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Aircraft Conceptual Design  
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Chapter 3

Aircraft Conceptual Design

3.1. Introduction
As outlined in Chapter 2, in order to implement the “Systems Engineering” discipline \[1\], the aircraft (i.e. system) design process includes four major phases: 1. Conceptual Design, 2. Preliminary Design, 3. Detail design, and 4. Test and evaluation. The purpose of this chapter is to present the techniques and selection processes in the aircraft conceptual design phase. Conceptual design is the first and most important phase of the aircraft system design and development process. It is an early and high level life cycle activity with potential to establish, commit, and otherwise predetermine the function, form, cost, and development schedule of the desired aircraft system. The identification of a problem and associated definition of need provides a valid and appropriate starting point for design at the conceptual level.

Selection of a path forward for the design and development of a preferred system configuration, which will ultimately be responsive to the identified customer requirement, is a major responsibility of conceptual design. Establishing this early foundation, as well as requiring the initial planning and evaluation of a spectrum of technologies, is a critical first step in the implementation of the systems engineering process. Systems engineering, from an organizational perspective, should take the lead in the definition of system requirements from the beginning and address them from a total integrated life-cycle perspective.
The aircraft design process generally commences with the identification of a “what” or “desire” for something and is based on a real (or perceived) deficiency. As a result, a system requirement is defined along with the priority for introduction, the date when the system capability is required for customer use, and an estimate of the resources necessary for acquiring this new system. To ensure a good start, a comprehensive statement of the problem should be presented in specific qualitative and quantitative terms, in enough detail to justify progressing to the new step. Need identification and formulation is discussed in Chapter 2.

As the name implies, the aircraft conceptual design phase is the aircraft design at the concept level. At this stage, the general design requirements are entered in a process to generate a satisfactory configuration. The primary tool in this stage of design is the “selection”. Although
there are a variety of evaluation and analysis, but there are not many calculations. The past design experience plays a crucial role in the success of this phase. Hence, the members of conceptual design phase team must be the most experienced engineers of the corporation. The details of the advantages and disadvantages of each configuration are described in chapters 5 through 11.

Figure 3.1 illustrates the major activities which are practiced in the conceptual design phase. The fundamental output of this phase is an approximate three-view of the aircraft that represents the aircraft configuration. Section 3.2 concerns with primary function and role for each aircraft component. The aircraft components (e.g. wing, fuselage, tail, landing gear, and engine) configuration alternatives are addressed in Section 3.3. Aircraft classifications from variety of aspects are reviewed in Section 3.4. In Section 3.5, the principles of trade-off analysis to determine the most satisfactory configuration are introduced. Section 3.6 examines the conceptual design optimization with an emphasis on the application of the multidisciplinary design optimization technique.

3.2. Primary Functions of Aircraft Components

An aircraft comprised of several major components. It mainly includes wing, horizontal tail, vertical tail, fuselage, propulsion system, landing gear and control surfaces. In order to make a decision about the configuration of each aircraft component, the designer must be fully aware of the function of each component. Each aircraft component has inter-relationships with other components and interferes with the functions of other components.

1. **Wing**: The main function of the wing is to generate the aerodynamic force of lift to keep the aircraft airborne. The wing tends to generate two other unwanted aerodynamic productions: an aerodynamic drag force plus an aerodynamic pitching moment. Furthermore, the wing is an essential component in providing the aircraft lateral stability which is fundamentally significant to flight safety. In almost all aircraft, the aileron is arranged to be at the trailing edge of the outboard section. Hence, the wing is largely influential in providing the aircraft lateral control.

2. **Fuselage**: The primary function of the fuselage is to accommodate the payload which includes passengers, cargo, luggage, and other useful loads. The fuselage is often a home for pilot and crewmembers, and most of the times, fuel tanks and engine(s). Since the fuselage is providing a moment arm to horizontal and vertical tail, it plays an influential role in longitudinal and directional stability and control. If the fuselage is decided to be short, a boom must be provided to allow for the tails to have the sufficient arm.

3. **Horizontal tail**: The horizontal tail’s primary function is to generate an aerodynamic force to longitudinally trim the aircraft. Furthermore, the vertical tail is an essential component is providing the aircraft longitudinal stability which is a fundamental requirement for flight.
safety. In majority of the aircraft, the elevator is a movable part of the horizontal tail, so longitudinal control and maneuverability is applied through horizontal tail.

4. **Vertical tail:** The vertical tail’s primary function is to generate an aerodynamic force to directionally trim the aircraft. Furthermore, the vertical tail is an essential component is providing the aircraft directional stability which is a fundamental requirement for flight safety. In majority of the aircraft, the rudder is a movable part of the vertical tail, so directional control and maneuverability is applied through vertical tail.

5. **Engine:** The engine is the main component in the aircraft propulsion system to generate the power and/or thrust. The aircraft requires a thrust force to move forward (as in any other vehicle), so the engine primary function is to generate the thrust. The fuel is considered to be a necessary item of the propulsion system and it sometimes constitutes a large part of aircraft weight. An aircraft without engine is not able to take-off independently, but it is capable of gliding and landing, as are performed by sailplanes and gliders. Sailplanes and gliders take off with the help of other aircraft or outside devices (such as winch), and climb with the help of wind and thermal currents.

6. **Landing gear:** The primary function of the landing gear is to facilitate take-off and landing operations. During take-off and landing operations, the fuselage, wing, tail, and aircraft components are kept away from the ground through the landing gear. The wheels of the landing gear in land-based and ship-based aircraft also play a crucial role in safe acceleration and deceleration of the aircraft. Rolling wheels as part of landing gear allows the aircraft to accelerate without spending a considerable amount of thrust to overcome the friction.

<table>
<thead>
<tr>
<th>No</th>
<th>Component</th>
<th>Primary function</th>
<th>Major areas of influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fuselage</td>
<td>Payload accommodations</td>
<td>Aircraft performance, longitudinal stability, lateral stability, cost</td>
</tr>
<tr>
<td>2</td>
<td>Wing</td>
<td>Generation of lift</td>
<td>Aircraft performance, lateral stability</td>
</tr>
<tr>
<td>3</td>
<td>Horizontal tail</td>
<td>Longitudinal stability</td>
<td>Longitudinal trim and control</td>
</tr>
<tr>
<td>4</td>
<td>Vertical tail</td>
<td>Directional stability</td>
<td>Directional trim and control, stealth,</td>
</tr>
<tr>
<td>5</td>
<td>Engine</td>
<td>Generation of thrust</td>
<td>Aircraft performance, stealth, cost, control</td>
</tr>
<tr>
<td>6</td>
<td>Landing gear</td>
<td>Facilitate take-off and landing</td>
<td>Aircraft performance, stealth, cost</td>
</tr>
<tr>
<td>7</td>
<td>Control surfaces</td>
<td>Control</td>
<td>Maneuverability, cost</td>
</tr>
</tbody>
</table>

*Table 3.1. Aircraft major components and their functions*

The above six components are assumed to be the fundamental components of an air vehicle. However, there are other components in an aircraft that are not assumed here as a major one. The roles of those components are described in the later sections whenever they are
mentioned. Table 3.1 illustrates a summary of aircraft major components and their functions. This table also shows the secondary roles and the major areas of influence of each aircraft component. The table also shows the design requirements that are affected by each component. The functions described in table 3.1 are only the primary functions of each component, and does not addresses the secondary functions. The full explanations about the function and role for each component are outlined in Chapters 5 through 12.

