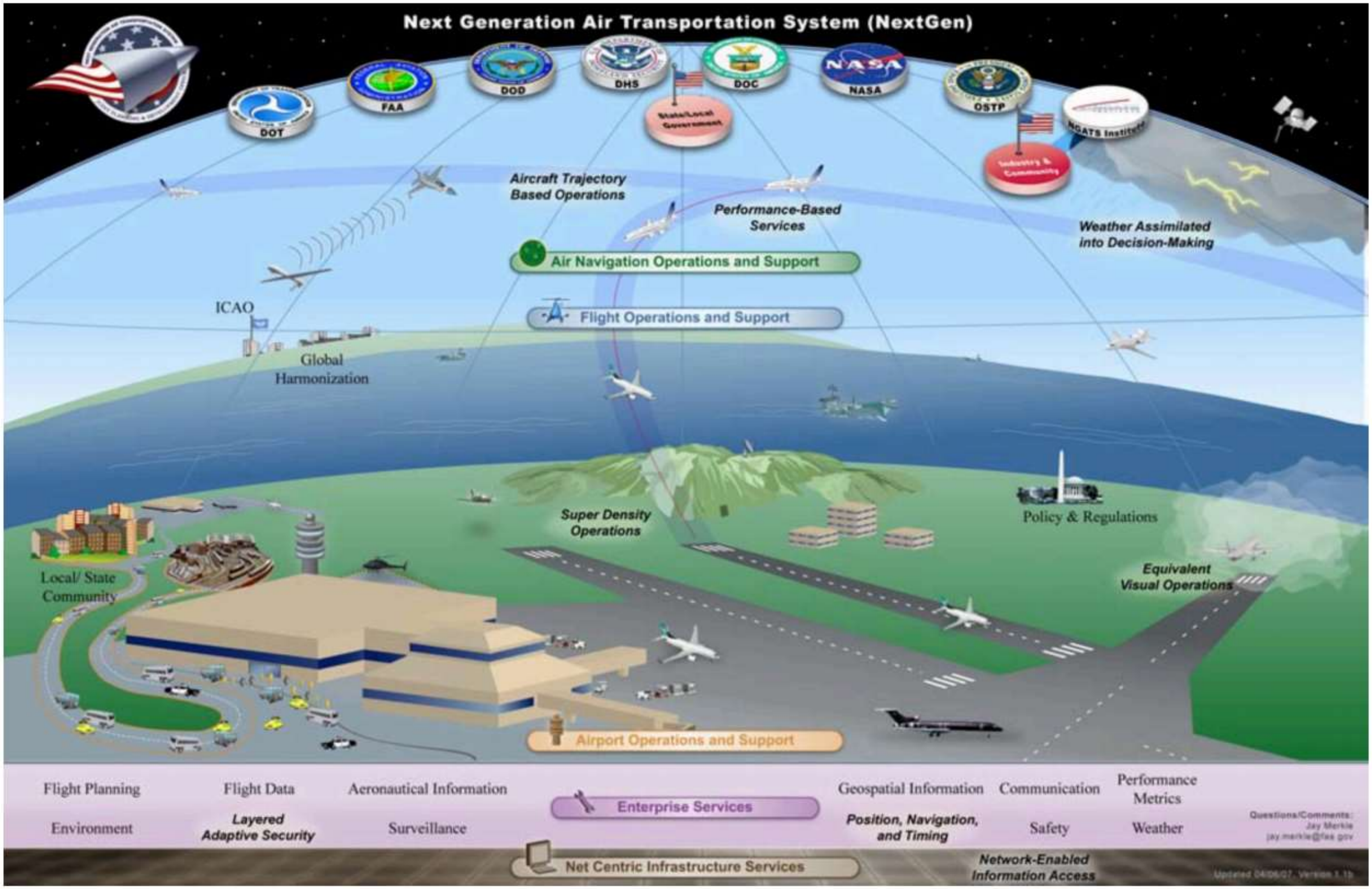


Figure 5. Conceptual illustration of NextGen.[27]

UNIT II

Conceptual Design Process

1) Future demand for airplanes should be assessed with the required number of airplanes in the certain time, for example, 5-10 years. This information can be found in publication from periodical editions, describing the airplanes of a given type, and in review magazines dedicated to international air shows.

2) History of the development should be investigated, and achieved perfection degree of a given type of airplanes should be mentioned. The average statistical and maximum values of the most important performance parameters, geometric and weight parameters, the mileage rating and cost efficiency of these airplanes should be given. Also maintenance and operating features - airplane cost, traffic handling cost, an airplane life, reliability indexes, comfort ratios and etc. should be included.

3) Development prospects should be studied, and changes in main performance and relative airplane parameters should be forecasted for the near future. Thus, dynamic and static diagrams for the most important prototype parameters should be plotted using data from statistic tables; then their trend functions with an approximation errors should be figured out and forecasted (extrapolated) parameter values should be found [4]. New engineering solutions that are expected to improve the value of each parameter should be mentioned.

The functional requirements

These requirements give the general idea for creation of a new airplane. They define the airplane type and class, the airplane functions and main parameters and characteristics. This group includes the following airplane design properties:

1. Airplane type.

2. The main tasks fulfilled by an airplane.

3. The variants of operation for an airplane and its possible modifications.

4. The content of payload

5. Airplane crew.

6. Degree of automation of the main flight stages.

7. Conditions of stationing, airfield class, runway types.

8. The equipment necessary for handling freights/payload.

9. The opportunity for personnel and material airdrops.

10. The opportunity of autonomous maintenance at unprepared airfield.

11. Armament.

12. Mission tactics and combined arms requirements, time to prepare for the next sortie

13. ECM and other defense.

The technical requirements

1. High cruise speed.

2. Time necessary for loading and unloading freights.

3. The possibility for transportation and air-dropping of light- and mid-weight infantry equipment.

4. Good taking-off and landing performance and the opportunity to operate from unpaved runways.

5. High fuel efficiency.

6. The opportunity for autonomous maintenance at unprepared airfields.

7. The convenience of maintenance and repair.

The paired comparison method.

The method contains the following stages. All important requirements are listed in random order. Each pair of listed requirements is considered one after another. Within the pair requirements are compared. According to this comparison each requirement is given a number of points. The scale of points can vary. For example, the most important requirement can obtain 2 points, the requirement of less importance - 0.

Considering each pair of requirements one after another, you should give the comparative evaluation of importance using the mentioned above three-point scale.
a) Requirement "1" - Requirement "2".

Decreasing the time of loading and unloading is more important than decreasing the time of the cruise flight (achieved by high cruise speed). Thus the requirement "2" gets 2 points, the requirement "1" gets 0.

b) Requirement "1" - Requirement "3".
The necessity of transportation and air-dropping personnel and equipment is more important than the increased flight velocity. Thus, the requirement "3" gets 2 points; the requirement "1" gets 0.
c) Requirement "1" - Requirement "7".
These two requirements are approximately equal in importance, that's why they get 1 point each. The results are entered in the Table 2.1 after comparing all requirements.

The results of ranking requirements

№	1	2	3	4	5	6	7	score	rank
1	☼	0	0	0	0	1	1	2	7
2	2	☼	1	1	2	2	2	10	1
3	2	1	☼	1	1	1	1	7	3
4	2	1	1	☼	2	2	1	9	2
5	2	0	1	0	☼	0	0	3	6
6	1	0	1	0	2	☼	2	6	4
7	1	0	1	2	2	0	☼	6	5

The ranked results enable to make the list of requirements in the decreasing order of their importance.

1. Time necessary for loading and unloading freights.

2. Good taking-off and landing performance and the opportunity to operate from unpaved runways.

3. The possibility for transportation and air-dropping of light- and mid-weight infantry equipment.

4. The opportunity for autonomous maintenance at unprepared airfields.

5. The convenience of maintenance and repair.

6. High fuel efficiency.

7. High cruise speed.

Conceptual System Design

Definition

From the perspective of synthesis, system design is nominally comprised of conceptual, preliminary, and detail design. Conceptual design is the first and most important phase of the system design and development process. It is an early and high-level lifecycle activity with potential to establish, commit, and otherwise predetermine the function, form, cost, and development schedule of the desired system. An appropriate starting point for design at the conceptual level is the identification of a problem and associated definition of need. The primary responsibility of conceptual design is the selection of a path forward for the design and development of a preferred system configuration, which ultimately is responsive to the identified customer requirements. A critical first step in the implementation of the SE process is to establish this early foundation, as well as to require the initial planning and development of a spectrum of manufacturing technologies. From an organizational perspective, systems engineering should take the lead in the definition of system requirements from the beginning and address them from a total integrated lifecycle perspective.

As the name implies, the outcome of the conceptual design phase is a concept or configuration which does not necessarily accompany any details. The requirements need for a specific new system first comes into focus during the conceptual design process. It is this recognition that initiates the system conceptual design process to meet these needs. Then, during the conceptual design of the system, consideration should simultaneously be given to its production and support. This gives rise to a parallel lifecycle for bringing a manufacturing capability into being.

Conceptual Design Flowchart

Throughout the conceptual system design phase (commencing with the need analysis), one of the major objectives is to develop and define the specific design-to requirements for the system as an entry. In general, the following steps must be performed during the conceptual design phase:

1. Identify the problem and translate it into a definition of the need for a system that will provide a solution.
2. Accomplish system planning (e.g., Gantt chart) in response to the identified need.
3. Conduct a feasibility study, making sure the system is practical and leads to the details of a technical approach for system design.
4. Develop system operational requirements describing the functions that the system must perform in accomplishing its designated mission.
5. Propose a production/maintenance plan for sustained support of the system throughout its desired lifecycle.
6. Identify and prioritize technical performance measures (TPMs) and related criteria for design.
7. Perform a system-level functional analysis and allocate requirements to the various subsystems.
8. Formulate needs and generating metrics to evaluate them.
9. Brainstorm and design a couple of concepts to address the design requirements and list their characteristics.
10. Accomplish trade-off analysis to select the best concept.
11. Develop a system specification.
12. Conduct a conceptual design review (CDR).
13. If the CDR does not confirm the concept, select a new approach and generate new concepts.

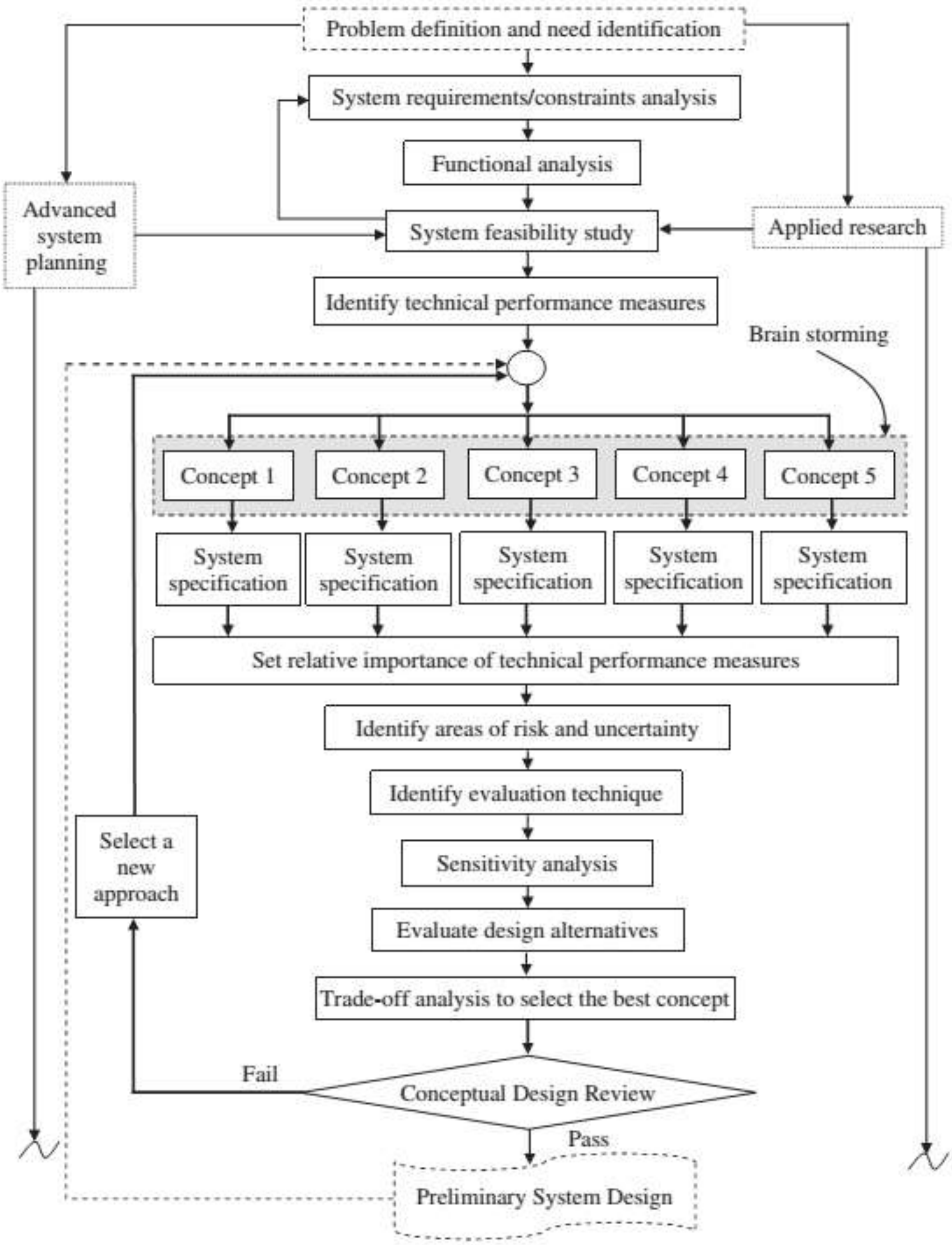
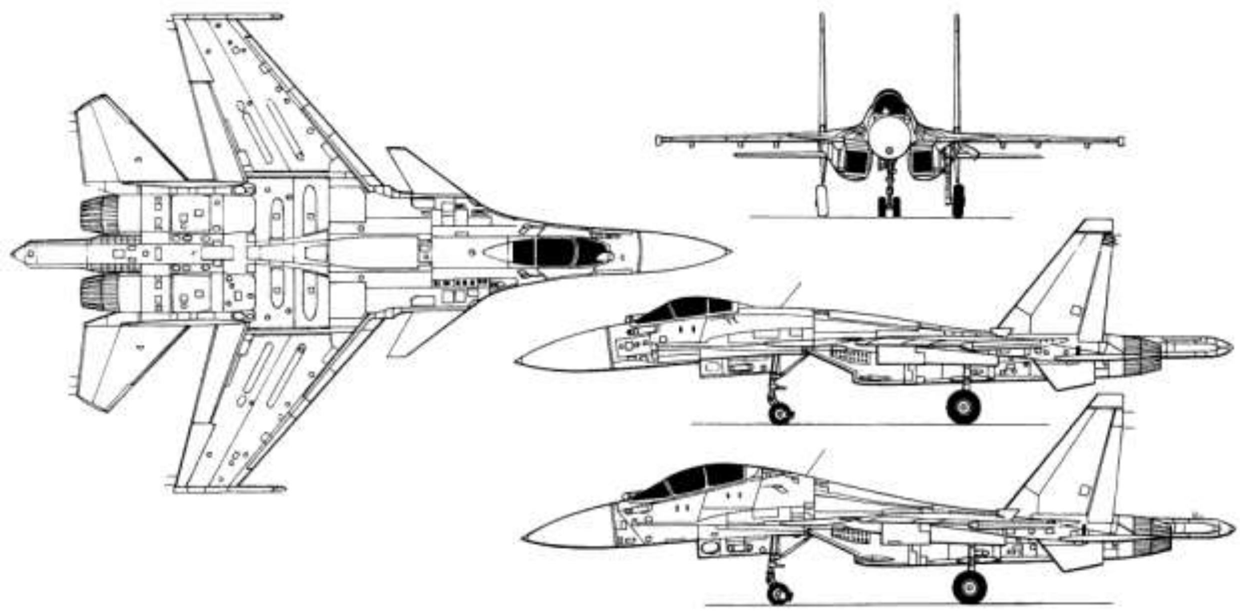


Figure 2.4 Conceptual design process

Conceptual Sketch Examples

Sukhoi Su-35



General characteristics

- **Crew:** 1
- **Length:** 21.9 m (72 ft 11 in)
- **Wingspan:** (with wingtip pods) 15.3 m (50 ft 2 in)
- **Height:** 5.9 m (19 ft 5 in)
- **Wing area:** 62 m² (667 ft²)
- **Empty weight:** 17,200 kg[citation needed] (37,920 lb)
- **Loaded weight:** 25,300 kg (56,660 lb) at 50% internal fuel
- **Max. takeoff weight:** 34,500 kg (76,060 lb)
- **Fuel capacity:** 11,500 kg (25,400 lb) internally
- **Powerplant:** 2 × Saturn AL-41F1S afterburning turbofans
  - **Dry thrust:** 86.3 kN (19,400 lbf) each

- **Thrust with afterburner:** 142 kN (31,900 lbf) each

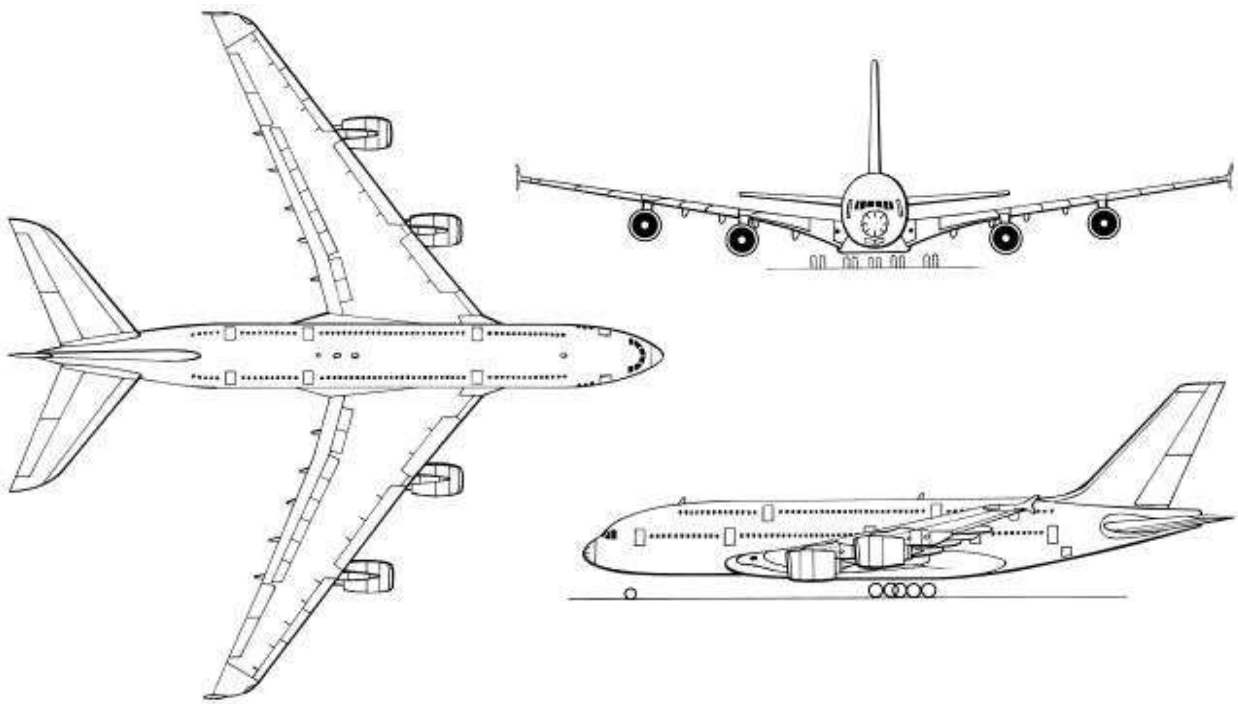
Performance

- **Maximum speed:**
  - **At altitude:** Mach 2.25 (2,400 km/h; 1,490 mph)
  - **At sea level:** Mach 1.13 (1,400 km/h; 870 mph)
- **Range:**
  - **At altitude:** 3,600 km (2,240 mi; 1,940 nmi)
  - **At sea level:** 1,580 km (980 mi; 850 nmi)
- **Combat radius:** around 1,500 km[167] (932 mi; 810 nmi)
- **Ferry range:** 4,500 km (2,800 mi; 2,430 nmi) with 2 external fuel tanks
- **Service ceiling:** 18,000 m (59,100 ft)
- **Rate of climb:** >280 m/s (>55,000 ft/min)
- **Wing loading:**
  - **With 50% fuel:** 408 kg/m² (84.9 lb/ft²)
  - **With full internal fuel:** 500.8 kg/m² ()
- **Thrust/weight:** 1.13 at 50% fuel (0.92 with full internal fuel)
- **Maximum *g*-load:** +9 g

Armament

- **Guns:** 1 × internal 30 mm Gryazev-Shipunov GSh-30-1 autocannon with 150 rounds
- **Hardpoints:** 12 hardpoints, consisting of 2 wingtip rails, and 10 wing and fuselage stations with a capacity of 8,000 kg (17,630 lb) of ordnance and provisions to carry combinations of:

Airbus A380



Variant	**A380-800**
Cockpit crew	**Two**
seating	**575 Typical, 853 Max** **555: 22F + 96J + 437Y**
Exit limit	**868: 538 lower + 330 upper deck**
cargo	**175.2 m^3 (6,190 cu ft)**
Length	**72.72 m (238 ft 7 in)**
Wingspan	**79.75 m (261 ft 8 in)**
Height	**24.09 m (79 ft 0 in)**
Fuselage	**Width: 7.14 m (23 ft 5 in)**

	Height: 8.41 m (27 ft 7 in)
Cabin width[373]	**6.50 m (21 ft 4 in) main deck** **5.80 m (19 ft 0 in) upper deck**
Cabin length[373]	**49.9 m (163 ft 9 in) main deck** **44.93 m (147 ft 5 in) upper deck**
Wing[374]	**845 m² (9,100 sq ft), AR 7.53, sweep 33.5°**
MTOW	**575 t (1,268,000 lb)**
OEW	**277 t (611,000 lb)**
Max. payload	**84 t (185,000 lb)**
Fuel capacity	**253 983 kg / 559 937 lb**
Engines (4 ×)	**GP7200 / Trent 900**
Thrust (4 ×)	**332.44–356.81 kN (74,740–80,210 lbf)**
MMo[373]	**Mach 0.89 (945 km/h; 511 kn)]**
Cruise speed	**Mach 0.85 (903 km/h; 488 kn)**
Landing speed	**138 kn (256 km/h)**
Takeoff (MTOW, SL, ISA)	**3,000 m (9,800 ft)**
Range	**14,800 km / 8,000 nmi**
Service ceiling	**13,100 m (43,000 ft)**

Layout of supersonic aircraft and explain the design peculiarities

Supersonic flight brings with it substantial technical challenges, as the aerodynamics of supersonic flight are dramatically different from those of subsonic flight (i.e., flight at speeds slower than that of sound). In particular, aerodynamic drag rises sharply as the aircraft passes the transonic regime, requiring much greater engine power and more streamlined airframes.