Traditional aircraft configuration design attempts to achieve improved performance and reduced operating costs by minimizing maximum takeoff weight. From the point of view of an aircraft manufacturer, however, this method does not guarantee the financial viability of an aircraft program. A better design approach would take into account not only aircraft performance and manufacturing cost, but also factors such as aircraft flying qualities, and systems engineering criteria.

The historical choice of minimizing gross take-off weight (GTOW) as the objective in aircraft design is intended to improve performance and subsequently lower operating costs, primarily through reduced fuel consumption. However, such an approach does not guarantee the optimality of a given aircraft design from the perspective of the aircraft consumer. In an increasingly competitive market for aircraft, manufacturers may wish to design for improved systems engineering of an aircraft program, as well as technical merit, before undertaking such a costly investment.

3.3. Aircraft Configuration Alternatives
When the necessary aircraft components, to satisfy design requirements, are identified and the list of major components is prepared, the step to select their configurations begin. Each aircraft major component may have several alternatives which all satisfy design requirements. However, each alternative carry advantages and disadvantages by which design requirements are satisfied at different levels. Since each design requirement has a unique weight, each configuration alternative results in a different level of satisfaction. This section reviews the configuration alternatives for each major component. The description of the advantages and disadvantages for each configuration will be addressed in Chapters 5 through 12.
3.3.1. Wing Configuration
In general, wing configuration alternatives from seven different aspects are as follows:

1. **Number of wings**
   1.1. Monoplane
   1.2. Biplane
   1.3. Triplane

2. **Wing location**
   2.1. High wing
   2.2. Mid wing
   2.3. Low wing
   2.4. Parasol wing

3. **Wing type**
   3.1. Rectangular
   3.2. Tapered
   3.3. Delta
   3.4. Swept back
   3.5. Swept forward
   3.6. Elliptical

4. **High lift device**
   4.1. Plain flap
   4.2. Split flap
   4.3. Slotted flap
   4.4. Kruger flap
   4.5. Double slotted flap
   4.6. Triple slotted flap
   4.7. Leading edge flap
   4.8. Leading edge slot

5. **Sweep configuration**
   5.1. Fixed wing
   5.2. Variable sweep

6. **Shape**
   6.1. Fixed shape
   6.2. Morphing wing

7. **Structural configuration**
   7.1. Cantilever
   7.2. Strut-braced (a. faired, b. un-faired)

The advantages and disadvantages of the wing configuration alternatives, plus the technique to select the best wing configuration alternative to meet the design requirements have been presented in Chapter 5. The primary impacts of the wing configuration alternatives are imposed
on cost, the duration of production, ease of manufacturing, lateral stability, performance, maneuverability, and aircraft life. Figure 3.2 illustrates several wing configuration alternatives.

### 3.3.2 Tail Configuration

In general, tail configuration alternatives from three different aspects are as follows:

1. **Aft or forward**
   - 1.1. Aft conventional tail
   - 1.2. Canard (foreplane)
   - 1.3. Three surfaces
2. **Horizontal and vertical tail**
   - 2.1. Conventional
   - 2.2. V-tail
   - 2.3. T-tail
   - 2.4. H-tail
   - 2.5. Inverted U
3. **Attachment**
   - 3.1. Fixed tail
   - 3.2. Moving tail
   - 3.3. Adjustable tail

![Tail configuration alternatives](image)

The advantages and disadvantages of the tail configuration alternatives, plus the technique to select the best tail configuration alternative to meet the design requirements have been presented in Chapter 6. The primary impacts of the tail configuration alternatives are imposed on cost, the duration of production, ease of manufacturing, longitudinal and directional stability, longitudinal and directional maneuverability, and aircraft life. Figure 3.3 illustrates several tail configuration alternatives.

### 3.3.3 Propulsion System Configuration

In general, propulsion system configuration alternatives from four different aspects are as follows:

1. **Engine type**
   - 1.1. Human powered
   - 1.2. Solar powered
   - 1.3. Piston prop
   - 1.4. Turboprop
   - 1.5. Turbofan
   - 1.6. Turbojet
   - 1.7. Rocket
2. **Engine and the aircraft center of gravity**
   - 2.1. Pusher
2.2. Tractor

3. **Number of engines**
   - 3.1. Single-engine
   - 3.2. Twin-engine
   - 3.3. Tri-engine
   - 3.4. Four engine
   - 3.5. Multi-engine

4. **Engine location**
   - 4.1. In front of nose (inside)
   - 4.2. Inside fuselage mid-section
   - 4.3. Inside wing
   - 4.4. Top of the wing
   - 4.5. Under wing
   - 4.6. Inside vertical tail
   - 4.7. Side of fuselage at aft section
   - 4.8. Top of the fuselage

The advantages and disadvantages of the propulsion system alternatives, plus the technique to select the best engine configuration alternative to meet the design requirements have been presented in Chapter 9. The primary impacts of the engine configuration alternatives are imposed on cost of flight operation, cost of aircraft production, performance, duration of production, ease of manufacturing, maneuverability, flight time, and aircraft life. Figure 3.4 illustrates several engine configuration alternatives.

3.3.4. **Landing Gear Configuration**

In general, landing gear configuration alternatives from three different aspects are as follows:

1. **Landing gear mechanism**
   - 1.1. Fixed (a. faired, b. un-faired)
   - 1.2. Retractable
   - 1.3. Partially retractable

2. **Landing gear type**
   - 2.1. Tricycle (or nose gear)
   - 2.2. Tail gear (tail dragger or skid)
   - 2.3. Bicycle (tandem)
   - 2.4. Multi-wheel
   - 2.5. Bicycle (side-by-side)
   - 2.6. Float-equipped
   - 2.7. Removable landing gear

![Figure 3.4. Engine configuration alternatives](image)

![Figure 3.5. Landing gear configuration alternatives](image)
Figure 3.5 shows several landing gear configuration alternatives. Another design requirement that influences the design of the landing gear is the type of runway. There are mainly five types of runway.

3. Runway
   3.1. Land-based
   3.2. Sea-based
   3.3. Amphibian
   3.4. Ship-based
   3.5. Shoulder-based (for small remote controlled aircraft)

Various types of runways are introduced in Chapter 4. The runway requirements will also affect the engine design, wing design, and fuselage design. The advantages and disadvantages of the landing gear configuration alternatives, plus the technique to select the best landing gear configuration alternative to meet the design requirements have been presented in Chapter 8. The primary impacts of the landing gear configuration alternatives are imposed on cost of flight operation, cost of aircraft production, performance, duration of production, ease of manufacturing, and aircraft life.