Wings

To keep drag low, wing span must be limited, which also reduces the aerodynamic efficiency when flying slowly. Since a supersonic aircraft must take off and land at a relatively slow speed, its aerodynamic design must be a compromise between the requirements for both ends of the speed range.

One approach to resolving this compromise is the use of a variable-geometry wing, commonly known as the "swing-wing," which spreads wide for low-speed flight and then sweeps sharply, usually backwards, for supersonic flight. However, swinging affects the longitudinal trim of the aircraft and the swinging mechanism adds weight and cost.

Heating

Another problem is the heat generated by friction as the air flows over the aircraft. Most supersonic designs use aluminium alloys such as Duralumin, which are cheap and easy to work but lose their strength quickly at high temperatures. This limits maximum speed to around Mach 2.2.

Most supersonic aircraft, including many military fighter aircraft, are designed to spend most of their flight at subsonic speeds, and only to exceed the speed of sound for short periods such as when intercepting an enemy aircraft. A smaller number, such as the Lockheed SR-71 Blackbird reconnaissance aircraft and the Concorde supersonic airliner, have been designed to cruise continuously at speeds above the speed of sound, and with these designs the problems of supersonic flight are more severe.

Engines

Some early supersonic aircraft, including the first, relied on rocket power to provide the necessary thrust, although rockets burn a lot of fuel and so flight times were short. Early turbojets were more fuel-efficient but did not have enough thrust and some experimental aircraft were fitted with both a turbojet for low-speed flight and a rocket engine for supersonic flight. The invention of the afterburner, in which extra fuel is burned in the jet exhaust, made these mixed powerplant types obsolete. The turbofan engine passes additional cold air around the engine core, further increasing its fuel efficiency, and supersonic aircraft today are powered by turbofans fitted with afterburners.

Supersonic aircraft usually use low bypass turbofans as they have acceptable efficiency below the speed of sound as well as above; or if supercruise is needed turbojet engines may be desirable as they give less nacelle drag at supersonic speeds. The Pratt & Whitney J58 engines of the Lockheed SR-71 Blackbird operated in 2 ways, taking off and landing as turbojets with no bypass, but bypassing some of the compressor air to the afterburner at higher speeds. This allowed the Blackbird to fly at over Mach 3, faster than any other production aircraft. The heating effect of air friction at these speeds meant that a special fuel had to be developed which did not break down in the heat and clog the fuel pipes on its way to the burner.

Another high-speed powerplant is the ramjet. This needs to be flying fairly fast before it will work at all.

Transonic flight

Airflow can speed up or slow down locally at different points over an aircraft. In the region around Mach 1, some areas may experience supersonic flow while others are subsonic. This regime is called transonic flight. As the aircraft speed changes, pressure waves will form or move around. This can affect the trim, stability and controllability of the aircraft, and the designer needs to ensure that these effects are taken into account at all speeds.

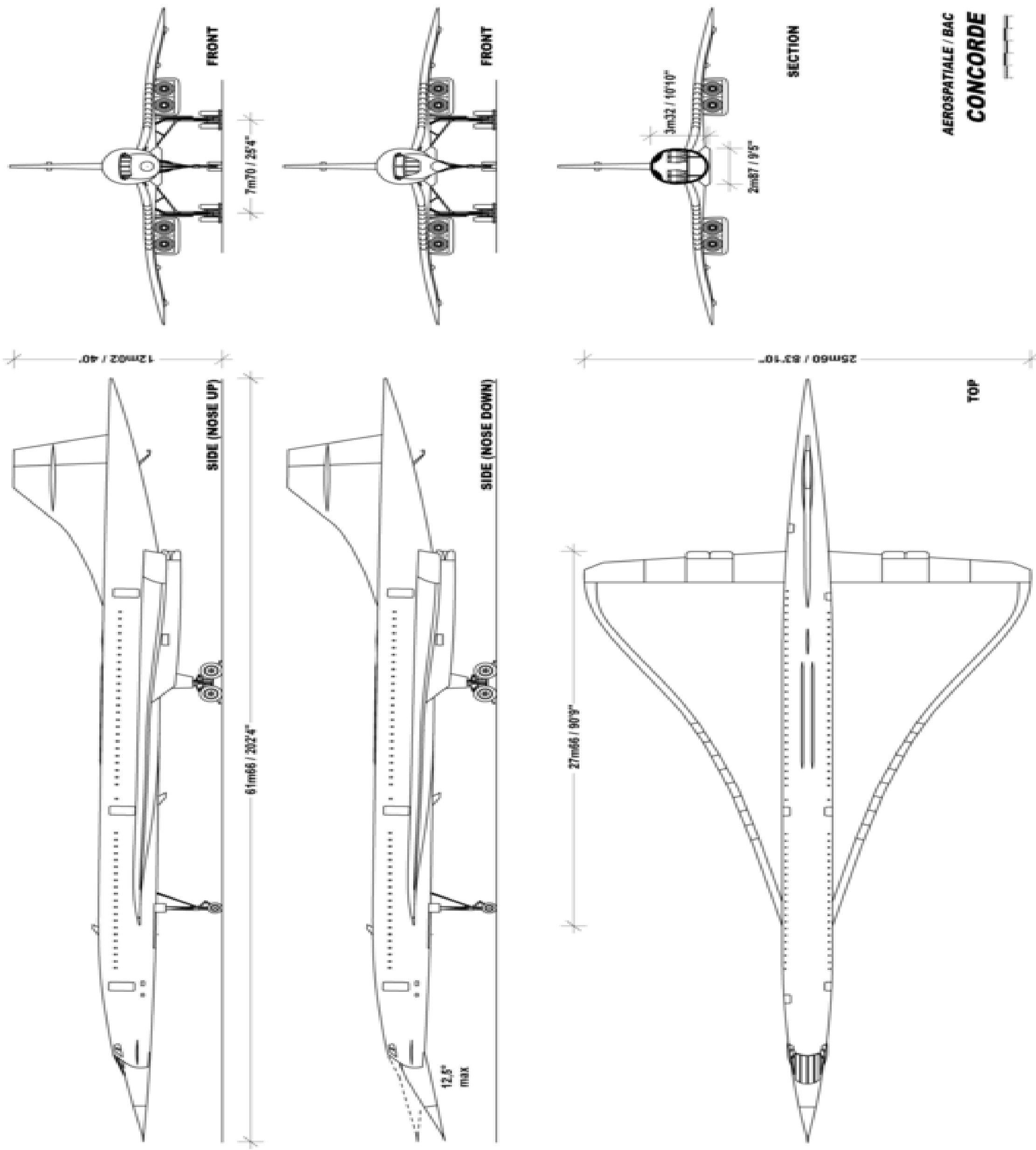
Hypersonic flight

Flight at speeds above about Mach 5 is often referred to as hypersonic. In this region the problems of drag and heating are even more acute. It is difficult to make materials which can stand the forces and temperatures generated by air resistance at these speeds, and hypersonic flight for any significant length of time has not yet been achieved.

Sonic boom

A sonic boom is the sound associated with the shock waves created whenever an object traveling through the air travels faster than the speed of sound. Sonic booms generate significant amounts of sound energy, sounding similar to an explosion or a thunder clap to the human ear. The crack of a supersonic bullet passing overhead or the crack of a bullwhip are examples of a sonic boom in miniature.

Sonic booms due to large supersonic aircraft can be particularly loud and startling, tend to awaken people, and may cause minor damage to some structures. They led to prohibition of routine supersonic flight over land. Although they cannot be completely prevented, research suggests that with careful shaping of the vehicle the nuisance due to them may be reduced to the point that overland supersonic flight may become a practical option.



Thrust-to-weight ratio

Thrust-to-weight ratio is a dimensionless ratio of thrust to weight of a rocket, jet engine, propeller engine, or a vehicle propelled by such an engine that indicates the performance of the engine or vehicle.

The instantaneous thrust-to-weight ratio of a vehicle varies continually during operation due to progressive consumption of fuel or propellant and in some cases a gravity gradient. The thrust-to-weight ratio based on initial thrust and weight is often published and used as a figure of merit for quantitative comparison of the initial performance of vehicles.

Calculation

The thrust-to-weight ratio can be calculated by dividing the thrust (in SI units – in newtons) by the weight (in newtons) of the engine or vehicle. It is a dimensionless quantity. Note that the thrust can also be measured in pound-force (lbf) provided the weight is measured in pounds (lb); the division of these two values still gives the numerically correct thrust-to-weight ratio. For valid comparison of the initial thrust-to-weight ratio of two or more engines or vehicles, thrust must be measured under controlled conditions.

The thrust-to-weight ratio and wing loading are the two most important parameters in determining the performance of an aircraft. For example, the thrust-to-weight ratio of a combat aircraft is a good indicator of the maneuverability of the aircraft.

The thrust-to-weight ratio varies continually during a flight. Thrust varies with throttle setting, airspeed, altitude and air temperature. Weight varies with fuel burn and changes of payload. For aircraft, the quoted thrust-to-weight ratio is often the maximum static thrust at sea-level divided by the maximum takeoff weight.

In cruising flight, the thrust-to-weight ratio of an aircraft is the inverse of the lift-to-drag ratio because thrust is the inverse of drag, and weight is the inverse of lift.

$$\left(\frac{T}{W}\right)_{cruise} = \frac{1}{\left(\frac{L}{D}\right)_{cruise}}$$

Propeller-driven aircraft

For propeller-driven aircraft, the thrust-to-weight ratio can be calculated as follows:

$$\frac{T}{W} = \left(\frac{550\eta_p}{V}\right)\left(\frac{hp}{W}\right)$$

where propulsive efficiency is typically 0.8 and V is true airspeed in feet per second.

Examples

	PAX	*Range* (nm)	M_{TO} (kg, lb)	*T/W*
Business jets				
Falcon 2000	19	3000	15 875, 35 000	0.327
Gulfstream V	14	6500	40 370, 89 000	0.332
Learjet 45	10	2200	8 845, 19 500	0.359
Canadair RJER	50	2270	23 133, 48 800	–
Beechcft 400A	8	1690	7 303, 16 100	0.360
Hawker 100	10	3010	14 061, 31 000	0.340
Citation	11	3300	15 650, 34 500	0.371
Commercial jets				
Fokker 100	107	1680	44 450, 98 000	0.308
Romero 1-11	109	1480	47 400, 104 500	0.289
RJ100	112	2090	44 000, 97 000	0.290
B717-200	106	1460	49 895, 110 000	0.291
A318-100	107	2350	64 500, 142 200	0.330

Weight groups for a aircraft

Civil Aircraft

Structure group (*MSTR* = *MFU* + *MW* + *MHT* + *MVTMN* + *MPY* + *MUC* + *MMISC*)

_ Fuselage group (*MFU*)

_ Wing group (*MW*): includes all structural items (e.g., flaps and winglets)

_ H-tail group (*MHT*)

_ V-tail group (*MVT*)

_ Nacelle group (*MN* and *MPY*) (nacelle and pylon)

_ Undercarriage group (*MUC*)

_ Miscellaneous (*MMISC*) (e.g., delta wing)

The basic structure of the aircraft – the fuselage shell (seats are listed separately under the Furnishing group) is as follows:

Power plant group (*MPP* = *ME* + *MTR* + *MEC* + *MFS* + *MOI*) (8.7)

_ Dry-equipped engine (*ME*)

_ Thrust reverser (*MTR*)

_ Engine control system (*MEC*)

_ Fuel system (*MFS*)

_ Engine oil system (*MOI*)

The power plant group comes as a package, with all items dedicated to the power plant installation. These are mostly bought-out items supplied by specialists:

Systems group (*MSYS* = *MECS* + *MFC* + *MHP* + *MELEC* + *MINS* + *MAV*) (8.8)

_ Environmental control system (*MECS*)

_ Flight-control system (*MFC*)

_ Hydraulic and pneumatic system (*MHP*) (sometimes grouped with other systems)
_ Electrical system (*MELEC*)
_ Instrument system (*MINS*)
_ Avionics system (*MAV*)

The systems group includes a variety of equipment, all vendor-supplied, bought-out items:
Furnishing group (*MFUR* = *MSEAT* + *MOX* + *MPN*) (8.9)
_ Seat, galleys, and other furnishings (*MSEAT*)
_ Oxygen system (*MOX*)
_ Paint (*MPN*)

Most of the weight is in the fuselage, yet the furnishings are itemized under different headings. Paint can be quite heavy. A well-painted B737 with airline livery can use as much as 75 kg of paint:
Contingencies (*MCONT*)
_ This is a margin to allow unspecific weight growth (*MCONT*).
The MEM is the total of the previous twenty-two items. This is the weight of the complete aircraft as it comes off the production line to be come airborne for the first time.

Add the following items to the MEM to obtain the OEM:

_ Crew: flight and cabin crews (*MCREW*)
_ Consumables: food, water, and so forth (*MCON*)

The OEM is when the aircraft is ready for operation.

Add the payload and requisite fuel to obtain the MRM. At the takeoff point at the edge of the runway, the MRM becomes the MTOM = (MRM – taxi fuel):

_ Payload (*MPL*) (passengers at 90 kg per passenger, including baggage)

_ Fuel (*MFUEL*) (for the design range, which may not fill all tanks)

MTOM: The aircraft at the end of the runway is ready for takeoff.

For civil aircraft, the MTOM is equal to

$$(MFU) + (MW) + (MHT) + (MVT) + (MN) + (MPY) + (MUC) + (MMISC)$$
$$+(ME) + (MTR) + (MEC) + (MFS) + (MOI) + (MECS) + (MFC) + (MHP)$$
$$+(MELEC) + (MINS) + (MAV) + (MSEAT) + (MOX) + (MPN) + (MCONT)$$
$$+(MCREW) + (MCONS) + MPL + MFUEL$$

Unit III

Prioritize and explain the factors to be considered for a Fuselage Design.

Fuselage Design

Functional Analysis and Design Flowchart

An early stage in the fuselage design is the functional analysis, which prepares a platform for a systematic approach. Depending upon the aircraft type, desired mission, aircraft configuration, and type of payload, the function of the fuselage may vary a great deal. However, for the majority of aircraft, the fuselage primary function is to accommodate the payload. By definition, the payload is the useful load that the aircraft is intended to carry. Payload does not basically include pilot, crew, or fuel. Therefore, it mainly contains passengers, luggage, and cargo. Therefore, the fuselage is defined as a shell containing the payload which must be carried a certain range at a specified speed. The payload accommodation must allow for a quick loading before take-off and a rapid unloading after landing. In addition, in order to reduce aircraft drag, a few other major components and systems – such as landing gear, engine, fuel system, and power transmission system – are highly likely to be enclosed by the fuselage. Therefore, for the fuselage, a couple of secondary functions are defined as listed in Table

Table 7.1 Functional analysis of the fuselage

No.	Functions and features	Description
1	Primary function	Accommodate the payload
2	Secondary functions	Accommodate crew members Accommodate flight attendants and other technical personnel Provide space for landing gear (if retracted inside fuselage) Provide space for engine (if inside fuselage) Provide space for fuel tanks (if inside fuselage) Provide sufficient room for systems (electric, hydraulic, mechanical, radio, etc.) Provide structural arm for empennage Keep the integrity of the aircraft structure (e.g., hold the wing)
3	Desired features and expectations	Generate the lowest drag Contribute positively to the lift generation Low weight Provide passenger/pilot/crew comfort Carry structural flight loads External symmetry Loading and unloading effectiveness Safe against environmental hazards (e.g., lightning) Low wetted area

In general, the fuselage is the most suitable aircraft component for housing the pilot cockpit, where the best location is the nose. In the case of an airliner, the flight crew and

other personnel also needs accommodation, which can be considered to be seated in the passenger cabin. The human attendants' (pilot, crew, passengers) accommodation by the fuselage must offer protection against climatic factors such as cold, low pressure, and very high wind speed. In case of a large engine, the fuselage should also keep the flight attendants protected from external noise, such as the engine's loud noise. The extents of comfort which must be provided by the fuselage to the human attendants are specified by the regulations and will be described in Section 7.4.
Another group of secondary functions concerns the non-human items such as landing gear, engine, electro-mechanical systems, and fuel tank. For these items, comfort is not a requirement. However, each non-human item that fits inside the fuselage requires specific requirements that will be discussed in later sections. The secondary requirements are not all required for all aircraft; each item is considered if it has been specified in the aircraft configuration design phase.
Other than fuselage functions, there are a few expectations that are recommended to be considered during the fuselage design process. The expectations include low weight, low drag, contributing positively to the lift generation, external symmetry, and safety against environmental hazards such as lightning. The fuselage drag usually contributes 30–50% of the aircraft zero-lift drag (CDo). Furthermore, the fuselage may be aerodynamically designed such that it provides as much as 50% of the total lift. For instance, in the fighter aircraft Mikoyan MIG-29 , about 40% of the total lift is created by the lift generating center fuselage. Furthermore, in the reconnaissance aircraft Lockheed SR-71 Blackbird, about 30% of the aircraft lift is generated by the fuselage. It is interesting to note that, in most General Aviation (GA) and transport aircraft, only as much as about 5% of the aircraft lift is produced by the fuselage.

Two major fuselage parameters that must be determined during the design process are:
(i) fuselage length (Lf) and (ii) maximum diameter (Df). The fuselage configuration as well as these two parameters are functions of several design requirements. In general, the following are the fuselage design requirements:

Other than fuselage functions, there are a few expectations that are recommended to be considered during the fuselage design process. The expectations include low weight, low drag, contributing positively to the lift generation, external symmetry, and safety against environmental hazards such as lightning. The fuselage drag usually contributes 30–50% of the aircraft zero-lift drag (CDo). Furthermore, the fuselage may be aerodynamically designed such that it provides as much as 50% of the total lift. For instance, in the fighter aircraft Mikoyan MIG-29 , about 40% of the total lift is created by the lift generating center fuselage. Furthermore, in the reconnaissance aircraft Lockheed SR-71 Blackbird, about 30% of the aircraft lift is generated by the fuselage. It is interesting to note that, in most General Aviation (GA) and transport aircraft, only as much as about 5% of the aircraft lift is produced by the fuselage.

Two major fuselage parameters that must be determined during the design process are:

(i) fuselage length (Lf) and (ii) maximum diameter (Df). The fuselage configuration as well as these two parameters are functions of several design requirements. In general, the following are the fuselage design requirements:

1. accommodation requirement;
2. operational and mission requirements;
3. airworthiness requirement;
4. crashworthiness requirement;
5. aerodynamic requirement;
6. aircraft stability requirement;
7. low weight;
8. low wetted area and low side area;
9. symmetry;
10. structural integrity and strength;
11. maintainability;
12. manufacturability;
13. cost;
14. long life;
15. radar detectability.

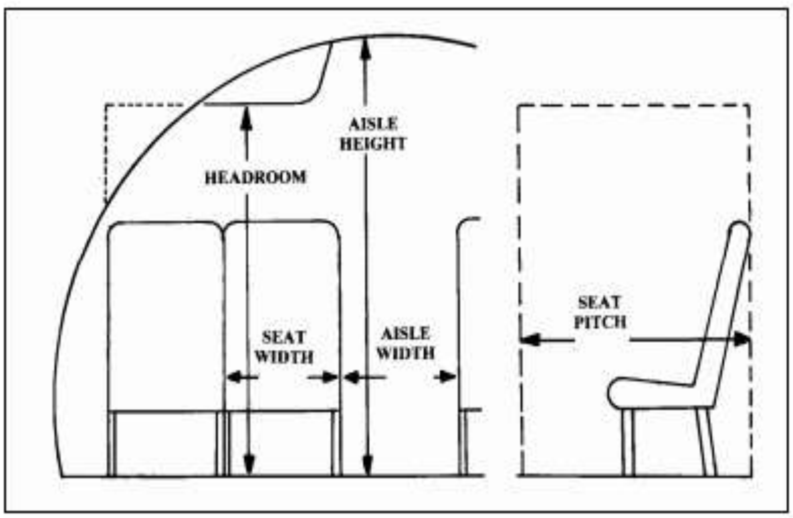
Fuselage cross-section and cargo compartment

Today's passenger aircraft have a constant fuselage cross-section in the central section. This design reduces the production costs (same frames; simply instead of doubly curved surfaces, i.e. a sheet of metal can be unwound over the fuselage) and makes it possible to construct aircraft variants with a lengthened or shortened fuselage. In this section we are going to examine the cross-section of this central fuselage section. In order to accommodate a specific number of passengers, the fuselage can be long and narrow or, conversely, short and wide. As the fuselage contributes approximately 25% to 50 % of an aircraft's total drag, it is especially important to ensure that it has a low-drag shape. A fuselage fineness ratio of approximately 6 provides the smallest tube drag1. However, as a longer fuselage leads to a longer tail lever arm, and therefore to smaller empennages and lower tail drag, a fineness ratio of 8 is seen as the ideal. Stretched versions of an aircraft can have fineness ratios of 14, and shorter versions will scarcely be less than 5. If one opts for a fineness ratio of 8 for the first version of a new type of aircraft, one obtains a low-drag fuselage that leaves the option open of constructing shorter or stretched versions at a later stage. The average fineness ratio for passenger planes is about 9.