3.3.5. Fuselage Configuration
In general, fuselage configuration alternatives from three different aspects are as follows:

1. Door
   1.1. Cabin
   1.2. Cockpit

2. Seat
   2.1. Tandem
   2.2. Side-by-side
   2.3. n-seats per row

3. Pressure system
   3.1. Pressurized cabin
   3.2. Pressurized hose
   3.3. Unpressurized cabin

The advantages and disadvantages of the fuselage configuration alternatives, plus the technique to select the best fuselage configuration alternative to meet the design requirements have been presented in Chapter 7. The primary impacts of the fuselage configuration alternatives are imposed on cost of flight operation, cost of aircraft production, performance, duration of production, ease of manufacturing, passenger comfort, and aircraft life. Figure 3.6 illustrates several fuselage configuration alternatives.
3.3.6. Manufacturing-Related Items Configuration

In general, manufacturing configuration alternatives from four different aspects are as follows:

1. **Materials for structure**
   1.1. Metal (often aerospace aluminum)
   1.2. Wood and fabric
   1.3. Composite materials
   1.4. Metal and composite materials

2. **Assembly technique**
   2.1. Kit-form (Kit-plane rule: 51% amateur construction)
   2.2. Semi-kit form
   2.3. Modular

3. **Metallic components manufacturing technique**
   3.1. Welding
   3.2. Machining
   3.3. Casting
   3.4. Sheet metal work

4. **Composite materials manufacturing technique**
   4.1. Hand layup
   4.2. Machine layup
   4.3. Wet layup
   4.4. Filament winding
   4.5. Resin transfer molding
   4.6. Pultrusion
   4.7. Sandwich construction

The descriptions of engineering materials and manufacturing processes are out of the scope of this book. For the details of these materials and techniques, the reader is encouraged to consult with the relevant references such as [2] and [3]. The primary impacts of these alternatives are imposed on cost, the duration of production, ease of manufacturing, and aircraft life.

3.3.7. Subsystems Configuration

In general, subsystems configuration alternatives from five different aspects are as follows:

1. **Primary control surfaces**
   1.1. Conventional (i.e. elevator, aileron, and rudder)
   1.2. Elevon-rudder
   1.3. Aileron-ruddervator
   1.4. Flaperon-rudder-aileron
   1.5. Cross (x) or plus (+) section

2. **Secondary control surfaces**
   2.1. High lift device (e.g. flap, slat, slot)
2.2. Spoiler
2.3. Tab

3. **Power Transmission**
   3.1. Mechanical
   3.2. Hydraulic
   3.3. Pneumatic
   3.4. Fly-by-wire
   3.5. Fly-by-optic

4. **Fuel tank**
   4.1. Inside fuselage
   4.2. Inside wing (both sides) (a. between two spars, b. in front of main spar)
   4.3. Tip-tank
   4.4. Fuel tank location

5. **Store**
   5.1. Camera
   5.2. Rocket
   5.3. Missile
   5.4. Gun
   5.5. External tank

The advantages and disadvantages of some of these configuration alternatives, plus the technique to select the best subsystem configuration alternative to meet the design requirements have been presented in Chapters 5 through 12. Table 3.2 illustrates a summary of configuration alternatives for aircraft major components.

<table>
<thead>
<tr>
<th>No</th>
<th>Component</th>
<th>Configuration alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fuselage</td>
<td>- Geometry: lofting, cross section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Seating arrangement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- What to accommodate (e.g. fuel, engine, and landing gear)?</td>
</tr>
<tr>
<td>2</td>
<td>Wing</td>
<td>- Type: Swept, tapered, dihedral;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Installation: fixed, moving, adjustable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Location: Low-wing, mid-wing, high wing, parasol</td>
</tr>
<tr>
<td>3</td>
<td>Horizontal tail</td>
<td>- Type: conventional, T-tail, H-tail, V-tail, inverted V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Location: aft tail, canard, three surfaces</td>
</tr>
<tr>
<td>4</td>
<td>Vertical tail</td>
<td>Single, twin, three VT, V-tail</td>
</tr>
<tr>
<td>5</td>
<td>Engine</td>
<td>- Type: turbofan, turbojet, turboprop, piston-prop, rocket</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Location: (e.g. under fuselage, under wing, beside fuselage)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Number of engines</td>
</tr>
<tr>
<td>6</td>
<td>Landing gear</td>
<td>- Type: fixed, retractable, partially retractable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Location: (e.g. nose, tail, multi)</td>
</tr>
<tr>
<td>7</td>
<td>Control surfaces</td>
<td>Separate vs. all moving tail, reversible vs. irreversible, conventional vs. non-conventional (e.g. elevon, ruddervator)</td>
</tr>
</tbody>
</table>

*Table 3.2. Aircraft major components with design alternatives*
<table>
<thead>
<tr>
<th>No</th>
<th>Configuration parameter</th>
<th>Configuration alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conventionality</td>
<td>1. Conventional, 2. Non-conventional</td>
</tr>
<tr>
<td>2</td>
<td>Power</td>
<td>1. Powered, 2. Unpowered</td>
</tr>
<tr>
<td>5</td>
<td>Engine and aircraft cg</td>
<td>1. Pusher, 2. Tractor</td>
</tr>
<tr>
<td>6</td>
<td>Engine installation</td>
<td>1. Fixed, 2. Tilt-rotor</td>
</tr>
<tr>
<td>8</td>
<td>Number of wings</td>
<td>1. One-wing, 2. Biplane, 3. Tri-plane</td>
</tr>
<tr>
<td>9</td>
<td>Wing type</td>
<td>1. Fixed-wing, 2. Rotary-wing (a. helicopter, b. gyrocopter)</td>
</tr>
<tr>
<td>10</td>
<td>Wing geometry</td>
<td>1. Rectangular, 2. Tapered, 3. Swept, 4. Delta</td>
</tr>
<tr>
<td>11</td>
<td>Wing sweep</td>
<td>1. Fixed sweep angle, 2. Variable sweep</td>
</tr>
<tr>
<td>12</td>
<td>Wing setting angle</td>
<td>1. Fixed setting angle, 2. Variable setting angle</td>
</tr>
<tr>
<td>14</td>
<td>Wing installation</td>
<td>1. Cantilever, 2. Strut-braced</td>
</tr>
<tr>
<td>15</td>
<td>Tail or canard</td>
<td>1. Tail, 2. Canard, 3. Three-surfaces</td>
</tr>
<tr>
<td>17</td>
<td>Vertical tail</td>
<td>1. No vertical tail (VT), 2. One VT at fuselage end, 3. Two VT at the fuselage end, 4. Two VT at the wing tips</td>
</tr>
<tr>
<td>21a</td>
<td>Seating (in two-seat)</td>
<td>1. Side-by-side, 2. Tandem</td>
</tr>
<tr>
<td>21b</td>
<td>Seating (in higher number of passengers)</td>
<td>1. 1×n, 2. 2×n, 3. 3×n,…, 10×n. (n: number of rows)</td>
</tr>
<tr>
<td>22</td>
<td>Luggage pallet</td>
<td>Based on types of luggage and payload, it has multiple options</td>
</tr>
<tr>
<td>23</td>
<td>Cabin or Cockpit</td>
<td>1. Cabin, 2. Cockpit</td>
</tr>
<tr>
<td>24</td>
<td>Horizontal tail Control surfaces</td>
<td>1. Tail and elevator, 2. All moving horizontal tail</td>
</tr>
<tr>
<td>25</td>
<td>Vertical tail Control surfaces</td>
<td>1. Vertical tail and rudder, 2. All moving vertical tail</td>
</tr>
<tr>
<td>26</td>
<td>Wing control surfaces</td>
<td>1. Aileron and flap, 2. Flaperon</td>
</tr>
<tr>
<td>28</td>
<td>Power system</td>
<td>1. Mechanical, 2. Hydraulic, 3. Pneumatic, 4. FBW¹, 5. FBO²</td>
</tr>
<tr>
<td>29</td>
<td>Material for structure</td>
<td>1. Full metal, 2. Full composite, 3. Primary structure: metal, secondary structure: composite</td>
</tr>
<tr>
<td>30</td>
<td>Secondary control surfaces</td>
<td>1. Trailing edge Flap, 2. Leading edge slot, 3. Leading edge slat</td>
</tr>
</tbody>
</table>