If we work on the basis of this average fineness ratio, the number of seats abreast is as shown in equation (6.1).

$$n_{SA} = 0.45 \cdot \sqrt{n_{PAX}} \quad .$$

A circular or near-circular cross-section is suitable for a pressure cabin for reasons of strength. If no baggage is to be transported under the cabin floor, the fuselage can be flattened out at the bottom (Fokker 50, for example). The fuselage cross-section can also be composed of two overlapping circular cross-sections. Thus, special requirements in terms of the ratio of dimensions for the cabin and cargo compartment can be met. The two circles can be on top of each other or next to each other. Such a fuselage cross-section is called a *double bubble*. An alternative to the *double bubble* is an oval fuselage. For an aircraft **without a pressure cabin,** a **rectangular cross-section** is cheaper to produce. Furthermore, in small aircraft, a rectangular cross-section also provides more space for passengers sitting in the window seats (Shorts 330 and 360, for example).



Definition of key cabin and seat dimensions

	First class	Economy	High density/ small aircraft
Seat pitch (in.)	38–40	34–36	30–32
Seat width (in.)	20–28	17–22	16–18
Headroom (in.)	>65	>65	–
Aisle width (in.)	20–28	18–20	≥12
Aisle height (in.)	>76	>76	>60
Passengers per cabin staff (international-domestic)	16–20	31–36	≤50
Passengers per lavatory (40″ × 40″)	10–20	40–60	40–60
Galley volume per passenger (ft³/pass)	5–8	1–2	0–1

Typical cabin and seat dimensions

The certification regulations define minimum requirements for the **width and number of aisles**. However, the figures in the certification regulations should be seen as minimum safety standards, which are, for example, intended to allow successful emergency evacuation. Today's comfort standards require larger aisle widths and fewer seats at the aisles than prescribed.

JAR 25.815 **Width of aisle**

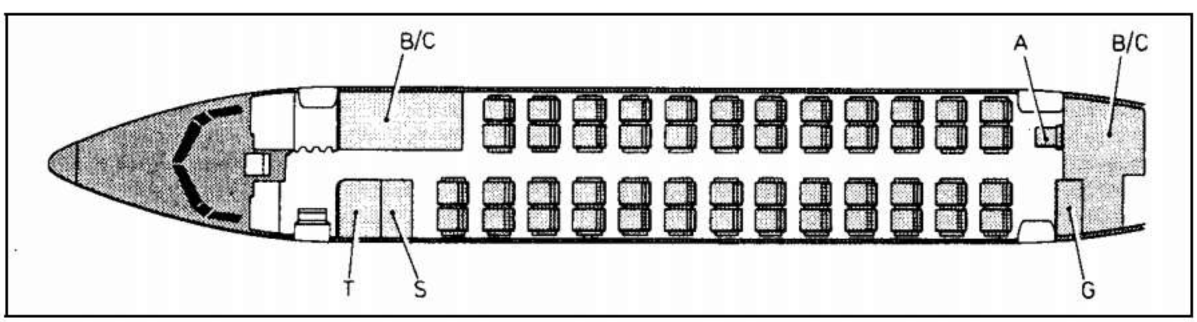
The passenger aisle width at any point between seats must equal or exceed the values in the following table:

Passenger seating capacity	Minimum passenger aisle width (inches)	
	Less than 25 inches from floor	25 inches and more from floor
10 or less	12 *	15
11 to 19	12	20
20 or more	15	20
	* A narrower width not less than 9 inches may be approved when substantiated by tests found necessary by the authority.	

A trolley has a width of approximately 12 inches. If the width of the aisle is 24 inches, it is possible to steer the trolley past a person standing in the aisle. This increases passenger comfort.

JAR 25.817 **Maximum number of seats abreast**

On aeroplanes having only one passenger aisle, no more than 3 seats abreast may be placed on each side of the aisle in any one row.



Cabin design of the Fokker 50. Baggage and cargo are also accommodated in the cabin. A: attendant seat, B: baggage, C: cargo, G: galley, S: stowage, wardrobe, T: toilet.

Cargo compartment

The fuselage must have adequate volume to accommodate baggage and cargo in addition to passengers. After the cabin cross-section has been drawn, the volume of the cargo compartment can be checked:

1.) The necessary volume can be calculated from the required mass of the cargo and the baggage (see Table 3.3) with the aid of the density. **Average densities** according to [TORENBEEK 88] are:

- Baggage: 170 kg/m³,
- Cargo: 160 kg/m³.

2.) On more modern planes, 0.05 m³ to 0.065 m³ per passenger is available for carry-on baggage, in the form of overhead stowage compartments. In practice it has been shown that this volume is in fact utilized because especially business passengers insist on taking their baggage into the cabin with them. The *required* cargo compartment volume $V_{CARGO\_COMPARTMENT}$ is consequently calculated from the required volume for baggage and cargo $\left(V_{BAGGGAGE} + V_{CARGO}\right)$ minus the volume of the overhead stowage compartments $V_{OVERHEAD\_STOWAGE}$

$$V_{CARGO\_COMPARTMENT} \geq \left(V_{BAGGAGE} + V_{CARGO}\right) - V_{OVERHEAD\_STOWAGE} \quad .$$

3.) The *available* cargo compartment volume can be roughly calculated. The following applies:

$$V_{CARGO\_COMPARTMENT} = d_F \cdot \frac{l_F}{d_F} \cdot S_{CARGO\_COMPARTMENT} \cdot k_{CARGO\_COMPARTMENT} \quad .$$

$S_{CARGO\_COMPARTMENT}$ is the usable cross-section area of the cargo compartment, measured according to the drawn fuselage cross-section.

$k_{CARGO\_COMPARTMENT}$ defines how much of the total length of the fuselage can be used as a cargo compartment. $k_{CARGO\_COMPARTMENT}$ assumes values of between 0.35 and 0.55. The smaller value applies to regional planes and the larger values to widebody airliners.

4.) To permit fast loading and unloading, standardized **containers** should be used wherever possible. Therefore, the shape of the cargo compartments is important in addition to their volume. The drawn cabin cross-section must consequently be adapted to allow the use of standard containers (as far as possible).

Tabulate and explain the weight breakdown for fuselage group. (Torenberk)

\ detailed subdivision of all weight con-
ributions is given in Table D-1. Not all
items mentioned are applicabl to each con-
figuration. For example: main l nding gear
loors may be counted as part of the wing
roup if the main landing gear is retracted
nto the wing.

omputation takes place in four stages.

TAGE 1: Calculation of the weight of the
uselage shell, which carries the primary
oads and contributes approximately a third
o one half of the fuselage weight (gross
shell weight).

STAGE 2: The weight of material removed for
cutouts and openings is subtracted from the
gross shell weight (net shell weight).

STAGE 3: Weight is added for the materials
used to fill the holes and for the surround
structure required to recover strength (mod-
ified shell weight).

STAGE 4: Weight contributions and penalties
are added for floors, bulkheads, support
structure and various additional items, re-
sulting in the total fuselage group weight.

GROSS SHELL	
	SKIN
	STRINGERS AND LONGERONS
	FRAMES
GROSS SHELL MODIFICATIONS	
	MATERIAL REMOVED
	PASSENGER AND CREW DOORS
	CARGO HOLD DOORS
	(LARGE) FREIGHT HOLD DOORS & RAMPS
	ESCAPE HATCHES
	ENCLOSURES AND WINDSHIELDS
	WINDOWS & PORTS
	LANDING GEAR DOORS
	EQUIPMENT ACCESS DOORS
	SPEEDBRAKES

MODIFIED SHELL
FLOORING
PASSENGER CABIN FLOOR, BEAMS AND RAILS
FREIGHT COMPARTMENT FLOOR & LOADING SYST.
CARGO/BAGGAGE HOLD FLOOR
FLIGHT DECK FLOOR
EQUIPMENT BAY FLOOR
BULKHEADS AND PRESSURE FLOORS
FRONT PRESSURE BULKHEAD
REAR PRESSURE BULKHEAD
LANDING GEAR WHEELBAYS
COCKPIT BULKHEAD
SPECIAL (MOUNTING) FRAMES
SUPPORT STRUCTURE
WING-FUSELAGE INTERCONNECTION
TAILPLANE SUPPORT
ENGINE(S) SUPPORT
LANDING GEAR SUPPORT
FUSELAGE TANKS SUPPORT
ADDITIONAL WEIGHT ITEMS
FAIRINGS & FILLETS
AIRSCOOPS
STAIRS
PAINT, SEALING, REDUX
FASTENERS, JOINTS
MISCELLANUOUS
TOTAL BODY GROUP WEIGHT

Fuselage of airliners and general aviation aircraft.

The first design step, after identification of the payload and design requirements, is to decide on the fuselage configuration and determine the fuselage internal arrangement. This decision is very important and will influence all fuselage parameters. Fuselage configuration design is a conceptual design but at the fuselage level, and does not involve detailed calculations. Indeed, the configuration design of the fuselage requires several skills and long experience. At this point, the external shape as well as the internal arrangement will be determined. Since this is a type of conceptual design, the designer may use a hand drawing to present the selected configuration.

In some cases, a design may look desirable but may not be feasible. Thus, when a designer is deciding about the best seating arrangement, or the best location for cargo, he/she must already be aware of the fundamental solutions. For instance, a short fuselage with low weight and high drag is more desired, or a long fuselage with high weight and low drag. This is a fundamental question of cost versus performance. For a home-build designer the first alternative is the best option, while for a military aircraft designer the second alternative is the most desirable. Therefore, the designer should have the priority list upfront prior to the fuselage configuration design.

A conventional fuselage may consist of the following sections: pilot and crew station (cockpit), passenger compartment (cabin), luggage room, cargo compartment, nose section, doors, windows, rear section, fuel tanks, necessary flight carrying items (e.g., food, water), internal systems (i.e., electrical, mechanical, and hydraulic), and engine(s). Each section needs to be designed separately, since each has a unique design requirement. However, at this stage of design, the locations of these sections relative to each other need to be determined. Figure 7.2 illustrates a side view of four generic fuselage external shapes (note that the figures are not in scale). Although these external shapes have different aerodynamic characteristics, each one is optimum to serve for a particular mission.

The fuselage configuration is also a function of the internal arrangements. In order to specify the location for each internal item, one must first identify and decide what item/component is supposed to be accommodated. Figure 7.3 illustrates a side view of the fuselage for two typical aircraft with their internal arrangements: a civil passenger and a fighter aircraft. The volume and external shape of the fuselage are functions of what is desired to be stored inside.

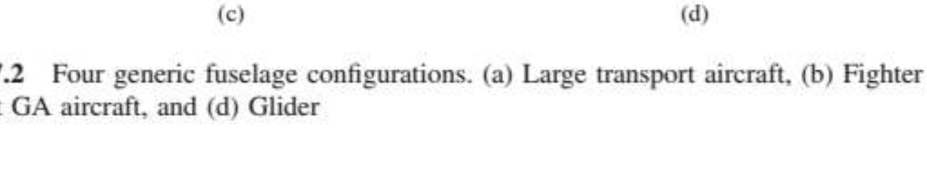


Figure 7.2 Four generic fuselage configurations. (a) Large transport aircraft, (b) Fighter aircraft, (c) Light GA aircraft, and (d) Glider

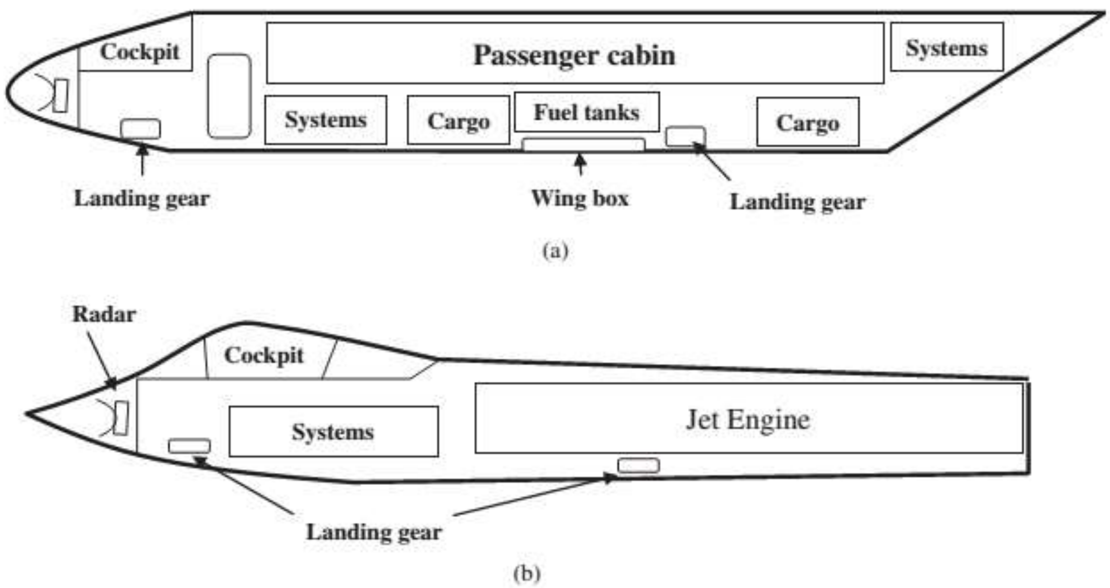


Figure 7.3 Internal arrangement of a civil passenger and a fighter aircraft. (a) Low-wing passenger aircraft, and (b) Fighter aircraft

In general, there are six basic rules for internal arrangement and to locate the allocated items inside the fuselage:

1. Keep the fuselage as small and compact as possible.
2. Arrangement to be symmetric from the top view as far as possible.
3. There must be sufficient space to accommodate all of the items.
4. Usable loads such as fuel must be close to the aircraft center of gravity.
5. The pilot cockpit must be allocated the most forward location of the fuselage, to enable the pilot to view the runway during take-off and landing.
6. Arrangements must be such that the aircraft center of gravity is close to the wing/fuselage aerodynamic center.

Furthermore, the requirements introduced in Section 7.2 must be considered.

Whenever all the fuselage sections are designed, the geometry and dimensions of each section will be finalized. For instance, when the fuel volume is calculated, the exact location will be determined. Or, when the landing gear is designed, the retraction system and landing gear storage will be specified. As a recommendation, try to keep the fuel out of the fuselage for the sake of flight attendants, since it may leak or catch fire in an emergency situation. Figure 7.4 compares the fuselage of three aircraft: a transport (Airbus A-321), a fighter (Sukhoi Su-27), and a GA (Piper PA-28-161 Cherokee Warrior II).

Passenger Cabin Design

When an aircraft is an airliner or is to transport passengers, the passenger compartment or cabin must be designed as part of the fuselage design. A variety of requirements including marketing, economic, and airworthiness regulations must be considered in a cabin design. As the cabin volume is increased, the fuselage volume is increased too which is not a desirable outcome. The number of passengers is the only major known parameter that the cabin designer must start with. However, the first step is to determine the number of seats to be placed abreast (n_S). The optimum fuselage length-to-diameter ratio $(L_f/D_f)_{opt}$ or slenderness ratio is a fundamental variable which must be determined by a systems engineering approach. Section 7.8 presents a technique to calculate the optimum slenderness ratio.

The cabin hardware which concerns passengers most is seating. Although passengers evaluate accommodation in a transport aircraft based on level of comfort, there are a number of minimum requirements which must be met. Comfort in a cabin is primarily dependent upon the following factors:

1. Adjustability of the seat and the available legroom, and headroom. It is desirable that each passenger seat has fore and aft travel, swivel, and reclining capability.
2. The room available to move about, including the aisle.
3. The number of lavatories, washrooms, and lounges.
4. Flight attendant services (drinks, meals, and snacks).
5. Air conditioning and pressurization.
6. Interior design including light (e.g., window), sound (or noise), and entertainment.
7. Carry-on bag compartment.
8. Number of flight attendants.

Beside the number of seats in each row, the following parameters should also be determined: seat pitch (P_S), seat width (W_S), aisle height, and aisle width (W_A). The seat pitch is defined as the distance between the back of one seat and the back of the next seat (side view). Passenger cabin parameters with six seats abreast are illustrated in Figure 7.13. The FAR 25 regulates various aspects of a cabin. For instance, Section 25.817 limits the number of seats on each side of an aisle to three and also

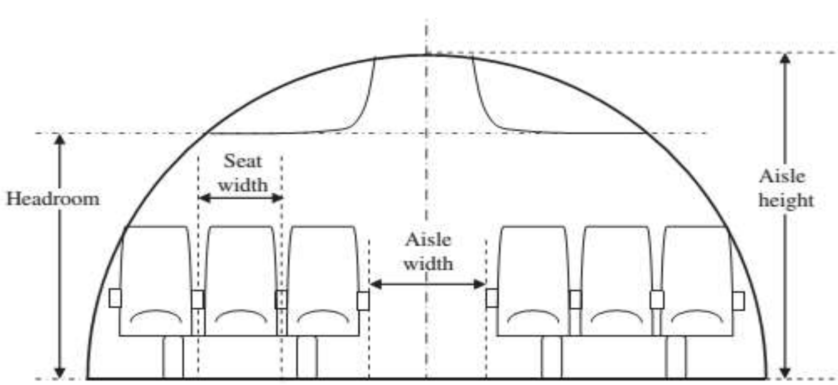


Figure 7.13 Passenger cabin parameters

the minimum permissible width of the aisle. Thus, an aircraft with more than six seats abreast is required to provide two aisles.

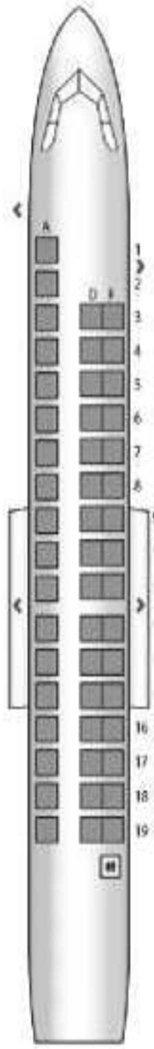
A twin-turbofan regional airliner with 50 passengers, three abreast at a seat pitch of 79 cm, has an aisle width of 43.2 cm, headroom of 146 cm, and seat width of 44 cm. In the Boeing 757, the first class seats are four abreast, at 96.5 cm pitch, while the tourist seat pitch is 81 or 86 cm, mainly six abreast in mixed arrangements. The typical Boeing 747-400 has 421 seats with a three-class configuration accommodation, with 42 business class seats on the upper deck, 24 first class in the front cabin, 29 business class in the middle cabin, and 326 economy class in the rear cabin on the main deck. The passenger seating of the Airbus A-340 (Figure 8.7), with 295–335 seats, is typically six abreast in first class, six abreast in business class, and eight abreast in economy, all with twin aisles.

Aisle width requirements from FAR 25 for transport aircraft

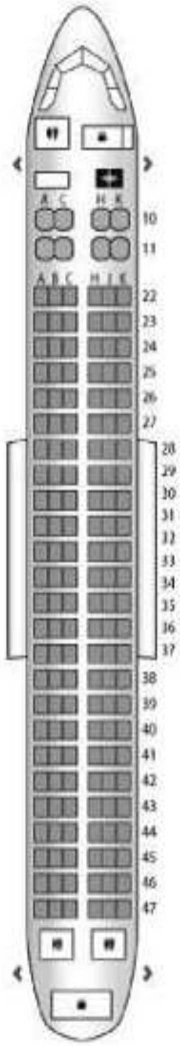
Passenger seating capacity	Minimum passenger aisle width (in.)	
	Less than 25 in. from floor	25 in. and more from floor
10 or less	12	15
11–19	12	20
20 or more	15	20

Recommended cabin data (in centimeters)

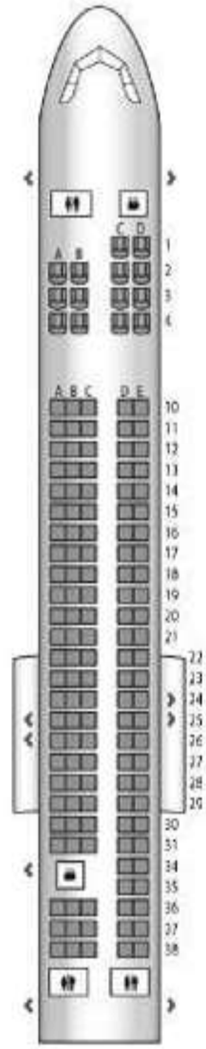
No.	Cabin parameter	GA aircraft	Transport aircraft		
			Economy		First class
			High density	Tourist	
1	Seat width (W_S)	38–43	42–46	48–55	60–75
2	Seat pitch (P_S)	55–65	65–72	75–86	92–104
3	Headroom	120–130	150–160	160–170	170–185
4	Aisle width (W_A)	35–40	40–50	43–53	60–70
5	Seatback angle (deg)	10–13	13–17	15–20	20–30



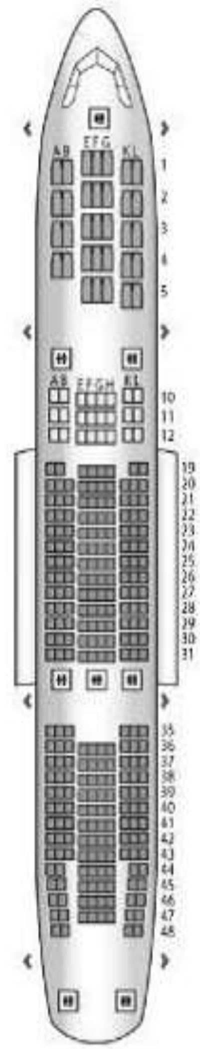
EMB-145
G:Galley,
L: Lavatory,
C: Closet



A-320-200
First two rows: First class



MD-88
First four rows: First class



B-777-200ER
First five rows: First class

Airplane Spatial-Weight Layout.

The development of the airplane layout contains three main stages:

1. Developing the spatial-weight layout that defines location inside the airplane of all loads: equipment, fuel, crew, payload, power plant and etc. (i.e. all the components of mass list). For military airplanes part of fuel and expendable combat load can be placed on hardpoints.

2. Developing the structural and load-carrying layout which means designing structural and load-carrying scheme of the airplane in general and load-carrying schemes of all of its units in particular and defining exact locations of main load-carrying elements: spars, ribs, bulkheads, beams, joints.

3. Updating the aerodynamic scheme by correlating locations of loads inside the airplane and load-carrying elements. As a result the dimensions and relative positions of the airplane units which define its external shape are defined more exactly.

Placement of the total load, the equipment and the airplane systems should satisfy the following requirements:

— providing the best crew operation environment;

— providing passenger comfort;

— providing the maximum operation efficiency of the equipment and the systems;

— providing the efficient usage of the internal fuselage volume $v_{ф}$ and the internal wing volume $v_{кр}$; it can be estimated by nominal density of empty equipped airplane

— providing the required balance of all possible airplane load variations, which can be achieved by placing variable load and consumable load (payload and fuel) as close as possible to the airplane center of mass or symmetrically to the airplane center of mass;

— providing the minimal moments of inertia.

While arranging the spatial-weight layout the following parameters are defined and updated:

- cockpit dimensions –
- passenger cabin dimensions –
- shape and size of fuselage cross-section
- shape and size of passenger cabin windows and doors
- dimensions of kitchens, wardrobes, water closets
- placement of passenger seats
- locations of emergency exits
- locations of cabin crew work places
- dimensions of baggage and cargo bays

(baggage and cargo bays can be increased for transporting large cargo with the decreased number of passengers);

- location and size of cargo doors
- placement of standard freight containers
- location of engines, dimensions of engine nacelles and engine pylons
- location and size of air intakes
- location of exhaust system
- location of the auxiliary power unit
- volume of fuel
- dimensions and location of the fuel tanks

While defining these parameters all of the decisions must be documented and references to the source of information that was used for justifying them must be listed. Then the locations of landing gear compartments or wheel nacelles are defined. Landing gear parameters chosen in section 3 are updated. The layout drawing should show the landing gear in both extended and retracted positions.

Functional kinematic diagrams of the gear retraction and extension are developed. Landing gear compartments (or wheel nacelles) should house the landing gear in the retracted position and strong load-carrying elements should transfer loads from the landing gear to the wing (or the fuselage) at landing. The fuel tank volume should be specified while dividing the fuel tanks into the groups of the fuel consumption. In order to minimize balance changes and to increase the fuel efficiency of passenger/transport airplanes, you should follow these simple rules:

— the fuel tank volume is calculated for the maximum range with the reduced payload;

— the fuel should be located as close as possible to the airplane center of mass;

— the fuel should be consumed separately from the front and rear tanks or the tank groups; thus consumption programming allow to keep the balance in the acceptable limits;

— the program of fuel consumption should be chosen in such a way that at the beginning of cruise flight the airplane center of mass shifts to the rear acceptable balance limit, to decrease the static stability margin and thus the balancing drag;

— for the same purpose fuel transfer from the front tanks or from the special balancing tanks to the additional tanks in the rear fuselage or in the fin should be considered for average- and long-range airplanes;

— fuel from the wing tip tanks should be consumed as later as possible, so it will provide unloading of the wing during the most part of flight and decrease bending stress at the most loaded wing root sections.

THE FIGHTER AIRCRAFT DESIGN SYSTEM

FADS is a collection of four related spreadsheet models that are designed to be used in the conceptual phase of the fighter aircraft design process. The models that comprise FADS are:

- Fighter Sizing Model (FSM)
- Range-Payload Model (RPM)
- Energy/Maneuverability Model (EMM)
- Cost Estimation Model (CEM).

A. Fighter Sizing Model (FSM)

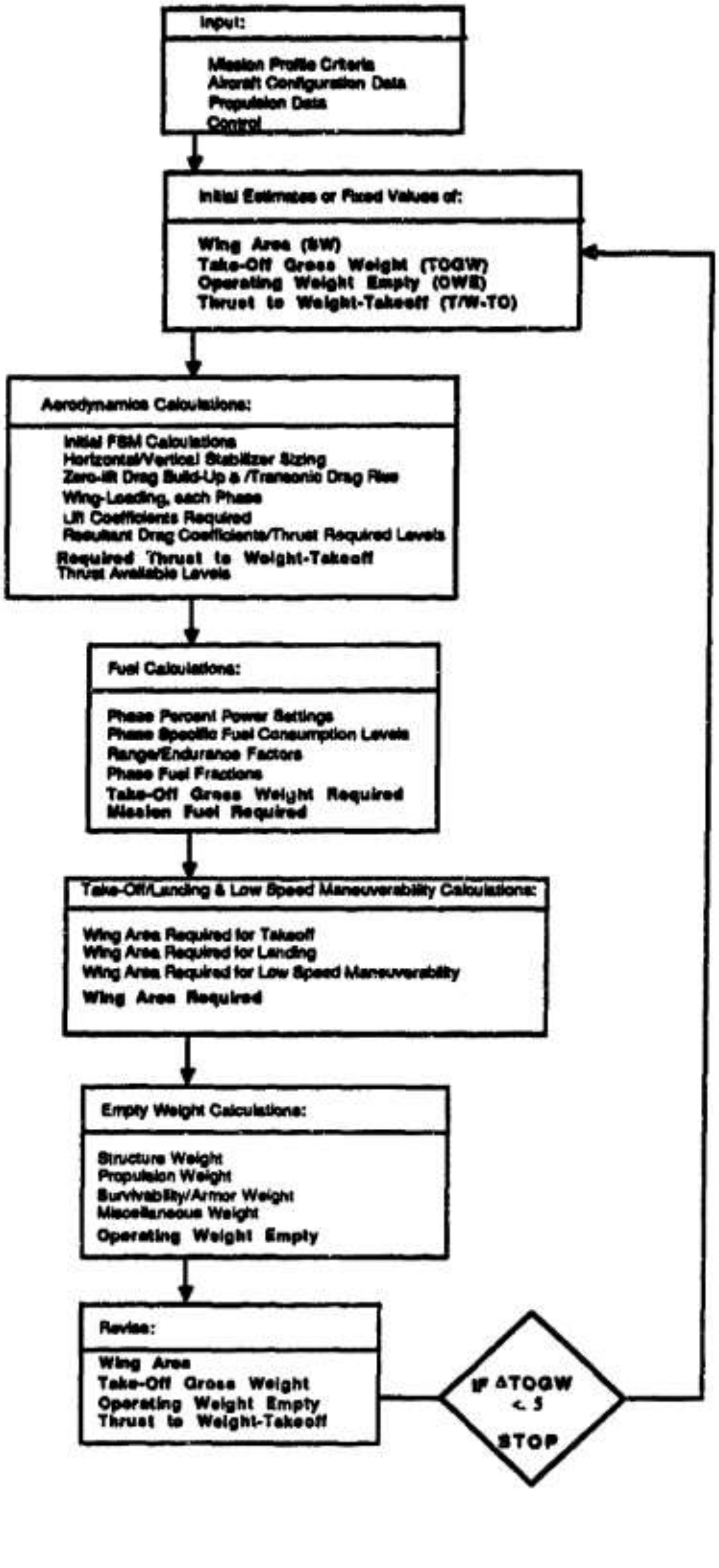
FSM can be run in a number of ways, depending on the control (CNTRL) inputs. By running the model without any calculation control inputs (W/S, Sw, T/W, T) the wing size, thrust required, and empty and gross weights are determined. In this mode of operation the program uses the mission profile, the required combat turn rate, and the take-off and landing distances for the aircraft sizing. If control inputs are used, the model overrides this procedure and uses the inputted constraints. In this second mode the specified performance may not be attained and the output will indicate if this occurs. The flowchart in Figure 2.1 depicts the generalized procedure used in the Fighter Sizing Model. There are two parts to the input data--tables and variables. FSM requires two types of input tables--the atmosphere characteristics and the engine specific fuel consumption and utilizes four types of input variables:

- Control (CNTRL)
- Mission Profile (MP)
- Aircraft Configuration (AC)
- Propulsion (PROP).

With this information, the model iterates until it converges on the design point. The design point is that point at which the aircraft gross weight changes by less than 0.5 pound with another iteration. The sizing model generates two separate outputs:

- Detail Output --lists all calculated variables in the order obtained
- Summary Output --lists inputs and outputs of primary interest.

In addition, the model tabulates those FSM input and output variable values that are required for RPM and EMM. This data can be transferred to the two off-design models to analyze the sized aircraft obtained in FSM.



Fighter Sizing Model Flow Chart

Weight and Balance Control of Large Aircraft /Multi Engine Aircraft

Establishing the Initial Weight of an Aircraft:

Prior to being placed into service, each aircraft is weighed and the empty weight and CG location established. New aircraft are normally weighed at the factory and are eligible to be placed into operation without reweighing if the weight and balance records were adjusted for alterations and modifications to the aircraft, such as interior reconfigurations

An aircraft transferred from one operator that has an approved weight and balance program to another operator with an approved program does not need to be weighed prior to use by the receiving operator unless more than 36 calendar months have elapsed since the last individual or fleet weighing, or unless some other modification to the aircraft warrants that the aircraft be weighed. Aircraft transferred, purchased, or leased from an operator without an approved weight and balance program, and that have not been modified or have been minimally modified, can be placed into service without being reweighed if the last weighing was accomplished by an acceptable method (for example, manufacturer's instructions or AC 43.13-2, Acceptable Methods, Techniques, and Practices—Aircraft Alterations) within the last 12 calendar months and a weight and balance change record was maintained by the operator. It is potentially unsafe to fail to reweigh an aircraft after it has been modified

When weighing large aircraft, compliance with the relevant manuals, operations specifications, or management specification is required to ensure that weight and balance requirements specified in the Aircraft Flight Manual (AFM) are met in accordance with approved limits. This provides information to the flight crew that allows the maximum payload to be carried safely.

Determining the Empty Weight and Empty Weight CG (EWCG)

When the aircraft is properly prepared for weighing, roll it onto the scales, and level it. The weights are measured at three weighing points: the two main wheel points and the nosewheel point. The empty weight and empty weight CG (EWCG) are determined by using the following steps with the results recorded in the weight and balance record for use in all future weight and balance computations.

1. Determine the moment index of each of the main-wheel points by multiplying the net weight (scale reading minus tare weight), in pounds, at

these points by the distance from the datum, in inches. Divide these numbers by the appropriate reduction factor.

2. Determine the moment index of the nosewheel weighing point by multiplying its net weight, in pounds, by its distance from the datum, in inches. Divide this by the reduction factor.

3. Determine the total weight by adding the net weight of the three weighing points and the total moment index by adding the moment indexes of each point.

4. Divide the total moment index by the total weight and multiply the result by the reduction factor. This gives the CG in inches from the datum.

5. Determine the distance of the CG behind the leading edge of the mean aerodynamic chord (LEMAC) by subtracting the distance between the datum and LEMAC from the distance between the datum and the CG.

6. Determine the EWCG in percentage of MAC (percent MAC) by using the formula

$$\text{EWCG in \% MAC} = \frac{\text{CG in inches from LEMAC} \times 100}{\text{MAC}}$$

Determining the Loaded CG of the Airplane in Percent MAC

A loading schedule is used to document compliance with the certificated weight and balance limitations contained in the manufacturer's AFM and weight and balance manual. The basic operating weight (BOW) and the operating index are entered into a loading schedule and the variables for a specific flight are entered as appropriate to determine the loaded weight and CG.

Operational Empty Weight (OEW)

Operational empty weight (OEW) is the basic empty weight or fleet empty weight plus operational items. The operator has two choices for maintaining OEW. The loading schedule may be utilized to compute the operational weight and balance of an individual aircraft, or the operator may choose to establish fleet empty weights for a fleet or group of aircraft.

Fleet Operating Empty Weights (FOEW)

An operator may choose to use one weight for a fleeter group of aircraft if the weight and CG of each aircraft is within the limits stated above for establishment of OEW. When the cumulative changes to an aircraft weight and balance log exceed the weight or CG limits for the established fleet weight, the empty weight for that aircraft should be reestablished. This may be done by moving the aircraft to another group, or reestablishing new fleet operating empty weights (FOEWs)

Determining the Correct Stabilizer Trim Setting

It is important before takeoff to set the stabilizer trim for the existing CG location. There are two ways the stabilizer trim setting systems may be calibrated: in percent MAC and in units airplane nose up (ANU).

If the stabilizer trim is calibrated in percent MAC, determine the CG location in percent MAC as has just been described, then set the stabilizer trim on the percentage figure thus determined. Some aircraft give the stabilizer trim setting in units of ANU that correspond with the location of the CG in percent MAC. When preparing for takeoff in an aircraft equipped with this system, first determine the CG in percent MAC in the way described above

Determining CG Changes Caused by Modifying the Cargo

Since large aircraft can carry substantial cargo, adding, subtracting, or moving any of the cargo from one hold to another can cause large shifts in the CG.

Effects of Loading or Off-loading Cargo

Both the weight and CG of an aircraft are changed when cargo is loaded or offloaded. In the following example, the new weight and CG are calculated after 2,500 pounds of cargo is offloaded from the forward cargo hold

Effects of Shifting Cargo from One Hold to Another

When cargo is shifted from one cargo hold to another, the CG changes, but the total weight of the aircraft remains the same.

Determining Cargo Pallet Loads and Floor Loading Limits

Each cargo hold has a structural floor loading limit based on the weight of the load and the area over which this weight is distributed. To determine the maximum weight of a loaded cargo pallet that can be carried in a cargo hold, divide its total weight, which includes the weight of the empty pallet and its tie down devices, by its area in square feet. This load per square foot must be equal to or less than the floor load limit.

Determining the Maximum Amount of Payload That Can Be Carried

The primary function of a transport or cargo aircraft is to carry payload, which is the portion of the useful load, passengers, or cargo that produces revenue. To determine the maximum amount of payload that can be carried, both the maximum limits for the aircraft and the trip limits imposed by the particular trip must be considered. In each of the following steps, the trip limit must be less than the maximum limit. If it is not, the maximum limit must be used.

Determining the Landing Weight

It is important to know the landing weight of the aircraft in order to set up the landing parameters and to be certain the aircraft is able to land safely at the intended destination.

Airplane Masses

Using the results of weight estimation, the list of the airplane masses is made that contains masses of all units included in the airplane take-off mass. These masses are grouped according to their functions. The total mass in the absolute form m_i (kg) and in the relative form m_i is defined for each group. Payload and fuel masses are not specified in this estimation. Their values are taken from the first approximation for take-off mass. The total mass obtained from the list of masses is the updated value of the airplane take-off mass - the second approximation for take-off mass.

№	Name	m_i kg	$\bar{m}_i$
I	AIRFRAME	xxx	xxx
	Wing	xxx	xxx
	Fuselage	xxx	xxx
	Empennage	xxx	xxx

	Landing gear Paint	xxx xxx	xxx
II	POWER PLANT Engines Propellers Engine mounting Engine nacelles or air intakes Exhaust system, thrust reversal Engine systems Fuel system units	xxx xxx xxx xxx xxx xxx xxx xxx	xxx
III A B	EQUIPMENT AND CONTROL SYSTEM Airplane equipment Hydraulics Electrical equipment Radio equipment Radar equipment Air navigation equipment Anti-ice system Control system Special equipment Passenger equipment Cargo handling equipment Armament, armor	xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx	xxx
IV	EMPTY AIRPLANE	xxx	xxx
V	MUNITIONS AND SERVICE LOAD Crew Survival equipment Munitions	xxx xxx xxx xxx	xxx
VI	EMPTY AIRPLANE EQUIPPED (IV+V)	xxx	xxx
VII	PAYLOAD Passengers Luggage Paid cargo, mail Shells, missiles, bombs	xxx xxx xxx xxx xxx	
VIII	FUEL Consumable fuel Air-navigation fuel margin External tank fuel	xxx xxx xxx xxx	xxx
IX	TOTAL LOAD (VII+VIII)	xxx	
X	TAKE-OFF MASS m_0^{II}	xxxx	

Example: Mass lists of Il-96-300 and Il-114 airplanes

Name of units and systems	Airplanes	
	IL-96-300	IL-114
	Mass, kg	
I. AIRFRAME	67159	6893
Wing	32718	2829
Fuselage	19865	2504
Tails	4984	640
Landing gear	9592	920
II. POWER PLANT	21933	2808
Engines:		
— engine (dry)	11800	1060
— engine accessories	2248	325
— thrust reverser	2280	-
Oil system	-	42
Propellers	-	430
Engine nacelles, mounting, exhaust system	1653	645
Engine pylons	2290	-
Control system of engines	86	64
Fuel system	855	109
Residual fuel	200	20
APU	521	113
III. EQUIPMENT	23065	5447

Electrical equipment	5084	1767
Radio equipment and cabin entertainment system	1006	225
Aircraft instrumentation, onboard automated control system and etc.	1614	631
Hydraulics	1654	216
Rudder and aileron control	1100	375
Lift augmentation control system	1574	138
Fire extinguishing system	391	67
Anti-ice system	145	59
Stationary oxygen system	85	21
High-altitude system (air-conditioning system and engine starter)	2078	374
Heat and noise insulation	1179	264
Water closets, water supply and sewerage systems	979	83
Kitchen appliances	338	27
Decoration, luggage compartments and partitions	2058	560
Seats for cockpit and cabin crew	250	67
Passenger seats	2757	439
Luggage equipment	547	124
Survival equipment mounting	226	10
Paint and coatings	325	55
Unaccounted parts	948	-
Total: Empty airplane	113431	15203
m_0	216000 kg	21000kg

Example: Mass lists of military airplanes

Units and Systems	Mass, kg						
	AlfaJet	F-16A	Jaguar S	Mirage 2000	A-10A	F-15C	Tornado
AIRFRAME	2055	3549	3343	3550	5620	6269	7330
Wing	636	970	720	1310	1700	1250	2250
Fuselage	810	1575	1380	1300	1587	3300	2650
Horizontal tail	90	128	156	-	190	272	268
Vertical tail	60	132	134	184	135	232	272
Nose landing gear	50	92	100	100	100	165	192
Main landing gear	210	424	440	450	470	745	818
Survival equipment (ejection seat, canopy)	170	175	180	173	165	190	370
Drag parachute, arresting hook, thrust reversal system	24	25	25	25	30	100	310
Paint, armor	5	28	208	8	1243	15	200
POWER PLANT	759	1787	1873	1858	1735	3765	2675
Engine	620	1540	1550	1602	1370	3280	1974
Fuel system	90	170	214	178	230	292	384
Engine control system	10	10	19	10	15	23	20
Engine starting system	20.5	46	47	48	40	90	127
Fire extinguishing system	18.5	21	43	20	80	80	170

EQUIPMENT	700	1445	1523	1670	1545	2360	2695
Avionics	180	610	520	670	606	795	1050
Electrical eq.	160	230	260	320	320	420	450
Oxygen and air-conditioning	120	144	143	150	119	285	215
Control system						260	
Hydraulics	240	461	450	390	500	550	760
Additional equipment	-	-	150	140	-	50	220
Gun without ammo	282	260	272	272	1000	260	350
EMPTY AIRPLANE	3796	7041	7011	7350	9900	12654	13050
WITH GUN	2414	4509	4809	4865	6600	8485	8600
COMBAT	117	175	162	225	540	105	300
LOAD	260	160	190	160	200	250	400
Ammo							
Crew, oil, residual fuel	1530	3162	3440	3360	4850	6100	6000
Fuel in internal tanks	25	105	108	120	105	218	200
Pylons, hardpoints, launchers	482	907	909	1000	905	1812	1700
Suspensions							
Normal take-off mass	6210	11550	11820	12215	16500	21139	21650

Aircraft Component Groups

The recognized groups of aircraft components are listed in exhaustive detail in the ATA's publication. This section presents consolidated, generalized groups (for both civil and military aircraft) suitable for studies in the conceptual design phase. Both aircraft classes have similar nomenclature; Each group includes subgroups of the system at the next level. Care must be taken that items are not duplicated – accurate bookkeeping is essential. For example, although the passenger seats are installed in the fuselage, for bookkeeping purposes, the fuselage shell and seats are counted separately.