Table 3.3. Configuration parameters and their options (set by designer)

¹ Fly-By-Wire (Electric signal)
² Fly-By-Optic (light signal)
Table 3.3 provides a list of configuration parameters and their design alternatives. These are determined and finalized by the designer. The optimization process will find and will prove which configuration is the best. The optimization methodology that is introduced in this paper will formulate a technique that enables a designer to select configuration parameters in order to meet the design requirements in an optimum fashion. These 30 groups of configurations (Table 3.3) are available reference for selection of alternatives by aircraft designers. It is observed that the number of design options is surprisingly large. The Multidisciplinary design optimization (see Section 3.6) process is a well-established process to optimize the configuration for multi-disciplined purpose.

### 3.4. Aircraft Classification and Design Constraints

One of the essential steps that a designer must take is to clarify the aircraft type with a relevant full description of specifications. This will help the design process to be straightforward and avoids confusions in the later stages. The aircraft type is primarily based on the aircraft mission, and its required specifications. This section examines the aircraft classifications and types from variety of aspects.

One of the basic aircraft classifications is to divide aircraft groups into three large types: 1. Military, 2. Civil - Transport, 3. Civil - General Aviation or GA. The GA aircraft refers to all aircraft other than military, airliner and regular cargo aircraft, both private and commercial. In terms of weight; GA aircraft has a maximum take-off weight of equal or less than 12,500 lb (for Normal and acrobatic categories), of equal or less than 19,000 lb (for Utility categories). Another difference between a GA aircraft and transport aircraft is in the number of seat. The commuter category of GA aircraft is limited to propeller-driven, multiengine airplanes that have a seating configuration, excluding pilot seats. Any non-military aircraft with a maximum take-off weight of more than 19,000 lb and passenger seats of more than 19 is considered to be a transport category aircraft. A transport aircraft is governed by Part 25 of FAR, while a GA aircraft is governed by Part 23 of FAR.

An aircraft that is ordered by a customer is accompanied with a list of requirements and constraints. In majority of cases, there is no way to escape from those requirements, unless the designer can prove to the customer, that a specific requirement is not feasible. Other than that, all requirements and constraints must be considered and met in the design process. There are other requirements as well that are imposed by airworthiness standards such as FAR, JAR and MIL-STD³. Several of these requirements might be grouped in the aircraft classification. Aircraft configurations can be classified in many ways, based on various aspects.

---
³ Military Standards
<table>
<thead>
<tr>
<th>No</th>
<th>Group</th>
<th>Design requirements and constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Standard, non-standard</td>
<td>1. Standard, 2. Homebuilt (or garage-built)</td>
</tr>
<tr>
<td>2</td>
<td>General type</td>
<td>1. Military (MIL-STD), 2. Civil - Transport (FAR(^4) 25), 3. Civil - General Aviation or GA (FAR 23), 4. Very Light Aircraft (VLA), …</td>
</tr>
<tr>
<td>3</td>
<td>Maneuverability</td>
<td>1. Normal or non-aerobatic, 2. Utility or semi-aerobatic, 3. Aerobatic or acrobatic, 4. Highly maneuverable (e.g. Fighters and anti-missile missiles)</td>
</tr>
<tr>
<td>6</td>
<td>Density</td>
<td>1. Lighter-than-air craft (a. balloon, b. airship), 2. Heavier-than-air craft</td>
</tr>
<tr>
<td>8</td>
<td>Weight</td>
<td>1. Model (less than 30 lb), 2. Ultra light aircraft (less than 300 kg), 3. Very light (less than 750 kg), 4. Light (less than 12,500 lb), 5. Medium weight (less than 100,000 lb), 6. Heavy or Jumbo (above 100,000 lb)</td>
</tr>
<tr>
<td>10</td>
<td>Take-off run</td>
<td>1. Short Take Off and landing (STOL) (runway less than 150 m), 2. Vertical Take Off and landing (VTOL), 3. Regular</td>
</tr>
<tr>
<td>12</td>
<td>Stage</td>
<td>1. Model, 2. Prototype, 3. Operational</td>
</tr>
<tr>
<td>13</td>
<td>Term of use</td>
<td>1. Long term (Regular), 2. Experimental (X aircraft) or Research</td>
</tr>
<tr>
<td>14</td>
<td>Payload</td>
<td>1. Number of passengers, 2. Payload weight, 3. Store, …</td>
</tr>
<tr>
<td>15</td>
<td>Aircraft subsystems</td>
<td>1. Air condition, 2. Weather radar, 3. Parachute, …</td>
</tr>
<tr>
<td>16</td>
<td>FAR, and MIL requirements</td>
<td>1. Number of crew, 2. Ejection seat, 3. Reserve fuel, …</td>
</tr>
<tr>
<td>18</td>
<td>Maneuverability</td>
<td>1. Turn radius, 2. Turn rate, 3. Load factor</td>
</tr>
</tbody>
</table>

Table 3.4. Design constraints and requirements (set by customer)

One of the major steps in configuration design is to apply constraints and select the classification and type. Table 3.4 illustrates design constraints and requirements that are set by

\(^4\) Federal Aviation Regulations
the customer. It introduces the most important classifications and can be expanded based on the situation. These constraints range from aircraft mission to payload type, to type of control, and to performance requirements. A designer initially has no influence over these requirements, unless he/she can prove that the requirements are not feasible and not practical. Otherwise, all of them must be followed and be met at the end of design process. Figure 3.7 depicts a civil transport aircraft (Boeing 747), a General Aviation (GA) aircraft (Cessna 182) and a military fighter aircraft (Eurofighter Typhoon). Figure 3.8 shows a lighter-than-air craft and a heavier-than-air craft (ATR-42). Figure 3.9 illustrates a manned aircraft, an unmanned aircraft, and a remote controlled aircraft.