Civil Aircraft

Structure group ($M_{STR} = M_{FU} + M_W + M_{HT} + M_{VT} M_N + M_{PY} + M_{UC} + M_{MISC}$)

- Fuselage group (M_{FU})
- Wing group (M_W): includes all structural items (e.g., flaps and winglets)
- H-tail group (M_{HT})
- V-tail group (M_{VT})
- Nacelle group (M_N and M_{PY}) (nacelle and pylon)
- Undercarriage group (M_{UC})
- Miscellaneous (M_{MISC}) (e.g., delta wing)

The basic structure of the aircraft – the fuselage shell (seats are listed separately under the Furnishing group) is as follows:

Power plant group ($M_{PP} = M_E + M_{TR} + M_{EC} + M_{FS} + M_{OI}$)

- Dry-equipped engine (M_E)
- Thrust reverser (M_{TR})
- Engine control system (M_{EC})
- Fuel system (M_{FS})
- Engine oil system (M_{OI})

The power plant group comes as a package, with all items dedicated to the power plant installation. These are mostly bought-out items supplied by specialists:

$$\text{Systems group}\,(M_{SYS} = M_{ECS} + M_{FC} + M_{HP} + M_{ELEC} + M_{INS} + M_{AV}) \tag{8.8}$$

- Environmental control system (M_{ECS})
- Flight-control system (M_{FC})
- Hydraulic and pneumatic system (M_{HP}) (sometimes grouped with other systems)
- Electrical system (M_{ELEC})
- Instrument system (M_{INS})
- Avionics system (M_{AV})

The systems group includes a variety of equipment, all vendor-supplied, bought-out items:

Furnishing group ($M_{FUR} = M_{SEAT} + M_{OX} + M_{PN}$)

- Seat, galleys, and other furnishings (M_{SEAT})
- Oxygen system (M_{OX})
- Paint (M_{PN})

Most of the weight is in the fuselage, yet the furnishings are itemized under different headings. Paint can be quite heavy. A well-painted B737 with airline livery can use as much as 75 kg of paint:

Contingencies (M_{CONT})

- This is a margin to allow unspecific weight growth (M_{CONT}).

The MEM is the total of the previous twenty-two items. This is the weight of the complete aircraft as it comes off the production line to be come airborne for the first time.

Add the following items to the MEM to obtain the OEM:

- Crew: flight and cabin crews (M_{CREW})
- Consumables: food, water, and so forth (M_{CON})

The OEM is when the aircraft is ready for operation.

Add the payload and requisite fuel to obtain the MRM. At the takeoff point at the edge of the runway, the MRM becomes the MTOM = (MRM – taxi fuel):

- Payload (M_{PL}) (passengers at 90 kg per passenger, including baggage)
- Fuel (M_{FUEL}) (for the design range, which may not fill all tanks)

MTOM: The aircraft at the end of the runway is ready for takeoff. The civil-aircraft MTOM is the total weight of all component groups, as shown in Equation 8.10.

The MTOM $= \int M(x)\,dx = \sum M_i$, where the subscript i stands for each component group listed previously.

For civil aircraft, the MTOM is equal to

$$\begin{aligned}&(M_{FU}) + (M_W) + (M_{HT}) + (M_{VT}) + (M_N) + (M_{PY}) + (M_{UC}) + (M_{MISC})\\&\quad + (M_E) + (M_{TR}) + (M_{EC}) + (M_{FS}) + (M_{OI}) + (M_{ECS}) + (M_{FC}) + (M_{HP})\\&\quad + (M_{ELEC}) + (M_{INS}) + (M_{AV}) + (M_{SEAT}) + (M_{OX}) + (M_{PN}) + (M_{CONT})\\&\quad + (M_{CREW}) + (M_{CONS}) + M_{PL} + M_{FUEL}\end{aligned}$$

Design Considerations for Stability: Civil Aircraft

The important points affecting aircraft configuration are reviewed as follows:

1. *Fuselage*. The fuselage has a destabilizing effect – the fuselage lift (although minimal) and moment add to instability – and its minimization is preferred. In addition to keeping costs down, the fuselage may be kept straight (with the least camber). Mass distribution should keep inertia close to the fuselage centerline. A BWB requires special considerations.

   The fuselage length and width are determined from the payload specifications. The length-to-average-diameter ratio for the baseline aircraft version may be around 10. The closure angles are important, especially the gradual closure of the aft end, which should not have an upsweep of more than what is necessary – even for a rear-loading door arrangement that must have an upsweep. The front closure is blunter and must provide adequate vision polar without excessive upper-profile curvature.

   For a pressurized cabin, the cross-section should be maintained close to the circular shape. Vertical elongation of the cross-section should be at a minimum to accommodate the below-floorspace requirements. For small aircraft, fuselage-depth elongation may be due to placement of the wing box; for larger aircraft, it may be due to the container size. Care must be taken so that the wing box does not interfere with the interior cabin space. Generous fairing at the wing–body junction and for the fuselage-mounted undercarriage bulge is recommended. An unpressurized fuselage may have straight sides (i.e., a rectangular cross-section) to reduce the production costs. In general, a rectangular fuselage cross-section is used in conjunction with a high wing. The undercarriage for a high-wing aircraft has a fuselage bulge.
2. *Wing*. Typically, an isolated wing has a destabilizing effect unless it has a reflex at the trailing edge (i.e., the tail is integrated into the wing such as all-wing aircraft like the delta wing and BWB). The larger the wing camber, the more significant is the destabilizing effect. Optimizing an aerofoil with a high L/D ratio and with the least C_{m_wing} is a difficult task not discussed herein. Wind-tunnel tests and CFD analyses are the ways to compromise. It is assumed that aerodynamicists have found a suitable aerofoil with the least destabilizing moment for the best L/D ratio. The coursework worked-out example uses an aerofoil from the proven NACA series.
3. *Nacelle*. The stability effects of a nacelle are similar to those of a fuselage. An isolated nacelle is destabilizing but, when integrated to the aircraft, its position relative to the aircraft CG determines its effect on the aircraft. That is, an aft-mounted nacelle increases stability and a forward-mounted nacelle on a wing decreases stability. The stability contribution of a nacelle also may be throttle-dependent (i.e., engine-power effects).

   The position of the nacelle on an aircraft is dictated by the aircraft size. The best position is on the wing, thereby providing bending relief during flight. The large forward overhang of a nacelle decreases air-flow interference with the wing. For smaller aircraft, ground clearance mitigates against wing-mounting; for these aircraft, nacelles are mounted on the aft fuselage. An over-wing nacelle mount for smaller aircraft is feasible – a practice yet to gain credence. Even a fuselage-mounted nacelle must adjust its position relative to how close the vertical height is from the aircraft CG without jet efflux interfering with the empennage in proximity.

4. *Fuselage, Wing, and Nacelle*. It is good practice to assemble these three components without the empennage in order to verify the total moment in all three planes of reference. The CG position is established with the empennage installed; then it is removed for a stability assessment. This helps to design the empennage as discussed herein. Figure 12.10 shows the typical trends of pitching moments of the isolated components; together, they will have a destabilizing effect (i.e., positive slope). The aim is to minimize the slope – that is, the least destabilizing moment.

5. *Empennage*. The empennage configuration is of primary importance in an aircraft design. The reference sizes are established by using statistical values of tail-volume coefficients, but the positioning and shaping of the empennage require considerable study. This is another opportunity to check whether the statistical values are adequate. The sweeping of the empennage increases the tail arm and may also enhance the appearance; even low-speed, smaller aircraft incorporate sweep. Chart 4.2 and Figures 4.24 and 4.25 show several possible empennage configurations.

6. *Undercarriage*. A retracted undercarriage does not contribute to the aerodynamic load but when it is extended, it generates substantial drag, creating a nose-down moment. To address this situation, there should be sufficient elevator nose-up authority at a near-stall, touch-down attitude, which is most critical at the forwardmost CG position. Designers must ensure that there is adequate trim authority (i.e., the trim should not run out) in this condition.

7. *Use of Any Other Surface*. It is clear how stability considerations affect aircraft configurations. Despite careful design, an aircraft prototype may show unsatisfactory flying qualities when it is flight-tested. Then, additional surfaces (e.g., ventral fin and delta fin) may be added to alleviate the problem. Figure 12.15 shows two examples of these modifications. It is preferable to avoid the need for additional surfaces, which add penalties in both weight and drag.

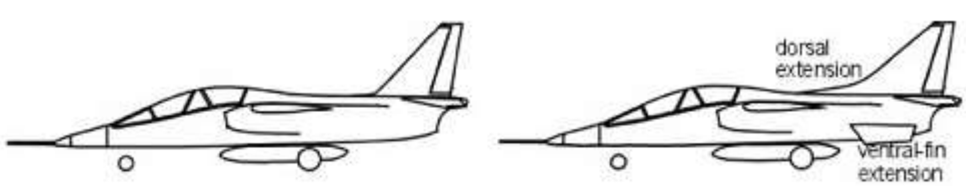


Figure 12.15. Aircraft configurations with modifications of additional surfaces

It is clear that stability considerations are important in aircraft-design configurations. Although the related geometrical parameters are from statistical data of past designs and subsequently sized, this chapter provides a rationale for their role in the conceptual design stage. It also has been shown that to control inherent aircraft motions, feedback-control systems such as a *stability augmentation system* (SAS) (e.g., a yaw damper) and a *control augmentation system* (CAS) have been routinely deployed for some time. In this final section, the rationale continues with a discussion on how the feedback-control system has advanced to the latest technologies, such as FBW and fly-by-light (FBL), known collectively as ACT. Today, almost all types of larger aircraft incorporate some form of ACT.

The advantages of FBW are discussed in various sections of this book; the concept is not new. FBW is basically a feedback-control system based on the use of digital data. Figure 12.17 shows the control of one axis, which can be used for all three axes. Earlier SAS and CAS had mechanical linkage from the pilot to the controls; FBW does not have the direct linkage (hence, the name). It permits the transmission of several digital signal sources through one communications system, known as *multiplexing*. A microprocessor is in the loop that continuously processes air data (i.e., flight parameters) to keep an aircraft in a preferred motion with or without pilot commands. Aircraft-control laws – algorithms relating a pilot's

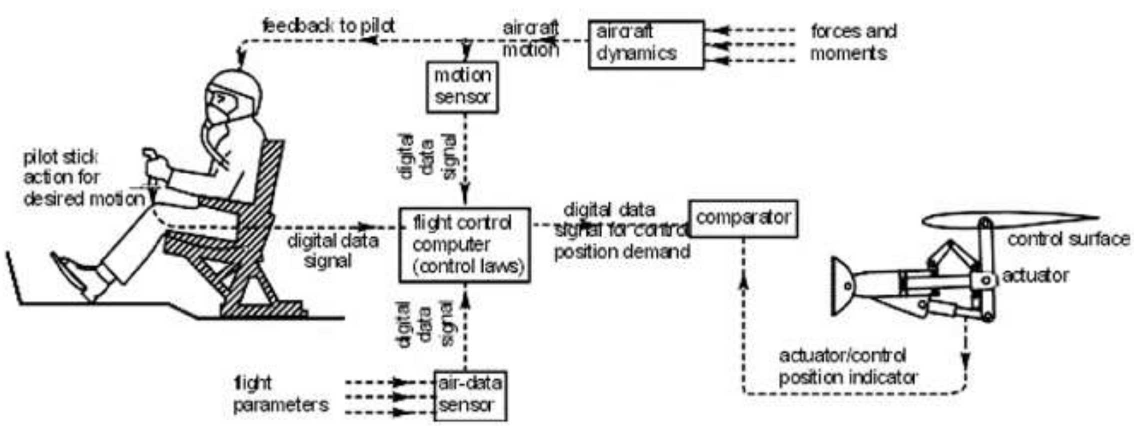


Figure 12.17. A schematic diagram of FBW

command to the control-surface demand and aircraft motion, height, and speed, which involve equations of motion, aircraft coefficients, and stability parameters – are embedded in the computer to keep the aircraft within the permissible flight envelope. Under the command of a human pilot, the computer acts as a subservient flier. The computer continuously monitors aircraft behavior and acts accordingly, ensuring a level of safety that a human pilot cannot match.

Figure 12.17 is a schematic diagram of the FBW feedback arrangement for pitch control. The flight-control computer takes the pilot's steering commands, which are compared to the commands necessary for aircraft stability to ensure safety and that control surfaces are activated accordingly. Air data are continually fed to the computers (i.e., speed, altitude, and attitude). Built into the computer are an aircraft's limitations, which enables it to calculate the optimum control-surface movements. Steering commands are no longer linked mechanically from the cockpit to the control surface but rather via electrical wiring. FBW flight-control systems seem to be the ideal technology to ensure safety and reduce a pilot's workload.

Because analog point-to-point wire bundles are an inefficient and cumbersome means of interconnecting sensors, computers, actuators, indicators, and other equipment onboard a modern military aircraft, a serial digital multiplex data bus was developed. MIL-STD-1553 (in use since 1983) defines all aspects of the bus (i.e., a subsystem of electrical lines for communication, named after electrical bus bars); therefore, many groups working with the military have adopted it. The MIL-STD-1553 multiplex data bus provides an integrated, centralized system control and a standard interface for all equipment connected to the bus. The bus concept provides a means by which all traffic is available and can be accessed using a single connection for testing and interfacing with the system.

FBW reacts considerably faster than a conventional control system and does not encounter fatigue problems. A strong driver for incorporating FBW in military-aircraft design is the ability to operate at relaxed stability (even extending to a slightly unstable condition) used for rapid maneuver (increased agility) as a result of minimal stiffness in the system. It is difficult for a typical pilot to control an unstable aircraft without assistance; a computer is needed and a regulator supplies the necessary stability. This system does not generate the natural stability of a conventional aircraft but automatically trims the aircraft to the preferred flight conditions. Progress in FBW systems depends to a great extent on the progress of onboard computer power.

An aircraft flying under relaxed stability using FBW does not have the same requirement for geometrical features to provide low stiffness and damping. Hence, stability and control-surface sizing are different than in a conventional design: They are smaller and, hence, lighter with less drag. This is what is meant by a CCV.

Stable designs already have a down-pitching force because of the position of the NP aft of the CG. Any balancing force must be generated by a larger downward lift of the H-tail. Again, this decreases the maximum possible lift and increases the trim drag. In an unstable layout (e.g., the CG moving aft), the elevator's lift is directed upward to counterbalance the moment. In this way, the aircraft's total lift is increased; the aircraft wing therefore can be designed to be smaller and lighter and still provide the same performance. There is another benefit from the use of an unstable design: In addition to the aircraft's increased agility, there is a reduction in drag and weight.

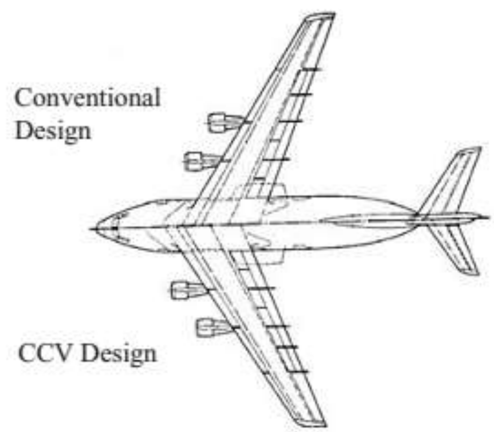
Table 12.1. *Conventional and CCV comparison*

	Conventional	CCV
MTOM (kg)	38,000	38,000
OEM (kg)	27,490	26,764
S_W (m^2)	130	130
S_H (m^2)	26	15.8
Payload (kg)	5,000	5,730
CG range (−%MAC)	15–35	32–53

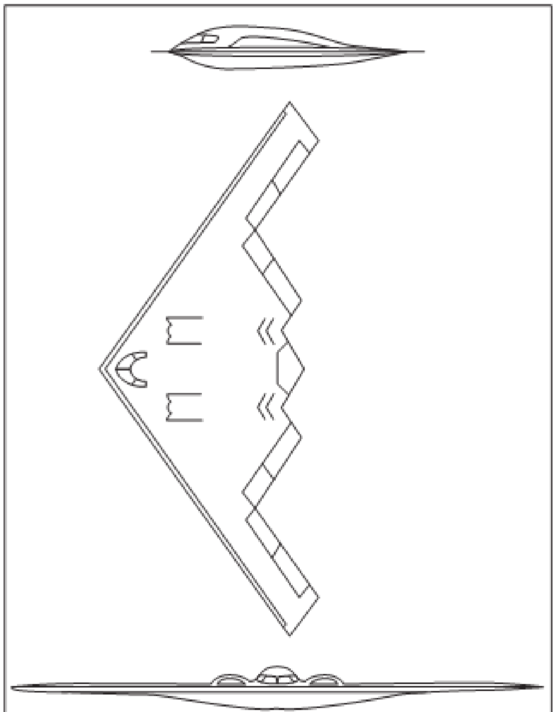
In summary, FBW provides considerable advantages, as follows:

- a simple and flexible system architecture although its design is complex
- consistent handling
- automatic stabilization
- safe maneuvering to the envelope limits
- ability to integrate with a wide range of designs (e.g., slats and swing-wing)
- ability to integrate with engine control through FADEC and the thrust vector
- use of side stick controller – provides free space in the cockpit layout and weight-saving
- incorporates relaxed stability for rapid maneuver, yet uses smaller control surfaces
- permits complex configurations for stealth aircraft, which may not be favorable for aerodynamic considerations leading to unstable aircraft (e.g., the F117 Nighthawk)
- digital data-handling allows multiplexing, which saves weight
- overall weight reduction
- allows standardization
- failure detection
- fault isolation
- built-in tests and monitoring

Figure 12.18. Comparison between a conventional and a CCV design



Project study: advanced deep interdiction aircraft



Northrop Grumman B-2A Spirit Stealth Bomber

When the F111 was retired from service in 1996 it was partially replaced by the F-15E. The balance of USAF deep-interdiction capabilities are provided by the F-117, B-1 and B-2 aircraft. All of these aircraft are expected to reach the end of their service lives in or before the year 2020. The need exists for a new aircraft which can effectively deliver precision guided tactical weapons at long range and which can rapidly deploy with minimum support to regional conflicts world-wide. Improved threat capabilities dictate that this new aircraft have signatures in all spectra comparable to or less than those of the F-117. The capability to super-cruise (fly supersonically without the use of afterburner) will allow these aircraft to respond to crises around the world in half the time required for current strike assets. Approximately 200 aircraft are needed to replace the F-15E, F-117, B-1 & B-2 aircraft.

Threat analysis

Interdictive strike aircraft are expected to operate early in the conflict. This is at a time when the enemy's defensive systems have not yet been degraded. To avoid threats, the traditional tactic relied on fast, low-level approach under the protective screen of the enemy radar. Improvements in radar technology and the introduction of relatively

cheap surface-to-air missiles (SAM) eventually made this tactic ineffective. Modern practice relies on aircraft stealth and high-altitude penetration. This avoids low and medium height threats from small-arms fire and low-technology SAM which now makes flight at altitudes below 20 000 ft very dangerous. A high-altitude mission profile ensures that the aircraft can only be attacked with much more sophisticated defensive

Stealth considerations

In recent years, the technical and popular press has focused so much attention on radar detection (radar cross-section, RCS) that it would be easy to forget that there are several other ways to identify and target an intruding aircraft. These include, infrared emissions (IR), electronic radiation, sound (aural signature) and sight (visual signature). Traditionally, the last of these led to the development of camouflage (the original stealth solution!). In modern warfare, it is important to make sure that each identifier is reduced to a minimum. None of the signatures should be more significant than the oth-

Radar

The AIAA specification required the RCS to be less than −13 dB. It is felt that with the expected technical improvements in radar performance in the period up to first flight (2020) this RCS may be too large. A value of −30 dB, if achievable, may be a better target for this aircraft. To achieve this figure will require as much help as possible from new technologies and the development of existing techniques. Existing methods include 'edge alignment', avoidance of shape discontinuities, elimination of flat surfaces, using radar absorbing structures (RAS), coating the external profile with radar

absorbing material (RAM), and hiding rotating engine parts from direct reflection of radar waves. Attention must also be given to the avoidance of radar scattering caused by the aircraft profiles and from the edges of access panels. All of these methods have been demonstrated and proved on the B-2 aircraft. However, the main objective of such techniques is to reduce radar reflectivity. This is important when the radar transmitter and receiver are at the some location.

New defensive radar systems now displace the two parts of the system. This makes it more important to absorb the radar energy into the structural framework and the materials covering the aircraft profile.

Passive stealth techniques are currently being developed. These use plasma generation to 'assimilate' the radar energy. Another method attempts to displace or disguise the returning radar signature. This is intended to confuse defensive systems and make targeting more difficult. Obviously, for security reasons, published information on

Infrared

Infrared radiation is a natural consequence of heat. It is more pronounced at higher temperatures therefore the best way to reduce the exposure is to lower the temperature of the hot parts of the aircraft. The engine exhaust gases and surrounding structure give rise to the main source of IR radiation. A pure-turbojet engine exhaust is obviously easier to detect than that of a bypass engine. In the bypass engine, the hot core airflow is mixed with the cooler bypass air before leaving the engine. This substantially reduces the exhaust stream temperature and therefore the IR signature. Another way of reducing the IR signature is by shielding the hot areas from the potential detector. For example, if the IR detector is likely to be below the aircraft (a good assumption for our high flying aircraft) it would be possible to use the colder aircraft structure to hide the engine nozzle location. Positioning the engine exhaust forward and above the rear wing structure would provide this protection.