![Boeing 747 (Courtesy Anne Deus)](image)

![Cessna 182 (Courtesy of Jenny Coffey)](image)

![Eurofighter Typhoon (Courtesy of Antony Osborne)](image)

**Figure 3.7. General aviation, civil-transport, and military aircraft**

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1. Air ship Zeppelin NT (Lighter-than-air craft)  
2. ATR-42 (Courtesy of Anne Deus)  
**Figure 3.8. Lighter-than-air craft versus heavier-than-air craft**

1. Beech 76 Duchess (Courtesy of Jenny Coffey)  
2. Global Hawk  
3. Radio controlled model aircraft  
**Figure 3.9. Manned aircraft, unmanned aircraft, and remote controlled aircraft**
One of the significant design constraints originates from government regulations. In this regards, the designer has two options: 1. design an aircraft to comply with government regulations and standards, 2. design an aircraft regardless to government regulations and standards. The designer is free to make the decision to select either of the above options, but he/she must be aware of the consequences. This decision will impact the whole design process, since this generates a totally different design environment and constraints. In general, the compliance with government regulations and standards increase the cost and makes the design harder. However, it will increase the quality of the aircraft and allows the aircraft to be sold in the US market.

An aircraft which has not been certified by the government aviation authorities is referred to as homebuilt or garage-built. These aircraft usually are designed by non-expert individuals and used by individual pilots. Their airworthiness has not been confirmed by authorities, hence, the probability of aircraft crash is much higher that the certified ones. Their flight permissions are limited to a few airspaces to reduce the risk of civilian casualties. Homebuilt aircraft are not allowed to be sold in the US market.

Several countries have established an official body to regulate the aviation issues and ratify and collect aviation standards. The US government body that regulates the aviation related issues including aircraft design and manufacture is called Federal Aviation Administration (FAA). The Civil Aviation Authorities of certain European countries (including England, France, Germany) have established common comprehensive and detailed aviation requirements (referred to as the Certification Specifications, formerly JARs) with a view to minimizing Type Certification problems on joint ventures, and also to facilitate the export and import of aviation products. The CSs are recognized by the Civil Aviation Authorities of participating countries as an acceptable basis for showing compliance with their national airworthiness codes.

In the USA, FAA [4] of Department of Transportation regulates the aviation standards and publishes Federal Aviation Regulations (FAR). Some important parts of the FAR are:

- Part 23: Airworthiness Standards for GA aircraft
- Part 25: Airworthiness Standards for Civil Transport aircraft
- Part 29: Airworthiness Standards for Helicopters
- Part 33: Airworthiness Standards for Aircraft engines
- Part 103: Airworthiness Standards for Ultralight aircraft

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5 The countries are: Austria, Belgium, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Luxembourg, Malta, Monaco, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey & United Kingdom.
Military aircraft are required to follow and comply with military standards. A United States defense standard, often referred to as a military standard, MIL-STD, MIL-SPEC (or informally Mil Specs), is used to help achieve standardization objectives by the US Department of Defense. Although the official definitions differentiate between several types of documents, all of these documents go by the general rubric of "military standard", including defense specifications, handbooks, and standards. Strictly speaking, these documents serve different purposes. According to the Government Accountability Office, military specifications "describe the physical and/or operational characteristics of a product", while military standards "detail the processes and materials to be used to make the product." Military handbooks, on the other hand, are primarily sources of compiled information and/or guidance.

MIL-STD is a document that establishes uniform engineering and technical requirements for military-unique or substantially modified commercial processes, procedures, practices, and methods. There are five types of defense standards: interface standards, design criteria standards, manufacturing process standards, standard practices, and test method standards. There are currently more than 33,000 defense standards. Defense Standards are considered reliable enough that they are often used by other government organizations and even non-government technical organizations or general industry.

MIL-PRF is a performance specification that states requirements in terms of the required results with criteria for verifying compliance, but without stating the methods for achieving the required results. A performance specification defines the functional requirements for the item, the environment in which it must operate, and interface and interchangeability characteristics. MIL-KHBK is a guidance document containing standard procedural, technical, engineering, or design information about the materiel, processes, practices, and methods covered by the Defense Standardization Program. MIL-STD-962 covers the content and format for defense handbooks.

Flying models are usually what is meant by the term aero-modeling. Most flying model aircraft can be placed in one of three groups: 1. Free flight model aircraft fly without any method of external control from the ground. This type of model pre-dates the efforts of the Wright Brothers and other pioneers. 2. Control Line model aircraft use cables (usually two) leading from the wing to the pilot. 3. Radio-controlled aircraft have a transmitter operated by the pilot on the ground, sending signals to a receiver in the craft. Some flying models resemble scaled down versions of manned aircraft, while others are built with no intention of looking like piloted aircraft.

It is important to note that there are several design alternatives that if they are selected, few other design alternatives are not feasible any more. For instance, if a designer selects a single engine configuration, he/she cannot select the side fuselage as the location of installation of the engine. The reason is that the aircraft becomes asymmetric, if the single engine is installed at the left or right of the fuselage. Another example is that, if a designer selects not to have any vertical tail (for the reason of stealth), the ruddervator is not an option for the control surfaces design.
Table 3.5 shows the relationship between aircraft major components and the design requirements. The third column in table 3.5 clarifies the aircraft component which affected most; or major design parameter by a design requirement. Every design requirement will normally affects more than one component, but we only consider the component that is influenced most.

For example, the payload requirement, range and endurance will affect maximum take-off weight (Section 4.2), maximum take-off weight, engine selection, fuselage design, and flight cost. The influence of payload weight is different than payload volume. Thus for optimization purpose, the designer must know exactly payload weight and its volume. On the other hand, if the payload can be divided into smaller pieces, the design constraints by the payload are easier to handle. Furthermore, the other performance parameters (e.g. maximum speed, stall speed, rate of climb, take-off run, ceiling) will affect (Section 4.3), the wing area and engine power/thrust.