Aerodynamic efficiency

For the specified mission, the aircraft will spend nearly all of the flight time at supersonic speed. Therefore, it is important that the aerodynamic design concentrates on the reduction of wave drag. For a given size of aircraft, the longitudinal distribution of the cross-sectional area of the aircraft volume has a considerable influence on wave drag. Several aerodynamic and design textbooks (e.g. reference 4) describe the Sears–Haack analysis. They show that a smooth progression (i.e. following a statistically normal distribution) produces the minimum wave drag. The minimum increase in drag area due to wave drag is calculated using the formula below:

$$(S \times C_{\text{Dwave}}) = 14.14[A_{\max}/L]^2$$

where S = aircraft reference (usually gross) wing area
$A_{\max}$ = maximum aircraft cross-sectional area
L = aircraft overall longitudinal length less any constant section segments

At supersonic speeds, a Mach wave is formed which surrounds the aircraft. The angle of this wave cone relative to the longitudinal axis of the aircraft is known as the Mach angle (μ). This angle is a function of the aircraft forward speed (Mach number)[5] such that:

$\mu = \sin^{-1}(1/\text{M})$ With the specified cruise speed of M1.6: $\mu = 38.7°$

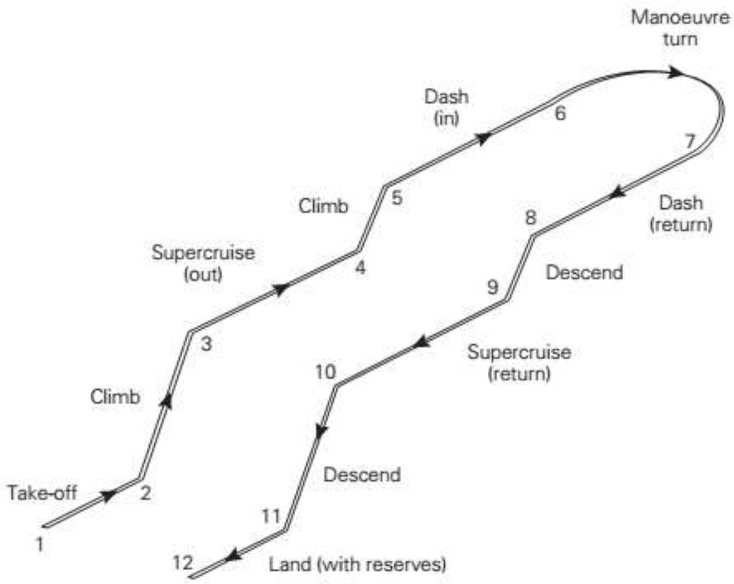
To avoid discontinuity in airflow regions, it is desirable to keep the aircraft geometry, particularly the wing planform, within the Mach cone (i.e. keeping the wing leading edge sweepback angle greater than $(90-\mu)°$). For our aircraft this dictates a **wing leading edge sweep angle greater than 51.3°**. As the air velocity in this region is substantially lower than free-stream, this also reduces wave drag.

Problem definition

The project description specifies a two-place advanced deep interdictor aircraft. The entire long-range mission will be flown at supersonic speed. The exact mission definition is shown in Figure 8.1. The long-duration, high-intensity flight conditions, much of which is over enemy territory, demands the security of twin-pilot operation. The long work periods and high manoeuvre load environment imposed on the pilots requires careful design of the cockpit. The workload related to flight safety and weapon delivery must be reduced by system design. Such systems must be made reliable and safe.

The aircraft must be capable of 'all-weather' operation from advanced NATO and other bases. Aircraft shelter dimensions may impose configurational constraints on the aircraft. Aircraft servicing and maintenance at austere operational bases demand minimum support equipment and skill. Easy access to primary system components must be provided.

Closed-loop, static and dynamic stability and handling flight characteristics must meet established military requirements. A digital flight control system will be necessary for a longitudinal unstable aircraft configuration. All systems must be protected against hostile damage and inherent unreliability.



Segment	*Description*	*Height*	*Speed*	*Distance/duration*
1–2	Warm-up, taxi and take-off	Sea level		NATO 8000 ft, icy
2–3	Climb to best supercruise alt.			
3–4	Supercruise to conflict area	Opt. alt.	M1.6	1000 nm
4–5	Climb to 50 000 ft			
5–6	Dash to target	50 000 ft	M1.6	750 nm
6–7	Turn and weapon release	50 000 ft		180°
7–8	Dash out	50 000 ft	M1.6	750 nm
8–9	Descend to supercruise alt.			
9–10	Supercruise return	50 000 ft	M1.6	1000 nm
10–11	Descend to base			
11–12	Land (with reserve fuel*)			NATO 8000 ft, icy

*Diversion and hold at sea level with 30 min fuel at economical flight conditions.

Fig. 8.1 Mission profile

In addition to strict stealth criteria, the AIAA problem description sets out several required design capabilities and characteristics. These include:

- The aircraft must accommodate two pilots but should be capable of single pilot operation. For such a long-range mission, pilot workload must be reduced by suitable design and specification of flight control and weapon delivery systems. Crew safety systems must be effective in all flight modes.
- The design layout should allow for easy maintenance. Minimum reliance on support equipment is essential for off-base operations.
- Structural design limit load factors of $+7$ to $-3g$ (aircraft clean and with 50 per cent internal fuel) are required. An ultimate design factor of 1.5 is to be applied. The structure must be capable of withstanding a dynamic pressure (q) of 2133 lb/sq. ft (i.e. equivalent to (q) at 800 kt) and be durable and damage tolerant.
- All fuel tanks must be self-sealing. Aviation fuel to JP8 specification (6.8 lb/US gal) is to be assumed.
- Stability and handling characteristics to meet MIL-F-8785B subsonic longitudinal static margins to be no greater than $+10$ per cent and no less than -30 per cent.
- The aircraft must be 'all-weather' capable. This includes operation from and on to icy 8000 ft runways.
- The aircraft must operate from austere bases with minimum support facilities. On these bases the aircraft will be required to fit into standard NATO shelters.
- The flyaway cost for 200 aircraft purchase must not exceed \$150 M (year 2000 dollars).

In addition to the high-altitude, supercruising mission shown in Figure 8.1 and described in section 8.2 above, the design specification sets the following manoeuvring targets (specific excess power, SEP, is defined as P_S in Chapter 2 (section 2.7.1)):

- SEP ($1g$) military thrust (dry), 1.6 M at 50 000 ft = 0 ft/s.
- SEP ($1g$) maximum thrust (wet), 1.6 M at 50 000 ft = 200 ft/s.
- SEP ($2g$) maximum thrust (wet), 1.6 M at 50 000 ft = 0 ft/s.
- Maximum instantaneous turn rate, 0.9 M at 15 000 ft = 8.0°/s.

(all the above performance criteria are specified at aircraft manoeuvre weight (defined as 50 per cent internal fuel with two AIM-120 and four 2000 lb JDAM)).

The design specification calls for five separate weapon capabilities:

- Four Mk-84 LDGP + two AIM-120.
- Four GBU-27 + two AIM-120.
- Four 2000 lb JDAM + two AIM-120.
- Four AGM-154 JSOW + two AIM-120.
- Sixteen 250 lb small smart bombs.

The details below suggest several potential design requirements:

- The field take-off requirement, particularly with regard to the icy runway conditions will require a high thrust/weight ratio.
- Initial climb performance will require good specific excess power to reach the supercruise altitude and speed in reasonable time.
- Supercruise will require low overall drag to give a good lift/drag ratio and thereby a lower fuel requirement.
- The rear movement of the centre of lift in supersonic flight may require fuel transfer to balance the aircraft and reduce trim drag.
- The climb from supercruise altitude to 50 000 ft for the dash phase may require a burst of afterburning to offset the low SEP at high/fast operation. Stealth may be compromised by either the use of afterburning or from the long-duration climb from supercruise altitude to dash without the extra thrust.
- The aircraft must be able to drop the weapons without significant trim changes.
- The SEP requirements and the turn performance may require the use of manoeuvring flaps although this may compromise stealth.
- Landing will require low wing loading to avoid high approach speed and to reduce aircraft energy on the ground.
- Icy conditions may demand aerodynamic braking assistance (parachutes and lift dumping).
- Compatibility with NATO shelter size will limit the aircraft to a span of less than 20 m (65 ft) and length to less than 30 m (98 ft).

Design concepts and selection

- Conventional, straight wing
- Pure delta/diamond
- Blended delta

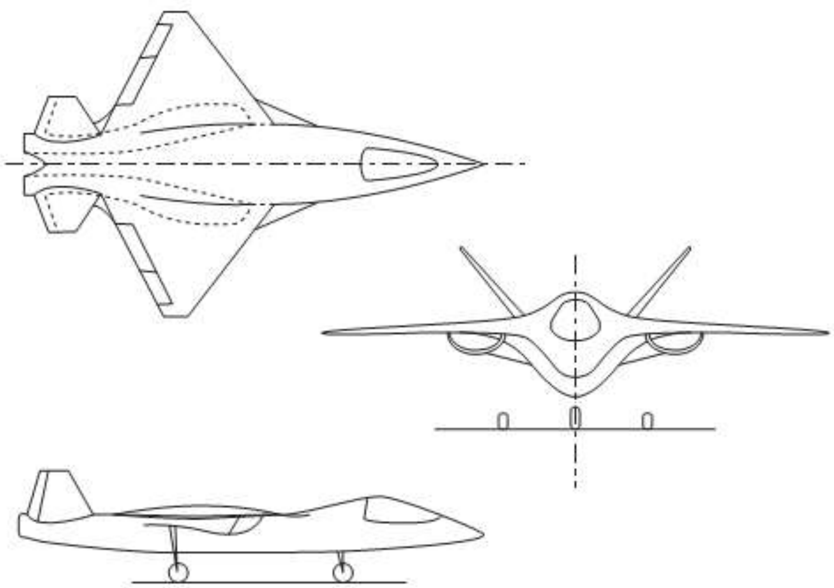


Fig. 8.2 Design concept – conventional straight wing

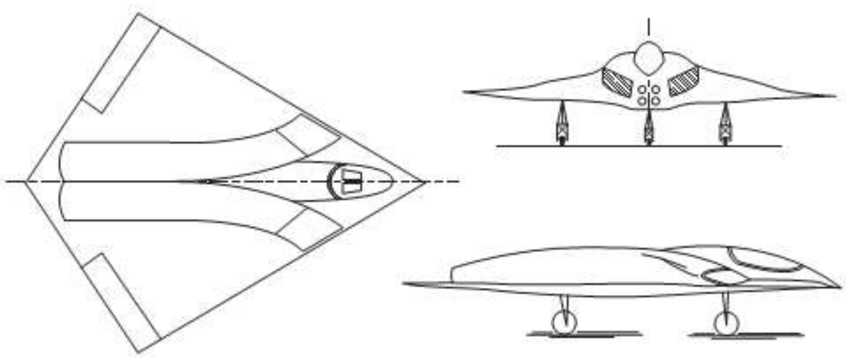


Fig. 8.3 Design concept – delta/diamond

A decision matrix method was used to analyse the different options on a consistent basis. The criteria used to assess the options in the selection process are listed below together with (in brackets) the significance (weighting) to the overall assessment.

Effectiveness of incorporating stealth technology into the layout (5)
Aerodynamic efficiency (mainly L/D ratio) of the layout (5)
Potential for low-weight design (4)
Technical difficulties (ease of analysis) and risk (3)

Field performance and rough ground handling (2)
Maintainability and operational dependability (2)
Survivability and ease of repair (2)
Multi-role capability (1)

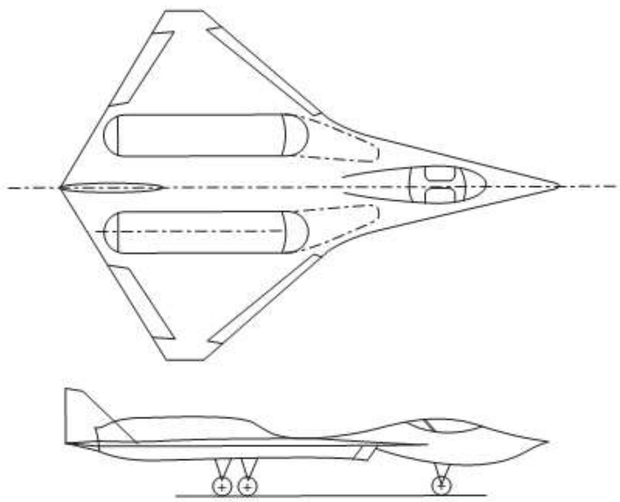


Fig. 8.4 Design concept – blended delta

Conventional option (56), Delta/diamond layout (72), Blended body (58)

- As some of the constraints are related to military thrust, it is necessary to define the increase in thrust from afterburning. We will initially assume $(T_{\max}/T_{\text{mil}}) = 1.5$.
- Initial climb to supercruise with final rate of climb of 1000 fpm (our requirement).
- Supercruise starts with 90 per cent MTOM.
- Dash starts with 80 per cent MTOM.
- Manoeuvres are at aircraft mass empty + crew + weapons + 50 per cent fuel $(25\,846 + 500 + 4000 + 15\,180 = 45\,526\text{ kg }(100\,385\text{ lb}))$.
  Basing all of the constraint analysis on our original mass estimate of 66 000 kg (145 530 lb) gives $\beta_{\text{manoeuvre}} = (W/W_{\text{TO}}) = 0.69$.
- Landing approach speed less than 160 kts (82 m/s) at 95 per cent MTOM.
- Landing on an icy* runway with fuel dumping and possibly emergency braking parachute.
- Landing in normal conditions will be determined at 95 per cent MTOM with emergency braking $(\mu = 0.5)$.

boundary for the case. This process is repeated for all constraints.

In the design proposal, there are several performance requirements:

- Take-off from 8000 ft (2440 m) runway, on standard day with icy runway.
- Climb to optimum supercruise altitude.
- Supercruise at optimum altitude at M1.6 for 1000 nm (less climb distance).
- Dash at M1.6 at 50 000 ft (min.).
- Manoeuvre with specific excess power (SEP), at specified weapon load and 50 per cent fuel:
  - at $1g$, M1.6, alt. $= 50\,000$ ft with SEP $= 0$ ft/s with no afterburning
  - at $1g$, M1.6, alt. $= 50\,000$ ft with SEP $= 200$ ft/s with afterburning
  - at $2g$, M1.6, alt. $= 50\,000$ ft with SEP $= 0$ ft/s with afterburning
- Land onto 8000 ft runway, on standard day with icy runway.

Before the analysis can be made there are several assumptions that must be made:

- Take-off from icy* conditions will be with afterburning (called maximum thrust).
- Take-off in normal conditions will be with no afterburning (called military thrust).

Table 8.3

Component	lb	kg	% *MTO*	*Arm* (m)
Wing	6 157	2 800	5.4	18.0
Control surfaces	832	378	0.7	23.5
Body	5 210	2 368	4.6	16.5
Main gear	2 835	1 289		19.7
Nose gear	868	394	3.2 (u/c)	6.7
Intakes	2 633	1 197	2.3	13.5
$\sum$ STRUCTURE	18 535	8 406	16.2	
Dressed engine	15 600	7 091	13.7	
Installation	769	349	0.7	
Engine system	1 054	478	0.9	
$\sum$ PROPULSION	17 423	8 728	15.3	18.8
Fuel system and tanks	1 723	783	1.5	19.5
Aircraft systems	1 546	701	1.4	14.0
Avionics	2 370	1 077	2.1	9.5
Cockpit systems	1 440	653	1.3	10.0
Weapon systems	1 500	682	1.3	17.0
$\sum$ FIXED EQUIP.	8 579	3 891	7.6	
$\sum\sum$ EMPTY	44 537	21 025	39.1	
Crew and op items	1 100	500	1.0	10.0
Weapons	13 448	6 113	11.8	17.5
$\sum\sum$ ZERO FUEL	59 082	27 623	51.9	
Fuel	55 000	25 000	48.1	18.0 (central) 20.5 (wing)
Max take-off	114 082	51 739	100.0	

Aircraft balance

Final baseline aircraft description

Aircraft description

Aircraft type:	Two-seat, high altitude, supersonic, low-observable, deep interdiction aircraft.
Design features:	Mid-wing, diamond planform, blended body, tailless, twin-engine layout. All weapons stored internally in a central bomb bay below the engine and equipment compartments. Side-by-side, high mounted, low-bypass engines with 2D variable geometry, under-wing intakes positioned close to the wing leading edge. Afterburning and vectoring rectangular nozzle positioned to the rear of the wing trailing edge. Mid-fuselage, side-by-side, twin pilot cockpit with limited external view. Access to the cockpit is through the forward bomb bay bulkhead. Artificial pilot vision and automatic flight control system. Cockpit capsule-escape system. Conventional tricycle retractable landing gear.
Stealth features:	Very low radar cross-sectional area, achieved by the blended profile with aligned external geometry and structure, and the application of radar absorbent materials and structure. Structure cooling to reduce kinetic heating. Shielded and intercooled engine exhaust flow. Polymer coatings to reduce infrared signature, and sound-profiling to reduce the sonic boom.
Structure:	Integrated wing and body internal and profiled structural framework. Extensive use of composite structural materials with RAM and RAS applied to reduce observable signature. Design limits $+7/-3g$, $V_D = $ M2.0 and max. dynamic pressure $= 2133$ lb/sq. ft (equivalent to 800 kt at SL).

Weapons: Common racking for combination weapon loads as defined below:

(4) Mk-84 LDGP + AIM-120
(4) GBU-27 + AIM-120
(4) 2000 lb JDAM + AIM-120
(4) AGM-154 JSOW + AIM-120
(16) 250 lb small smart bomb

Aircraft data

Dimensions:	Overall length	87.0 ft	26.5 m
	Overall span	42.6 ft	13.0 m
	Overall span (option)	52.5 ft	16.0 m
	Overall height	11.5 ft	3.5 m
	Wing aspect ratio	1.27	
	Wing taper ratio	0	
	Wing LE sweep	70°	
	U/C wheelbase	42.3 ft	13.5 m
	U/C track	14.8 ft	4.5 m
Areas:	Wing planform (ref)	1430 ft^2	133 m^2
	Exposed wing	700 ft^2	65.0 m^2
	Total wetted	2472 ft^2	230 m^2
	Max. cross-section	91.5 ft^2	8.6 m^2
	Elevators	56.0 ft^2	5.2 m^2
	Ailerons (normal)	56.0 ft^2	5.2 m^2
	Ailerons (option)	134 ft^2	12.5 m^2
Weight (mass)	Max. TO (design)	114 082 lb	51 739 kg
	Empty	44 537 lb	21 025 kg
	Manoeuvre	81 797 lb	37 100 kg
	Landing (90% MTO)	102 674 lb	46 565 kg
	Fuel load	55 000 lb	25 000 kg
	Fuel (US gals)	10 300	
	Weapons (max.)	13 448 lb	6113 kg
Loadings:	Wing loading (max.)	80 lb/sq. ft	3815 N/sq. m
	Thrust/Weight (TO)	0.58	Dry
	Thrust/Weight (combat)	0.18	Dry at 50 000 ft
Engines (each):	Thrust (ssl, dry)	33 080 lb	
	SFC dry (TO)	0.85	
	SFC dry (cruise)	1.20	
	Weight: mass	7800 lb	
	Bypass ratio	0.6	
Aerodynamics:	Supersonic cruise	$C_{Do} = 0.0205$	
		$C_L = 0.146$	
		$C_D = 0.0315$	
		$L/D = 4.65$	
	Subsonic (clean)	$C_{Do} = 0.0077$	
	(TO and land)	$C_{Do} = 0.0115$	
	(approach)	$C_L = 1.4$ (HAA)	

Performance:	*Mission:*	
	Cruise speed	M1.6
	Cruise height	54 to 63 000 ft
	Range	3500 nm
	Manoeuvre (SEP at M1.6 at 50 000 ft):	
	1*g* dry thrust	60 ft/s
	1*g* afterburning	370 ft/s
	2*g* afterburning	50 ft/s
	Turning (M0.9 at 15 000 ft):	
	Instantaneous	13.4°/s (4069 ft radius)
	Sustained	5.4°/s (10 097 ft radius)
	Sustained (A/B)	8.0°/s (6815 ft radius)
	Max. instantaneous	21.0°/s at 366 kt (1686 ft radius)
	Field:	
	TO run @ MTO	1009 ft dry (unfactored)
	Speed V_2	70 kt
	Balanced field	1150 ft normal, 2320 ice (unfactored)
	Approach speed	140 kt
	Landing roll (dry)	2530 ft (unfactored)
	(ice)	7000 ft (unfactored)
	(wet)	4700 ft (unfactored)
Recurrent flyaway unit cost (FY2000)		\$178 M for 200 production
		\$150 M for 430 production
		\$123 M for 1000 production