<table>
<thead>
<tr>
<th>No</th>
<th>Design requirements</th>
<th>Aircraft component that affected most, or major design parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Payload (weight) requirements</td>
<td>Maximum take-off weight</td>
</tr>
<tr>
<td>1b</td>
<td>Payload (volume) requirements</td>
<td>Fuselage</td>
</tr>
<tr>
<td>2</td>
<td>Performance Requirements (Range and Endurance)</td>
<td>Maximum take-off weight</td>
</tr>
<tr>
<td>3</td>
<td>Performance requirements (maximum speed, Rate of climb, take-off run, stall speed, ceiling, and turn performance)</td>
<td>Engine; Landing gear; and Wing</td>
</tr>
<tr>
<td>4</td>
<td>Stability requirements</td>
<td>Horizontal tail and vertical tail</td>
</tr>
<tr>
<td>5</td>
<td>Controllability requirements</td>
<td>Control surfaces (elevator, aileron, rudder)</td>
</tr>
<tr>
<td>6</td>
<td>Flying quality requirements</td>
<td>Center of gravity</td>
</tr>
<tr>
<td>7</td>
<td>Airworthiness requirements</td>
<td>Minimum requirements</td>
</tr>
<tr>
<td>8</td>
<td>Cost requirements</td>
<td>Materials; Engine; weight, …</td>
</tr>
<tr>
<td>9</td>
<td>Timing requirements</td>
<td>Configuration optimality</td>
</tr>
</tbody>
</table>

*Table 3.5. Relationship between aircraft major components and design requirements*

In general, design considerations are the full range of attributes and characteristics that could be exhibited by an engineered system, product, or structure. These interest both the producer and the customer. Design-dependent parameters are attributes and/or characteristics inherent in the design to be predicted or estimated (e.g. weight, design life, reliability, producibility, maintainability, and disposability). These are a subset of the design considerations for which the producer is primarily responsible. On the other hand, design-independent parameters are factors external to the design that must be estimated and forecasted for use in design evaluation (e.g. fuel cost per gallon, interest rates, labor rates, and material cost per pound). These depend upon the production and operating environment of the aircraft.

**3.5. Configuration Selection Process and Trade-Off Analysis**

In order to select the best aircraft configuration, a trade-off analysis must be established. Many different trade-offs are possible as the aircraft design progresses. Decisions must be made
regarding the evaluation and selection of appropriate components, subsystems, possible degree of automation, commercial off-the-shelf parts, various maintenance and support policies, and so on. Later in the design cycle, there may be alternative engineering materials, alternative manufacturing processes, alternative factory maintenance plans, alternative logistic support structures, and alternative methods of material phase-out, recycling, and/or disposal.

One must first define the problem, identify the design criteria or measures against which the various alternative configurations will be evaluated, the evaluation process, acquire the necessary input data, evaluate each of the candidate under consideration, perform a sensitivity analysis to identify potential areas of risk, and finally recommend a preferred approach. This process is shown in figure 3.10, and can be tailored at any point in the life cycle. Only the depth of the analysis and evaluation effort will vary, depending on the nature of the component.

Trade-off analysis involves synthesis which refers to the combining and structuring of components to create an aircraft system configuration. Synthesis is design. Initially, synthesis is used in the development of preliminary concepts and to establish relationships among various components of the aircraft. Later, when sufficient functional definition and decomposition have occurred, synthesis is used to further define "hows" at a lower level. Synthesis involves the creation of a configuration that could be representative of the form that the aircraft will ultimately take (although a final configuration should not be assumed at this early point in the design process). Given a synthesized configuration, its characteristics need to be evaluated in terms of the aircraft requirements initially specified. Changes will be incorporated as required, leading to a preferred design configuration. This iterative process of synthesis, analysis, evaluation, and design refinement leads to the establishment of the functional and product baselines.

One of the preliminary tasks in aircraft configuration design is identifying system design considerations. The definition of a need at the system level is the starting point for determining customer requirements and developing design criteria. The requirements for the system as an entity are established by describing the functions that must be performed. Design criteria constitute a set of "design-to" requirements, which can be expressed in both qualitative and quantitative terms. Design criteria are customer specified or negotiated target values for technical performance measures. These requirements represent the bounds within which the designer must "operate" when engaged in the iterative process of synthesis, analysis, and evaluation. Both operational functions (i.e. those required to accomplish a specific mission scenario, or series of missions) and maintenance and support functions (i.e. those required to ensure that the aircraft is operational when required) must be described at the top level.
After a baseline configuration has been established as a result of a formal design review, changes are frequently initiated for any one of a number of reasons: to correct a design deficiency, improve a product, incorporate a new technology, respond to a change in operational

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*Figure 3.10. Trade-off analysis process*
requirements, compensate for an obsolete section, and so on. Changes may be initiated from within the project, or as a result of some new externally imposed requirements.

At first, it may appear that a change is relatively insignificant in nature, and that it may constitute a change in the design of a prime equipment item, a software modification, a data revision, and/or a change in some process. However, what might initially appear to be minor often turns out to have a great impact across and throughout the system hierarchical structure. For instance, a change in the design configuration of prime component (e.g. a change in size, weight, repackaging, added performance capability) will probably affect related components, design of test and support equipment, type and quantity of spares/repair parts, technical data, transportation and handling requirements, and so on.

A change in any one component (e.g. horizontal tail) will likely have an impact on many other components (e.g. wing, fuselage) of the aircraft. Furthermore, if there are numerous changes being incorporated at the same time, the entire system configuration may be severely compromised in terms of maintaining some degree of requirements traceability. Past experiences with a variety of systems has indicated that many of the changes incorporated are introduced late in detail design phase, during production of construction, and early during the system utilization and sustaining support phase. While the incorporation of changes (for one reason or another) is certainly inevitable, the process for accomplishing such must be formalized and controlled to ensure traceability from one configuration baseline to another.

One of the most effective techniques in trade-off studies is multidisciplinary design optimization [5]. Researchers in academia, industry, and government continue to advance Multidisciplinary Design Optimization (MDO) and its application to practical problems of industry relevance (for instance see [6] through [8]. Multidisciplinary design optimization is a field of engineering that uses optimization methods to solve design problems incorporating a number of disciplines. Multidisciplinary design optimization allows designers to incorporate all relevant disciplines simultaneously. The optimum solution of a simultaneous problem is superior to the design found by optimizing each discipline sequentially, since it can exploit the interactions between the disciplines. However, including all disciplines simultaneously significantly increases the complexity of the problem.

Various aircraft designer have different priorities in their design processes. These priorities are based on different objectives, requirements and mission. There are primarily four groups of aircraft designers, namely: 1. military aircraft designer, 2. civil transport aircraft designer, 3. General Aviation (GA) aircraft designer, and 4. homebuilt aircraft designer. These four groups of designers have different interests, priorities, and design criteria. There are mainly ten figures of merit for every aircraft configuration designer. They are: production cost, aircraft performance, flying qualities, design period, beauty (for civil aircraft) or scariness (for military aircraft), maintainability, producibility, aircraft weight, disposability, and stealth requirement.
Table 3.6. Design objectives and an example of the priorities for various aircraft designer

Table 3.6 demonstrates priorities of each aircraft designer against ten figures of merit. This priority allocation is the author’s idea and may be different at some cases. References [9] and [10] are valuable references that describe true aircraft design stories and the lessons learned in the aircraft design over 60 years. Since they introduce multiple challenges and promises of several designs, they are helpful resources to determine the priorities in configuration design process.

Table 3.7. Three scenarios of weights (in percent) for a military aircraft designer

Among ten figures of merit (or criteria), grade “1” is the highest priority and grade “10” is the lowest priority. The grade “0” in this table means that, this figure of merit is not a criterion for this designer. As Table 3.6 illustrates, number one priority for a military aircraft designer is aircraft performance, while for a homebuilt aircraft designer cost is the number one priority. It is also interesting that stealth capability is an important priority for a military aircraft designer,
while for other three groups of designers, it is not important at all. These priorities (later called weights) reflect the relative importance of the individual figure of merit in the mind of the designer.