UNIT I

	Questions	opt1	opt2	opt3	opt4	opt5	opt6	Answer
1	Modern airframes are build on the principle of	stressed skin	strain skin	shear skin	smooth skin			stressed skin
2	The sheet metal covering of the structure which bears the structural loading is called as	ribs	longerons	skin	fuselage			skin
3	The basic function of the fuselage is to provide accommodation for the aircrew and the	spar	ribs	components	passengers			passengers
4	A stressed skin fuselage is usually designed with a cross sectional shape of	square	triangle	oval	none of the given			oval
5	The internal structure of fuselage mainly concentrated near the surface of the outer skin is known as	monocoque construction	semi-monocoque construction	partial monocoque construction	full monocoque construction			semi-monocoque construction
6	Structural bulkheads are often used in construction when we require more	weight	strength	drag	shape			strength
7	Which of the following bulkheads are used to carry tail unit loads	structural bulkhead	pressure bulkhead	fuel tank bulkhead	aerodynamic bulkhead			structural bulkhead
8	Large pressure bulkhead are often domed so that they can withstand the pressure loading without	weight	deformation	elongation	strenght			deformation
9	The strong longitudinal members of the fuselage structure are	ribs	spar	longerons	frames			longerons
10	The wing of almost all modern powered aircraft are of	simple construction	tough construction	stressed skin construction	skin construction			stressed skin construction
11	The direction in which an aircraft is headed can be indicated by the	pitot static tube	electrical circuits	magnetic compass	altimeter			magnetic compass
12	be given by	stable system	unstable system	pressure system	pneumatic system			pneumatic system
13	Fin is located on the	stabilizer	vertical stabilizer	wing	cockpit			vertical stabilizer
14	Cabin is also called as	cockpit	fuselage	instruments room	propeller area			cockpit
15	The aircraft power plant is usually enclosed in housing called a	nozzles	control engine	nacclle	cockpit			nacclle
16	The landing gear used in WRIGHT FLYER is	conventional gear	tricycle	skids	Fixed landing gear			skids
17	The tricycle landing gear has two main wheels and a	tail wheel	mid wheel	low wheel	nosewheel			nosewheel
18	The other name of wing is	airfoil	ribs	main plane	spars			main plane
19	The purpose of the main plane is to generate	lift	ratio	attack	wind			lift
20	The movable sections in the horizontal stabilizer of airplane is	rudder	aileron	propeller	elevator			elevator
21	The tail plane is also known as	vertical stabilizer	stabilizer	aileron	flaps			stabilizer
22	The vertical stabilizer for an airplane is the airfoil section forward of the	elevator	trim tab	rudder	aileron			rudder
23	The body which is mounted on the trailing edge of the wing near the wing tip	aileron	flaps	slats	rudder			aileron
24	Rudder are usually balanced statically and	in weight	aerodynamically	vectorly	in shape			aerodynamically
25	Undercarriage is the other name of	low fuselage	mid fuselage	landing gear	engine gear			landing gear
26	Avionics is the combination of ____________	Airline and Electronics	Aviation and Electronics	Aircraft and Electrical	Aviation and Electrical			Aviation and Electronics
27	Navigation system is used to ____________	Traffic control	Communication	Weather detection	Find position and direction			Find position and direction
28	During the First World War __________ technology is used for communication.	wireless	Dopple	Radio	RADAR			wireless
29	DME stands for _________	Distance measuring	Distance monitoring	Direct measuring equipment	Doppler monitoring equipment			Distance measuring
30	Electronic Warfare is mainly used to search the ___________	Communication signals	Ultrasonic waves	Sound waves	Radio frequency band			Radio frequency band
31	In communication system __________ is used as a transmitter links.	fiber	iron	mica	Silver			fiber
32	__________ memory is require a power to maintain the stored information.	Non volatile	virtual	protected	volatile			volatile
33	Fly-By-Wire system sends the information in the form of ____________	Electrical signals	Analog signals	Radio signals	Sky waves			Electrical signals
34	If an aircraft has a gross weight of 3000 kg and is then subjected to a total weight of 6000 kg the load factor will be	2G	3G	9G	15G			2G
35	A constant rate of climb is determined by	weight	wind speed	excess engine power	density			excess engine power
36	If both wings lose lift the aircraft	pitches nose up	pitches nose down	glides on a horizontal plane	glides on a vertical plane			pitches nose up
37	Under what conditions will an aircraft create best lift?	Cold dry day at 200 ft	Hot damp day at 1200 ft	Cold wet day at 1200 ft	Cold wet day at 1800 ft			Cold dry day at 200 ft
38	If there were an increase of density, what effect would there be in aerodynamic dampening?	None	Decreased	Increased	becomes zero			Increased
39	As Mach number increases, what is the effect on boundary layer?	Becomes more turbulent	Becomes less turbulent	Decreases in thickness	increases in thickness			Becomes more turbulent
40	When a slat is retracted it moves	towards the upper leading edge of the wing	towards the lower leading edge of the wing	towards the centre of the leading edge of the wing	towards the trailing edge			towards the upper leading edge of the wing
41	In a turn the up-going wing causes a	de-stabilising effect due to increased AoA	de-stabilising effect due to decreased AoA	stabilising effect due to decreased AoA	stabilising effect due to increased AoA			stabilising effect due to decreased AoA
42	The stagnation point consists of	dynamic and static air pressure	static air pressure	dynamic air pressure	absolute pressure			dynamic and static air pressure
43	Yawing is a rotation around	the normal axis obtained by the elevator	the lateral axis obtained by the rudder	the normal axis obtained by the alieron	the normal axis obtained by the rudder			the normal axis obtained by the rudder
44	Sweepback of the wings will	not affect lateral stability	increase lateral stability at high speeds only	increase lateral stability at all speeds	increase directional stability			increase lateral stability at all speeds
45	With the flaps lowered, the stalling speed will	increase	become zero	remain the same	decrease			decrease
46	When flying close to the stall speed a pilot applies left rudder the aircraft will	pitch nose up	roll to the left	stall the left wing	pitch nose down			stall the left wing
47	When flaps are down it will	increase AoA and increase slow speed stability	decrease AoA and decrease slow speed stability	the AoA remains the same on both wings	increase AoA and decreases low speed stability			decrease AoA and decrease slow speed stability
48	If you have an aircraft that is more laterally stable then directionally stable it will tend to:	skid	slip	bank	yaw			skid
49	A wing section suitable for high speed would be	thick with high camber	thin with high camber	thin with little or no camber	thick with low camber			thin with little or no camber
50	As the speed of an aircraft increases the profile drag	increases	decreases	decreases at first then increase	remains constant			increases
51	The stagnation point on an aerofoil is the point where	the suction pressure reaches a maximum	the boundary layer changes from laminar to turbulent	the airflow is brought completely to rest	the suction pressure reaches zero			the airflow is brought completely to rest
52	The stalling of an aerofoil is affected by the	airspeed	angle of attack	transition speed	density of air			angle of attack
53	What gives the aircraft directional stability?	alieron	Horizontal stabiliser	Elevators	Vertical stabiliser			Vertical stabiliser
54	The most fuel efficient of the following types of engine is the	rocket	turbo-jet engine	turbo-fan engine	turboprop			turbo-fan engine
55	The quietest of the following types of engine is the	rocket	turbo-jet engine	turbo-fan engine	turboprop			turbo-fan engine
56	Forward motion of a glider is provided by	control surfaces	the weight	the drag	the engine			the weight

UNIT II

57	An automatic device that uses error-sensing negative feedback to correct the performance of a mechanism.	pump	servomechanism	actuator	undercarriage			servomechanism
58	A device whuch displaces a volume by physical or mechanical action.	servomechanism	actuator	pump	air speed indicator			pump

59	A mechanical device for moving or controlling a mechanism or system	actuator	altimeter	pump	servomechanism			actuator
60	The instruments in the cockpit of an aircraft that provide the pilot with information about the flight situation is called	actuator	pump	servomechanism	flight instruments			flight instruments
61	A ground-based instrument approach system that provides precision guidance to an aircraft approaching and landing on a runway is called	landing system	instrument landing system	electrical system	indicator system			instrument landing system
62	The other name of landing gear is	undercarriage	wheels	base	stand			undercarriage
63	The height of the aircraft can be determined by	altimeter	variometer	air speed indicator	gyro horizon			altimeter
64	The speed of the aircraft is usually determined by the instrument	altimeter	air speed indicator	turn and bank indicator	mach meter			air speed indicator
65	The direction in which an aircraft is headed can be indicated by the	pitot static tube	electrical circuits	magnetic compass	altimeter			magnetic compass
66	The acceleration loads on the aircraft structure can be measured by the	variometer	accelerometer	vertical speed indicator	magnetic compass			accelerometer
67	The power for the operation of the landing gear retraction and extension can be given by	stable system	unstable system	pressure system	pneumatic system			pneumatic system
68	The purpose of the main plane is to generate	lift	decrease fuel ratio	increase angle of attack	manage relative wind			lift
69	According to newtons law, the gravitation is inversely proportional to	geometric altitude	geopotential altitude	absolute altitude	none of the given			absolute altitude
70	Hydrostatics is defined as the study of a body which is at rest in a	solid medium	liquid medium	gaseous medium	fluid medium			fluid medium
71	The other name of wing is	airfoil	ribs	main plane	spars			main plane
72	The Physical behaviour of water at rest and motion is called		Hydraulics					Hydraulics
73	A chamber for storing hydraulic fluid under pressure is called	Accumulator	servomechanism	fluids	jack			Accumulator
74	A device converting hydraulic pressure to mechanical motion is called	mechanical actuator	screw driver	Hydraulic Actuator	converter			Hydraulic Actuator
75	The valve used to set open at 26,201Kpa is called	valve	relief Valve	reveale valve	pressure valve			Relief Valve
76	A back pressure valve is installed in the	vacumn tube	velocity tube	air tube	Pressure tube			Pressure tube
77	The back pressure valve is similar in operation and construction to a	Check valve	contor valve	temp valve	pressure valve			Check valve
78	Pulley, cables etc are used in	hydraullic system	pnematic system	Mechanical Brake Systems	electronic brake system			Mechanical Brake Systems
79	Large Aircrafts use	ordinary brake system	oil brake system	dics brake system	Power Brake Systems			Power Brake Systems
80	Torque links is often referred to as	scalar system	Scissors assembly	pitot assembly	torsion assembly			Scissors assembly
81	The component located on the bottom of the strut piston and has the axles attached to it is called	axle	truck	pulley	ring			truck
82	The vertical member of the landing gear assembly that contains the shock absorbing mechanism is called	truck	Trunnion	Shimmy Damper	struts			struts
83	The top of the strut is attached to an integral part and is called as	truck	Trunnion	Shimmy Damper	Scissors assembly			Trunnion
84	The Strut is also called as	inner cylinder	ring	Outer Cylinder	piston			Outer Cylinder
85	The upper Bearing in strut keeps the inner cylinder aligned with the	Outer Cylinder	Trunnion	Shimmy Damper	Spring-oleo Type			Outer Cylinder
86	The portion of the landing gear assembly attachedto the airframe is called	truck	Shimmy Damper	Scissors assembly	Trunnion			Trunnion
87	The landing gear strut extends down from the approximate centre of the	landing system	Rigid landing gear	Trunnion	truss			Trunnion
88	A hydraulic snubbling unit that reduces the tendancy of the nose wheel to oscillator from side to side is called	Hydraulic Filter	Shimmy Damper	O-Rings	Omni-Radial			Shimmy Damper
89	Which of the following is a shock absorbing landing system	truck	Shimmy Damper	Scissors assembly	Spring-oleo Type			Spring-oleo Type
90	Non-Retractable landing gear usually works with the help of hydraulic or	Electric Power	motor	rotor	electric system			Electric Power
91	Retractable landing gear is designed to reduce	lift	weight	Drag	thrust			Drag
92	Non-Retractable landing gear is generallly called as	Movable Landing Gear	semi movable Landing Gear	Retractable landing gear	Fixed Landing Gear			Fixed Landing Gear
93	The landing gear which donot dissipate the energy of the aircraft contacting the groundduring landing is called	Movable Landing Gear	Non-Absorbing Landing Gear	semi movable Landing Gear	Retractable landing gear			Non-Absorbing Landing Gear
94	NALG are usually	Movable Landing Gear	Non-Absorbing Landing Gear	Rigid landing gear	Retractable landing gear			Rigid landing gear
95	The landing gear commonly found on the helicopters and the sail planes is called	Rigid landing Gear	Movable Landing Gear	semi movable Landing Gear	Retractable landing gear			Rigid landing Gear
96	which of the following does not come under landing gear classification	Hulls & Float	Retractable Gear	Fixed Gear	Non-Fixed Gear			Non-Fixed Gear
97	The number of the main wheels in conventional type of the landing gear is	One	Three	Two	Four			Two
98	The number of the Tail wheels in conventional type of the landing gear is	Three	One	Two	Four			One
99	The number of the landing gears used in Conventional landing gear is	One	Two	Four	Three			Three
100	The number of the nose wheels in Tricycle type landing gears is	Five	Four	One	Three			One
101	The number of wheels in Tricycle type of landing gears is	Three	Four	Five	Six			Three
102	which of the following is used during landing	Cockpit	Landing Gear	Wings	Tail			Landing Gear
103	The component which filters any particle that enter hydraulic fluid is called	Hulls & Float	Shimmy Damper	Hydraulic Filter	Scissors assembly			Hydraulic Filter
104	Hydraulic filters use	O-Rings	M-Rings	T-Rings	F-Rings			O-Rings
105	Which of the following does not come under Hydraulic Fluids	Vegetable base fluid	Mineral Base Fluids	Phosphate ester base Fluids	Sodium Nitrate base fliuds			Sodium Nitrate base fliuds
106	ACT is called	Passive Control Technology	Active Control Technology	Aircraft Control Technology	Adaptive Control Technology			Active Control Technology
107	Aircrafs are made statically and	Statically stable	Statically unstable	Dynamically unstable	Dynamically Stable			Dynamically Stable
108	Teleflux can be operated from	Rudder	Fuselage	Cockpit	Engine			Cockpit
109	By moving the control column fore&after the movement achieved is called	Yaw	Pitch	Roll	damping			Pitch
110	By moving the control column side to side the movement achieved is called	Pitch	Roll	damping	Roll			Roll
111	The rudder pedals controls the	Pitch	Roll	Yaw	damping			Yaw
112	The To-From indicator presents the direction to or from the station along the	Omni-vertical	Omni-Radial	Omni-stable	all the given			Omni-Radial
113	Guidance in Poor Visiblity condition can be done using	IFS	IRS	ISF	ILS			ILS
114	Auto Pilot system can be used during	Steady Flight	Unsteady Flight	Moderate flight	High flight			Steady Flight
115	Which of the following system use control cables?	Power assisted	Fully powered	Conventional system	Control system			Conventional system
	UNIT III							
115	Aircraft fixed axes such that the ox axis is parallel to the total velocity vector V_0 as___________	Stable	stability axes	dynamic stable	global axes			stability axes
116	All early thinking of human flight centered on the imitation of ___________	mechanics	cycle	birds	pilot			birds
117	The first real studies of flight in the 1480's was by________	Leonardo da Vinci	Sir George Cayley	John Stringfellow	Montgolfiers			Leonardo da Vinci
118	The number of wings in monoplane is ______________	One	Two	three	four			one
119	The first sucessful Bi-plane was invented by ______________	Wright Flier	octave chanute	percy pilcher	cayley			Wright Flier
120	Propulsion is the act of moving an object through _______________	water	space	air	clouds			air
121	Flaps are used to produce excess_____________	thrust	lift	speed	weight			lift
122	Banking in aircraft is performed with the help of	lateral surface	longitudinal surface	directional surface	control surface			control surface
123	Airfoil is a cross section of ______________	rudder	wing	slats	nose			wing
124	Trainer aircraft is used in _________________	airports	cargo	military	agriculture			military
125	The first flight with human passengers rose majestically into the air and lasted for .	5 minutes	15 minutes	50 minutes	25 minutes			25 minutes
126	The man who made the first real studies of flihgt in 1480's was	Leonardo da Vinci	Sir George Cayley	Montgolfiers	John Stringfellow			Leonardo da Vinci
127	Sir George Cayley is considered the father of aerodynamics	structures	propulsion system	aerodynamics	composite			aerodynamics
128	The machine called the boy carrier is a _________	biplane	monoplane	triplane	fourplane			triplane

129	The number of wings in biplane is ___________	One	Two	three	four			Two
130	Who is called as the first true Aeronautical Engineer ?	Leonardo da Vinci	Sir George Cayley	Montgolfiers	John Stringfellow			Sir George Cayley
131	Monoplane with swept forward wing was introduced by ________	William Samuel Henson	Felix Du Temple	Francis wenham	Leonardo da Vinci			Felix Du Temple
132	Number of wings used in a bi plane_________	One	Two	three	four			Two
133	The early engine that Wright brothers used generated almost	10 horse power	11 horse power	12 horse power	13 horse power			12 horse power
134	Which of the following wing has a swing wing	MIG 25	Boeing	F-14 Tomcat	F16			F-14 Tomcat
135	The inventor of the first Hot Air Ballon was___________	Leonardo da Vinci	Sir George Cayley	Montgolfier brothers	John Stringfellow			Montgolfier brothers
136	B-2 spirit is an aircraft which has _____________	swing wing	delta wing	swept wing	normal wing			delta wing
137	HS-123 is an example of________	monoplane	biplane	triplane	top wing			biplane
138	A Fokker Dr.I is an example of	jet engine aircraft	glider	airplane	triplane			triplane
139	Horizontal elevators for longitudinal control in the year 1900 was discovered by	William Samuel Henson	Leonardo da Vinci	Felix Du Temple	Wright Brothers			Wright Brothers
140	The number of wings in triplane is_________	One	Two	three	four			three
141	De Havilland Vampire T11 is an example of	low wing	mid wing	high wing	parasol wing			mid wing
142	Which of the following has a parasol wing configuration	De Havilland Dove	De Havilland Vampire T11	Havilland Canada Dash 8	Dornier Do 24			Dornier Do 24
143	Most military aircraft of World War 2 were	fighter	monoplane	biplane	All of the given			monoplane
144	Who is called as the Grand Parent of the Modern Aeroplane?	Leonardo da Vinci	Sir George Cayley	Montgolfier brothers	John Stringfellow			Sir George Cayley
145	The inventor of ' Aerial steam carriage' was	William Samuel Henson	Felix Du Temple	Francis wenham	Leonardo da Vinci			William Samuel Henson
146	Monoplane glider with birds wing planform was successfully invented by Lilienthal on	1892	1894	1860	1875			1894
147	The first to invent gasoline power engine suitable for aircraft in the year 1896 was	Langley	Sir George Cayley	Montgolfiers	John Stringfellow			Langley
148	The use of wing warping to control airplane in lateral motion in the year 1871-1948 was found by	William Samuel Henson	Leonardo da Vinci	Felix Du Temple	Wright Brothers			Wright Brothers
149	The wind tunnel for calculating the lift, drag and accurate aerodynamic measurement was found in the year __________	1902-1905	1901-1902	1900-1901	1900-1904			1901-1902
150	MIG15 aircraft was designed in the year__________	1940	1945	1950	1955			1950
151	Soviet M21B aircraft has__________	straight wing monoplane	delta wing monoplane	swept back wing	All of the given			delta wing monoplane
152	Turbo jet engined aircraft was developed in the year 1941 by	Leonardo da Vinci	Sir George Cayley	Sir Frank Whittle	Francis Wenham			Sir Frank Whittle
153	Which of the following is a USA flying boat	short sundarland	dornier	Boeing 314	WAL-1			Boeing 314
154	"HAWKER" a land based fighter was discovered in	USA	British	German	Japan			British
155	The first wind tunnel in the world to calculate aerodynamic forces was discovered by	Leonardo da Vinci	Sir George Cayley	Montgolfier brothers	Francis Wenham			Francis Wenham
156	The number of engines in DE HAVILLAND DH4.	One	Two	three	four			One
157	Samuel langley designed many models named	Amphibian	land plane	Aeroplane	Aerodrome			Aerodrome
158	The one who is world's greatest exponents of gliding	Leonardo da Vinci	Sir George Cayley	John Stringfellow	Otto liliental			Otto liliental
159	Aileron is used to obtain _____________	longitudinal control	lateral control	directional control	rolling control			longitudinal control
160	Rudder is fixed on the_________	horizontal stabilizer	vertical stabilizer	nose	cockpit			vertical stabilizer
161	Trim tabs are used under___________	neutral condition	balanced condition	unbalanced condition	motion			unbalanced condition
162	Servo tabs are similar to	trim tabs	spoilers	spring tabs	flaps			trim tabs
163	The forces and moments acting on an airplane is zero, then the airplane is in	danger	equilibrium	unbalanced condition	un equlibirium			equilibrium
164	Fuselage shape is	cylindrical	circle	square	cone			cylindrical
165	In propeller the power is converted into conventional rotational to produce	drag	thrust	lift	weight			thrust
166	Which in the following is a secondary control surface	aileron	rudder	trim tab	all the given			trim tab
167	Yawing movement is performed by	slats	flaps	aileron	rudder			rudder
168	Spoilers are used to decrease	wind turbulance	drag	moment	lift			lift
169	Hunter aircraft is a example of	single engine	multi engine	twin engine	glider			single engine
170	The body of the aircraft where the wings and tail are attached is called as	power plant	cabin	horizontal stabilizer	fuselage			fuselage
171	The aircraft power plant is used to produce	lift	drag	thrust	weight			thrust
172	The major component used for taxing in aircraft is	fuselage	landing gear	control stick	pitot static tube			landing gear
173	Which in the following landing gear does not exist.	single wheel	conventional	tricycle	tandem			single wheel
174	Conventional landing gear consist of	one wheel	two wheel	three wheel	four wheel			three wheel
175	Which of the landing gear has a nose wheel	tandem	tricycle	random	Bicycle			tricycle
176	The vehicle heavier than air and powered by an engine is called	Airship	Free ballon	Airplane	Capture ballon			Airplane
177	Rotating blade located on the front of the airplane is called	rudder	wing	engine	propeller			propeller
178	Which of the following comes under the classification of rotorcraft.	Land plane	Gyro plane	Sea plane	Glider			Gyro plane
	UNIT IV							
179	Low wing loading	increases stalling speed, landing speed and landing run	increases lift, stalling speed and manoeuvrability	decreases stalling speed, landing speed and landing run	decreases lift, stalling speed and manoeuvrability			decreases stalling speed, landing speed and landing run
180	Due to the change in downwash on an un-tapered wing (i.e. one of constant chord length) it will	not provide any damping effect when rolling	tend to stall first at the root	not suffer adverse yaw effects when turning	provide damping effect when rolling			tend to stall first at the root
181	True stalling speed of an aircraft increases with altitude	because reduced temperature causes compressibility effect	because air density is reduced	because humidity is increased and this increases drag	because increased temperature causes compressibility effect			because air density is reduced
182	As a general rule, if the aerodynamic angle of incidence (angle of attack) of an aerofoil is slightly increased, the centre of pressure will	never move	move towards the root	move towards the tip	move forward towards the leading edge			move forward towards the leading edge
183	The "wing setting angle" is commonly known as	angle of incidence	angle of attack	angle of dihedral	angle of andedral			angle of incidence
184	On a very humid day, an aircraft taking off would require	a shorter take off run	a longer take off run	humidity does not affect the take off run	high air intake			a longer take off run
185	An aircraft is flying at 350 MPH, into a head wind of 75 MPH, what will its ground speed be?	175 mph	350 mph	200 mph	275 mph			275 mph
186	When does the angle of incidence change?	When the aircraft attitude changes	When the aircraft is descending	It never changes	When the aircraft is ascending			It never changes
187	As the angle of attack decreases, what happens to the centre of pressure?	It moves forward	It moves rearwards	Centre of pressure is not affected by angle of attack decrease	increases			It moves rearwards