<table>
<thead>
<tr>
<th>No</th>
<th>Criteria</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cost</td>
<td>Minimum direct operating cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum total manufacturing cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum system cost over X years (life-cycle cost)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum profit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum return on investment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum payload per $</td>
</tr>
<tr>
<td>2</td>
<td>Performance</td>
<td>Maximizing cruise speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximizing range</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximizing endurance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximizing absolute ceiling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimizing take-off run</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximizing rate of climb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximizing maneuverability</td>
</tr>
<tr>
<td>3</td>
<td>Weight</td>
<td>Minimum take-off weight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum empty weight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum fuel weight</td>
</tr>
<tr>
<td>4</td>
<td>Flying qualities (stability and control)</td>
<td>Most controllable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most stable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Highest flying qualities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most luxurious for passengers</td>
</tr>
<tr>
<td>5</td>
<td>Size</td>
<td>Smallest wing span</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Smallest fuselage length</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Smallest aircraft height</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most spacios fuselage</td>
</tr>
<tr>
<td>6</td>
<td>Beauty or scariness</td>
<td>Most attractive (civil) or most scariest (fighter)</td>
</tr>
<tr>
<td>7</td>
<td>Systems engineering criteria</td>
<td>Most maintainable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most Producible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most disposable (environmental compatibility)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most flight testable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most stealth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most flexible (growth potential)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most reliable</td>
</tr>
<tr>
<td>8</td>
<td>Design and operation duration</td>
<td>Minimum duration of design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum duration of manufacture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum aircraft operating life</td>
</tr>
</tbody>
</table>

Table 3.8. Optimization criteria at group level

In design evaluation, an early step that fully recognizes design criteria is to establish a baseline against which a given alternative or design configuration may be evaluated. This
baseline is determined through the iterative process of requirements analysis (i.e. identification of needs, analysis of feasibility, definition of aircraft operational requirements, selection of a maintenance concept, and planning for phase-out and disposal). The mission that the aircraft must perform to satisfy a specific customer should be described, along with expectations for cycle time, frequency, speed, cost, effectiveness, and other relevant factors. Functional requirements must be met by incorporating design characteristics within the aircraft and its configuration components. As an example, Table 3.7 illustrates three scenarios of priorities (in percent) for military aircraft designers.

Design criteria may be established for each level in the system hierarchical structure. Possible optimization objectives for each level are demonstrated in table 3.8. These objectives must be formulated in order to determine the optimum design. A selected aircraft configuration would be optimum based on only one optimization function. Applicable criteria regarding the aircraft should be expressed in terms of technical performance measures and should be prioritized at the aircraft (system) level. Technical performance measures are measures for characteristics that are, or derive from, attributes inherent in the design itself. It is essential that the development of design criteria be based on an appropriate set of design considerations, considerations that lead to the identification of both design-dependent and design-independent parameters, and that support the derivation of technical performance measures.

One of the most effective techniques in trade-off studies is multidisciplinary design optimization (MDO). Most of MDO techniques require large numbers of evaluations of the objectives and the constraints. The disciplinary models are often very complex and can take significant amounts of time for a single evaluation. The solution can therefore be extremely time-consuming. Many of the optimization techniques are adaptable to parallel computing. Much of the current research is focused on methods of decreasing the required time. No existing solution method is guaranteed to find the global optimum of a general problem.

In MDO an objective function subject to a set of constraints is defined and a mathematical process is used to minimize this objective function without violating the constraints. Sensitivity derivatives are usually computed as part of the optimization process. For a single mission aircraft, the formulation of the objective function might be a simpler task. But, if an aircraft is a multi-role aircraft, the formulation of a single objective function would be difficult if not impossible.

The aircraft design process has, historically, ranged from sketches on napkins to trial, error, and natural selection, to sophisticated computer-aided design programs. Because the process is so complex, involving hundreds or thousands of computer programs, many people at many locations, it is very difficult to manage all recourses toward an optimized design. Thus most companies are continuing to improve on the strategy and developing a new approach. In the early days of airplane design, people did not do much computation. The design teams tended to
be small, managed by a single “chief designer” who knew about all of the design details and could make all of the important decisions.

Modern design projects are often so complex that the problem has to be decomposed and each part of the problem tackled by a different team. The way in which these teams should work together is still being debated by managers and researchers. The goal of these processes, whatever form they take, is to design what is, in some sense, the best or optimum aircraft configuration.

The design process of the F/A-18E/F (Figure 12.27) multi-mission fighter aircraft including a comparison between three configurations (YF-17, F/A-18A, and F/A-18E) is described in [11 and 12] discusses the analytical properties of three approaches to formulating and solving MDO problems that achieve varying degrees of autonomy by distributing the problem along disciplinary lines. The external configuration design of unguided missiles is optimized in [13] and [14] has employed MDO for configuration design of a generic air-breathing aerospace vehicle considering fidelity uncertainty. An assessment of configuration design methodologies including a detailed description of the general design configuration process—i.e., preprocessing, optimization, and post-processing—is given in [15].

3.6. Conceptual Design Optimization

3.6.1. Mathematical Tools

In mathematics, the term optimization refers to the study of problems in which one seeks to minimize or maximize a real function by systematically choosing the values of real or integer variables from within an allowed set. An optimization problem is one requiring the determination of the optimal (maximum or minimum) value of a given function, called the objective function, subject to a set of stated restriction, or constraints, placed on the variables concerned. In this process, we need to first describe an optimization problem in terms of the objective function and a set of constraints. Then algebraically manipulate and possibly graphically describe inequalities, and then solve a linear programming problem in two real variables. The final action is to solve the optimization problem using a mathematical technique.

Basically, the elements of optimization are: design variable, objective function, constraints, and design space [16]. Even when there is no uncertainty, optimization can be very difficult if the number of design variables is large, the problem contains a diverse collection of design variable types, and little is known about the structure of the performance function. If we have estimates, it may not be possible to conclusively determine if one design is better than another, frustrating optimization algorithms that try to move in improving directions. The comparison of two system designs (aircraft configurations) is computationally easier than the simultaneous comparison of multiple (more than two) configurations. The dynamic optimization problem can be stated as minimizing or maximizing a cost function subject to dynamic equation...
constraints, control inequality constraints, interior state equality constraints, interior state inequality constraints, and specified initial and final states.

In general a constrained single objective optimization problem [16] is to

\[
\text{optimize } f(x) \quad \text{subject to } x \in \Omega
\]  

(3.1)

The function \( f : \mathbb{R}^n \rightarrow \mathbb{R} \) that we wish to optimize (maximize or minimize) is a real-valued function called the objective function or cost function. The vector \( x \) is an \( n \)-vector of independent variables: \( x = [x_1, x_2, \ldots, x_n]^T \in \mathbb{R}^n \). The variables \( x_1, x_2, \ldots, x_n \) are often referred to as decision variables. The set \( \Omega \) is a subset of \( \mathbb{R}^n \) called the constraint set or feasible set. This optimization problem can be viewed as a decision problem that involves finding the “best” vector \( x \) of the decision variables over all possible vectors in \( \Omega \). The “best” is the one that results in the optimum (smallest or largest) value of the objective function. This vector is called the optimizer or extremizer of \( f \) vector over \( \Omega \). Often, the constraint set \( \Omega \) takes the form

\[
\Omega = \left\{ x : h(x) = 0, \ g(x) \leq 0 \right\},
\]

where \( h \) and \( g \) are given functions.