188	A decrease in pressure over the upper surface of a wing or aerofoil is responsible for	approximately 2/3 (two thirds) of the lift obtained	approximately 1/3 (one third) of the lift obtained	approximately ½ (one half) of the lift obtained	approximately twice of the lift obtained			approximately 2/3 (two thirds) of the lift obtained
189	Which of the four forces act on an aircraft?	Lift, gravity, thrust and drag	Weight, gravity, thrust and drag	Lift, weight, gravity and drag	Lift, weight, gravity and thrust			Lift, gravity, thrust and drag
190	Which of the following types of drag increases as the aircraft gains altitude?	Parasite drag	Induced drag	Interference drag	wave drag			Induced drag
191	The layer of air over the surface of an aerofoil which is slower moving, in relation to the rest of the airflow, is known as	camber layer	boundary layer	chord layer	skin layer			boundary layer
192	What is a controlling factor of turbulence and skin friction?	Aspect ratio	Fineness ratio	Counter-sunk rivets used on engine	Counter-sunk rivets used on skin exterior			Counter-sunk rivets used on skin exterior
193	Changes in aircraft weight	will not affect total drag since it is dependant only upon speed	will not affect total lift since it is dependant only upon speed	will only affect total drag if the lift is kept constant	cause corresponding changes in total drag due to the associated lift change			cause corresponding changes in total drag due to the associated lift change
194	The aircraft stalling speed will	increase with an increase in weight	be unaffected by aircraft weight changes since it is dependant upon the angle of attack	increase with an decrease in weight	decrease with an increase in weight			increase with an increase in weight
195	In a bank and turn	extra lift is not required	extra lift is not required if thrust is increased	extra thrust is not required	extra lift is required			extra lift is required
196	To achieve the maximum distance in a glide, the recommended air speed is	as close to the stall as practical	as high as possible with VNE	the speed where the L/D ratio is maximum	the speed where the L/D ratio is minimum			the speed where the L/D ratio is maximum
197	If the C of G is aft of the Centre of Pressure	changes in lift produce a pitching moment which acts to increase the change in lift	when the aircraft sideslips, the C of G causes the nose to turn into the sideslip thus applying a restoring moment	when the aircraft yaws the aerodynamic forces acting forward of the Centre of Pressure	when the aircraft rolls the aerodynamic forces acting forward of the Centre of Pressure			changes in lift produce a pitching moment which acts to increase the change in lift
198	Porpoising is an oscillatory motion in the	pitch plane	roll plane	yaw plane	all three planes			pitch plane
199	Due to the interference effects of the fuselage, when a high wing aeroplane sideslips	the accompanying rolling due to keel surface area is destabilizing	the accompanying lift changes on the wings produces a stabilizing effect	the accompanying rolling due to the fin is destabilizing	the accompanying drag changes on the wings produces a stabilizing effect			the accompanying lift changes on the wings produces a stabilizing effect
200	The power required in a horizontal turn	is greater than that for level flight at the same airspeed	must be the same as that for level flight at the same airspeed	is less than that for level flight at the same airspeed	is less than that for level flight at the same altitude			is greater than that for level flight at the same airspeed
201	A wing mounted stall sensing device is located	usually on the under surface	always at the wing tip	always on the top surface	always on empennage			usually on the under surface
202	For an aircraft in a glide	thrust, drag, lift and weight act on the aircraft	weight, lift and drag act on the aircraft	weight and drag only act on the aircraft	weight, lift and thrust act on the aircraft			weight, lift and drag act on the aircraft
203	The upper part of the wing in comparison to the lower	develops more drag	develops the same lift	develops less lift	develops more lift			develops more lift
204	What effect would a forward CG have on an aircraft on landing?	Increase stalling speed	No effect on landing	Reduce stalling speed	Reduce ground speed			Increase stalling speed
205	An aspect ratio of 8 would mean	span 64, mean chord 8	mean chord 64 , span 8	span squared 64 ,chord 8	span squared 4 ,chord 8			span 64, mean chord 8
206	If an aircraft in level flight loses engine power it will	pitch nose up	pitch nose down	not change pitch without drag increasing	not change pitch without drag decreasing			pitch nose down
207	The lift /drag ratio at stall	increases	decreases	remains constant	Remains constant upto stalling point			decreases
208	On a straight unswept wing, stall occurs at	the thick portion, at the wing root	the thick portion, at the wing tip	the thin portion, at the wing tip	the thick portion, at the wing tip			the thick portion, at the wing root
209	During a climb from a dive	the thrust required is greater than required for level flight	the thrust required is lower than for level flight	the thrust required is the same as for level flight	the thrust required is equal to thrust available			the thrust required is lower than for level flight
210	When power is off, the aircraft will pitch	nose down	nose up	trim level	remains constant			nose down
211	Angle of attack on a down going wing in a roll	is zero	decreases	is unaffected	increases			increases
212	For any given speed, a decrease in aircraft weight, the induced drag will	increase	decrease	remain the same	be zero			decrease
213	The amount of lift generated by a wing is	greatest at the root	greatest at the tip	constant along the span	constant along the chord			greatest at the root
214	Induced Drag is	greatest towards the tip	greatest towards towards the root	decreased from tip to root	increased from tip to root			greatest towards the tip
215	Induced Drag is	equal to profile drag at stalling angle	equal to profile drag	greater than profile drag	less than profile drag			equal to profile drag
216	For a given IAS an increase in altitude will result in	no change in the value of induced drag	an increase in induced drag	an increase in profile drag	an increase in skin friction drag			an increase in induced drag
217	Stall inducers may be fitted to a wing	at the tip to cause the root to stall first	at the root to cause the tip to stall first	at the tip to cause the tip to stall first	at the root to cause the root to stall first			at the root to cause the root to stall first
218	With increasing altitude pressure decreases and	temperature decreases at the same rate as pressure reduces	temperature decreases but at a lower rate than pressure reduces	temperature remains constant to 8000ft	temperature remains constant			temperature decreases but at a lower rate than pressure reduces
219	Krueger Flap	increases the leading edge camber	allows high pressure air from beneath the wing to flow to the top	energizes the air flowing over the ailerons	increases the trailing edge camber			increases the leading edge camber
220	Which conditions will give the shortest take off distance?	Hot Humid day at high elevation	rainy day at sea level	Hot summer day at sea level	Cold winter day at sea level			Cold winter day at sea level
221	The optimum angle of attack of an aerofoil is the angle at which	the aerofoil produces maximum lift	the aerofoil produces zero lift	the highest lift/drag ratio is produced	the lowest lift/drag ratio is produced			the highest lift/drag ratio is produced

222	A high aspect ratio wing has a	increased induced drag	decreased induced drag	decreased skin friction drag	increased skin friction drag			decreased induced drag
223	Minimum total drag of an aircraft occurs	at the stalling speed	when profile drag equals induced drag	when induced drag is least	when wave drag is least			when profile drag equals induced drag
224	If the weight of an aircraft is increased, the induced drag at a given speed	will increase	will decrease	will remain the same	will remain the same upto 8000 ft			will increase
225	The transition point on a wing is the point where	the flow separates from the wing surface	the boundary layer flow changes from laminar to turbulent	the flow divides to pass above and below the wing	the boundary layer flow changes from turbulent to laminar			the boundary layer flow changes from laminar to turbulent
226	The boundary layer of a body in a moving air stream is	a thin layer of air over the surface where the air is stationary	a layer of separated flow where the air is turbulent	a layer of air over the surface where the airspeed is changing from free stream speed to zero speed	a layer of separated flow where the air is laminar			a layer of air over the surface where the airspeed is changing from free stream speed to zero speed
227	A laminar boundary layer will produce	more skin friction drag than a turbulent one	less skin friction drag than a turbulent one	less pressure drag than a turbulent one	more pressure drag than a turbulent one			less skin friction drag than a turbulent one
228	Longitudinal stability is given by	the fin	the wing dihedral	the horizontal tailplane	the vertical tailplane			the horizontal tailplane
229	Lateral stability is given by	the ailerons	the wing dihedral	the horizontal tailplane	the fin			the wing dihedral
230	Stability about the lateral axis is given by	wing dihedral	the fin	the ailerons	the horizontal tailplane			the horizontal tailplane
231	Sweepback of the wings will	increase lateral stability	decrease lateral stability	decrease longitudinal stability	increase longitudinal stability			increase lateral stability
232	On an aircraft in an un-powered steady speed descent	the lift equals the weight	the weight equals the drag	the weight equals the resultant of the lift and drag				the weight equals the resultant of the lift and drag
233	When an aircraft rolls to enter a turn and power is not increased	the lift equals the weight	the lift is greater than the weight	the lift is less than the weight	the lift equals the drag			the lift is less than the weight
234	The boundary layer is	thickest at the leading edge	thickest at the trailing edge	constant thickness from leading to trailing edges	thickest at the lower trailing edge			thickest at the trailing edge
235	The amount of thrust produced by a jet engine or a propeller can be calculated using	Newton's 1st law	Newton's 2nd law	Newton's 3rd law	all the given			Newton's 2nd law
236	An engine which produces an efflux of high speed will be	more efficient	less efficient	speed of efflux has no affect on the engine efficiency	less efficient in case of propeller engines			less efficient
237	Directional stability may be increased with	pitch dampers	horn balance	alierons	yaw dampers			yaw dampers
238	Lateral stability may be increased with	increased lateral dihedral	increased lateral anhedral	increased longitudinal dihedral	increased longitudinal anhedral			increased lateral dihedral

UNIT V

239	On a swept wing aircraft if both wing tip sections lose lift simultaneously the aircraft will	roll	pitch nose up	pitch nose down	Yaw			pitch nose up
240	Lift on a delta wing aircraft	increases with an increased angle of incidence (angle of attack)	decreases with an increase in angle of incidence (angle of attack)	does not change with a change in angle of incidence (angle of attack)	increases with an increased angle of incidence upto Stall			increases with an increased angle of incidence (angle of attack)
241	On a straight wing aircraft, stall commences at the	root on a low thickness ratio wing	tip on a high thickness ratio wing	tip on a low thickness ratio wing	root on a high thickness ratio wing			root on a high thickness ratio wing
242	For the same angle of attack, the lift on a delta wing	is greater than the lift on a high aspect ratio wing	is lower than the lift on a high aspect ratio wing	is the same as the lift on a high aspect ratio wing	is greater than the lift on a low aspect ratio wing			is lower than the lift on a high aspect ratio wing
243	The ISA	is taken from the equator	is taken from 45 degrees latitude	is taken from 30 degrees latitude	is taken from 60 degrees latitude			is taken from 45 degrees latitude
244	At higher altitudes as altitude increases, pressure	decreases at constant rate	increases exponentially	remains constant	decreases exponentially			decreases exponentially
245	When the pressure is half of that at sea level, what is the altitude?	12,000 ft	8,000 ft	10,000 ft	18,000 ft			18,000 ft
246	During a turn, the stalling angle	increases with AOA	decreases	remains the same	increases with an increased angle of incidence upto Stall			remains the same
247	The C of G moves in flight. The most likely cause of this is	movement of passengers	movement of the centre of pressure	consumption of fuel and oils	altitude			consumption of fuel and oils
248	The C of P is the point where	all the forces on an aircraft act	the three axis of rotation meet	the lift can be said to act	CG Point			the lift can be said to act
249	The three axis of an aircraft act through the	C of G	C of P	stagnation point	Chord line			C of G
250	Pressure decreases	proportionally with a decreases in temperature	inversely proportional to temperature	Pressure and temperature are not related	proportionally with a increase in temperature			proportionally with a decreases in temperature
251	As air gets colder, the service ceiling of an aircraft	reduces	increases	remains the same	becomes zero			increases
252	When the weight of an aircraft increases, the minimum drag speed	decreases	increases	increases upto stall	remains the same			increases
253	An aircraft will have	less gliding distance if it has more payload	more gliding distance if it has more payload	the same gliding distance if it has more payload	more gliding distance if it has less payload			the same gliding distance if it has more payload
254	When an aircraft experiences induced drag	air flows under the wing span-wise towards the tip and on top of the wing spanwise towards the root	air flows under the wing span-wise towards the root and on top of the wing span-wise towards the tip	air flows under the wing span-wise towards the tip	air flows on top of the wing spanwise towards the root			air flows under the wing span-wise towards the tip and on top of the wing spanwise towards the root
255	At stall, the wingtip stagnation point	moves toward the lower surface of the wing	moves toward the upper surface of the wing	moves toward the lower wing tip	moves toward the upper wing tip			moves toward the lower surface of the wing

256	The rigging angle of incidence of an elevator is	the angle between the mean chord line and the horizontal in the rigging position	the angle between the bottom surface of the elevator and the horizontal in the rigging position	the angle between the bottom surface of the elevator and the longitudinal datum	the angle between the bottom surface of the elevator and the lateral datum			the angle between the mean chord line and the horizontal in the rigging position
257	What is the lapse rate with regard to temperature?	0.98°C per 1000 ft	1.98°F per 1000 ft	4°C per 1000 ft	1.98°C per 1000 ft			1.98°C per 1000 ft
258	What happens to load factor as you decrease turn radius?	It increases	It decreases	It remains constant	load factor is not related to turn radius			It increases
259	If you steepen the angle of a banked turn without increasing airspeed or angle of attack, what will the aircraft do?	It will remain at the same height	It will sideslip with attendant loss of height	It will stall	It will decent			It will sideslip with attendant loss of height
260	An aircraft wing tends to stall first at	the tip due to a higher ratio thickness/chord	the tip due to a lower ratio thickness/chord	the root due to a higher ratio thickness/chord	the root due to a lower ratio thickness/chord			the root due to a higher ratio thickness/chord
261	Dihedral wings combat instability in	pitch	yaw	roll	sideslip			sideslip
262	To stop aircraft decreasing in height during a sideslip, the pilot can	advance the throttle	pull back on the control column	adjust the rudder position	adjust the elevator position			advance the throttle
263	What control surface movements will make an aircraft fitted with ruddervators yaw to the left?	Left ruddervator lowered, right ruddervator raised	Right ruddervator lowered, left ruddervator raised	Both ruddervators raised	Both ruddervators lowered			Left ruddervator lowered, right ruddervator raised
264	When a leading edge slat opens, there is a gap between the slat and the wing. This is	to allow it to retract back into the wing	to allow air through to re-energize the boundary layer on top of the wing	to keep the area of the wing the same	to change the area of the wing			to allow air through to re-energize the boundary layer on top of the wing
265	Which of the following is true?	Lift acts at right angles to the wing chord line and weight acts vertically down	Lift acts at right angles to the relative airflow and weight acts vertically down	Lift acts at right angles to the relative airflow and weight acts at right angles to the aircraft centre line	Lift acts at right angles to the chord line and weight acts at right angles to the aircraft centre line			Lift acts at right angles to the relative airflow and weight acts vertically down
266	If the wing tips stall before the root on a swept wing aircraft, the aircraft will	roll	pitch nose up	pitch nose down	Yaw			pitch nose up
267	Standard sea level temperature is	0 degrees Celsius	15 degrees Celsius	20 degrees Celsius	22 degrees Celsius			15 degrees Celsius
268	As altitude increases, pressure	decreases at constant rate	increases exponentially	decreases exponentially	Remains constant			decreases exponentially
269	Lapse rate usually refers to	Pressure	Density	Temperature	altitude			Temperature
270	The vertical fin of a single engined aircraft is	parallel with both the longitudinal axis and vertical axis	parallel with the longitudinal axis but not the vertical axis	parallel with the vertical axis but not the longitudinal axis	Perpendicular with both the longitudinal axis and vertical axis			parallel with the vertical axis but not the longitudinal axis
271	Aircraft flying in the transonic range most often utilize	sweptback wings	advanced supercritical airfoils	high wings	delta wings			sweptback wings
272	Which type of flap changes the area of the wing?	Fowler	Split	Slotted	plain			Fowler
273	Forward swept wings tend to stall at the root first so the aircraft retains lateral control, so why are they never used on passenger aircraft?	Because the wing tips wash in at high wing loads	Because the wing tips wash out at high wing loads	Because at high loads their angle of incidence increases	Because at high loads their angle of incidence decreases			Because at high loads their angle of incidence increases
274	What happens to air flowing at the speed of sound when it enters a converging duct?	Velocity decreases, pressure and density increase	Velocity increases, pressure and density decreases	Velocity, pressure and density remains constant	Velocity, pressure and density increase			Velocity decreases, pressure and density increase
275	As the angle of attack of an airfoil increases the centre of pressure	moves forward	moves aft	remains stationary	moves towards CG			moves forward
276	An aircraft, which is longitudinally stable, will tend to return to level flight after a movement about which axis?	Pitch	Roll	Yaw	all three axis			Pitch
277	Vapour trails from the wingtips of an aircraft in flight are caused by	low pressure above the wing and high pressure below the wing causing vortices	high pressure above the wing and low pressure below the wing causing vortices	low pressure above the wing and high pressure below the wing causing a temperature rise	low pressure above the wing and low pressure below the wing causing a temperature rise			low pressure above the wing and high pressure below the wing causing vortices
278	Vortex generators on the wing are most effective at	high speed	low speed	low angles of attack	high angles of attack			high angles of attack
279	The chord line of a wing is a line that runs from	the centre of the leading edge of the wing to the trailing edge	half way between the upper and lower surface of the wing	one wing tip to the other wing tip	camber line			the centre of the leading edge of the wing to the trailing edge
280	The angle of incidence of a wing is an angle formed by lines	parallel to the chord line and longitudinal axis	parallel to the chord line and the lateral axis	parallel to the chord line and the vertical axis	perpendicular to the chord line and the lateral axis			parallel to the chord line and longitudinal axis
281	The centre of pressure of an aerofoil is located	30 - 40% of the chord line back from the leading edge	30 - 40% of the chord line forward of the leading edge	50% of the chord line back from the leading edge	10% of the chord line back from the leading edge			30 - 40% of the chord line back from the leading edge
282	Compressibility effect is	drag associated with the form of an aircraft	drag associated with the friction of the air over the surface of the aircraft	the increase in total drag of an aerofoil in transonic flight due to the formation of shock waves	the increase in total drag of an aerofoil insubsonic flight due to the formation of shock waves			the increase in total drag of an aerofoil in transonic flight due to the formation of shock waves
283	Lateral control of an aircraft at high angle of attack can be maximised by using	fences	vortex generators	wing slots	flaps			vortex generators
284	Stall strips are always	on the trailing edge of a wing	on the leading edge of a wing	fitted forward of the ailerons	fitted aft of the ailerons			on the leading edge of a wing
285	Due to the interference of the airflow on a high wing aircraft between the fuselage and the wings, the lateral stability of the aircraft in a gusty wind situation will cause	the upper wing to increase its lift	the upper wing to decrease its lift	the lower wing to decrease its lift	the lower wing to increase its lift			the upper wing to decrease its lift
286	Slats	reduce the stall speed	reduce the tendency of the aircraft to Yaw	decrease the aerofoil drag at high speeds	decrease lift			reduce the stall speed
287	A high aspect ratio wing will give	high profile and low induced drag	low profile and high induced drag	low profile and low induced drag	high profile and high induced drag			high profile and low induced drag
288	Aerofoil efficiency is defined by	lift over drag	drag over lift	lift over weight	drag over weight			lift over drag

289	An aircraft banks into a turn. No change is made to the airspeed or angle of attack. What will happen?	The aircraft enters a sideslip and begins to lose altitude	The aircraft turns with no loss of height	The aircraft yaws and slows down	The aircraft begins to gain altitude			The aircraft enters a sideslip and begins to lose altitude
290	The relationship between induced drag and airspeed is, induced drag is	directly proportional to the square of the speed	inversely proportional to the square of the speed	directly proportional to speed	inversely proportional to speed			inversely proportional to the square of the speed
291	What is Boundary Layer?	Separated layer of air forming a boundary at the leading edge	Turbulent air moving from the leading edge to trailing edge	low energy air that sticks to the wing surface and gradually gets faster until it joins the free stream flow of air	Separated layer of air forming a boundary at the trailing edge			low energy air that sticks to the wing surface and gradually gets faster until it joins the free stream flow of air
292	The normal axis of an aircraft passes through	the centre of gravity	a point at the centre of the wings	at the centre of pressure	Chord line			the centre of gravity
293	On a high winged aircraft, what effect will the fuselage have on the up-going wing?	The up-going wing will have a decrease in angle of attack and therefore a decrease in lift	The down-going will have a decrease in angle of attack and therefore a decrease in lift	The up-going wing will have an increase in angle of attack and therefore a	The up-going wing will have an decrease in angle of attack and therefore a			The up-going wing will have a decrease in angle of attack and therefore a decrease in lift
294	What is the collective term for the fin and rudder and other surfaces aft of the centre of gravity that helps directional stability?	Effective keel surface	Empennage	Fuselage surfaces	ruddervators			Effective keel surface
295	Temperature above 36,000 feet will	decrease exponentially	remain constant	increase exponentially	Increses at 1 degree for 1000 feet			remain constant
296	A decrease in incidence toward the wing tip may be provided to	prevent adverse yaw in a turn	prevent span-wise flow in manoeuvres	retain lateral control effectiveness at high angles of attack	prevent yaw in a turn			retain lateral control effectiveness at high angles of attack
297	The angle of attack which gives the best L/D ratio	decreases with a decrease in density	in unaffected by density changes	increases with a decrease in density	decreases with a increase in density			in unaffected by density changes
298	For a given aerofoil producing lift, where P = pressure and V = velocity:	P1 is greater than P2, and V1 is greater than V2	P1 is less than P2 and V1 is greater than V2	P1 is greater than P2, and V1 is less than V2	P1 ,P2, and V1 , V2 remain constant			P1 is greater than P2, and V1 is less than V2