**Definition:** suppose that \( f : \mathbb{R}^n \rightarrow \mathbb{R} \) is a real-valued function defined on some set \( \Omega \subset \mathbb{R}^n \). A point \( x^* \in \Omega \) is a local optimizer of \( f \) over \( \Omega \) if there exists \( \varepsilon > 0 \) such that \( f(x) \geq f(x^*) \) for all \( x \in \Omega \setminus \{x^*\} \) and \( \| x - x^* \| < \varepsilon \). A point \( x^* \in \Omega \) is a global minimize of \( f \) over \( \Omega \) if \( f(x) \geq f(x^*) \) for all \( x \in \Omega \setminus \{x^*\} \). Strictly speaking, an optimization problem is solved only when a global minimizer (in general, extremizer) is found.

**Theorem 1. First order necessary condition:** let \( \Omega \) be a subset of \( \mathbb{R}^n \) and \( f \in C^1 \) a real-valued function on \( \Omega \). If \( x^* \) is a local minimizer of \( f \) over \( \Omega \), then for any feasible direction \( d \) at \( x^* \), we have

\[
d^T \nabla f(x^*) \geq 0. \quad \text{(3.2)}
\]

When an optimization problem involves only one objective function, it is a single-objective optimization. Most engineering problems, including aircraft configuration design optimization, require the designer to optimize a number of conflicting objectives. The objectives are in conflict with each other if an improvement in one objective leads to deterioration in another. Multi-objective problems in which there is competition between objectives may have no
single, unique optimal solution. Multi-objective optimization problems are also referred to as multicriteria or vector optimization problems. In a multi-objective optimization problem, we are to find a decision variable that satisfies the given constraints and optimizes a vector function whose components are objective functions.

The formulation of a multi-objective optimization problem is as follows:

\[
\begin{align*}
\text{minimize} \quad & f(x) = \begin{bmatrix} f_1(x_1, x_2, \ldots, x_n) \\ f_2(x_1, x_2, \ldots, x_n) \\ \vdots \\ f_j(x_1, x_2, \ldots, x_n) \end{bmatrix} \\
\text{subject to} \quad & x \in \Omega \\
\text{where} \quad & f : \mathbb{R}^n \to \mathbb{R} \quad \text{and} \quad \Omega \subseteq \mathbb{R}^n.
\end{align*}
\] (3.3)

In general, we may have three different types of multi-objective optimization problems: a. minimize all the objective functions, b. maximize all the objective functions, c. minimize some and maximize other objective functions. However, any of these can be converted into an equivalent minimization problem. Analytically

\[
\text{minimum} \quad f(x) = -\text{maximum} \quad [-f(x)] 
\] (3.4)

In some cases it is possible to deal with a multi-objective optimization problem by converting the problem into a single-objective optimization problem, so that standard optimization methods can be brought to bear. One method [17] is to form a single objective function by taking a linear combination, with positive coefficients, of the components of the objective function vector (\( f(x) = \begin{bmatrix} f_1(x), \ldots, f_j(x) \end{bmatrix}^T \)). Equivalently, we form a convex combination of the components of the objective function. In other word, we use

\[
F(x) = c^T f(x) 
\] (3.5)

as the single objective function, where \( c \) is a vector of positive components. This method is called the weighted-sum method, where the coefficients of the linear combination (i.e. components of \( c \) are called weights. These weights reflect the relative importance of the individual components in the objective vector. In general, the factors that are deemed more important in a given case should be weighted more heavily in the associated performance measure. This weighting process is particularly subjective if strictly objective criteria are not
evident—because of this, results obtained by using optimization theory should be carefully examined from the standpoint of overall acceptability.

In configuration design, physical and economic limitations often exist which act to limit system optimization. These limitations arise for a variety of reasons and generally cannot be ignored by the decision maker. Accordingly, there may be no choice except to find the best or optimum solution subject to the constraints. The list of constraints includes: 1. time-constrained configuration design, 2. cost-constrained configuration design, 3. geometry-constrained configuration design, 4. weight-constrained configuration design, 5. physically-constrained configuration design, 6. performance-constrained configuration design, 7. safety-constrained configuration design.

For example consider a firefighting aircraft that is required to carry a fixed volume of water or specific liquid with fixed weight, while a particular transport aircraft may be required to carry a specific piece of equipment that has a fixed geometry beside its fixed weight. In the case of firefighting aircraft, the payload weight and total volume are fixed, but the total volume can be divided into several parts. On the other hand, the transport aircraft has the fixed volume, and payload cannot be broken into smaller parts.

Optimization is only a means for bringing mutually exclusive alternatives into comparable (or equivalent) states. When multiple criteria are present in a decision situation, neither x optimization nor y optimization are sufficient. Although necessary, these steps must be augmented with information about the degree to which each alternative meets (or exceeds) specific criteria. One means for consolidating and displaying this information is through the decision evaluation display approach [17].

The optimization problem can be classified based on: 1. existence of constraints, 2. nature of the design variables, 3. physical structure of the problem, 4. nature of the equations involved, 5. permissible values of the design variables, 6. deterministic nature of the variables, 7. separability of the functions, and 8. nature of the objective functions.

3.6.2. Methodology
Given a set of arbitrary objects, configuration design corresponds to finding a suitable placement for all objects within a given space while satisfying spatial constraints and meeting or exceeding performance objectives. Most optimization practices are restricted to a solution domain defined by a selection of design variables. However, optimization theory makes a distinction between design variables and design parameters. For aircraft configuration design problems, variables specify limited differences within an aircraft configuration while parameters relate to complex variations within a configuration and inter-type differences, i.e. differences in configuration. During an optimization, parameters are normally fixed and the optimization is limited to finding a combination of values for the design variables that will minimize or maximize an objective
function like weight or speed. The mathematics required to optimize, at a higher level and support the choice between different concepts, emanates from the differential calculus.

The goal of this research is to derive a technique of determining a configuration that converges to an optimal solution, meet the design requirements and satisfies constraints, and requires minimal time and cost. The goal here is not to find an optimum aerodynamic shape, rather to find the best configuration as to yield the optimum design index. Sometimes manufacturing technology such as casting, welding, milling, sheet metal working, riveting, lay-up (for composite materials) will influence the design. Figure 3 shows the Phases in the configuration Design optimization. As this figure indicates, there is a feedback loop that shows the iterative nature of the configuration design process.

Figure 3.11. The Phases in the configuration design optimization

The methodology estimates the characteristics of systems so we can compare two designs in a quantitative way. The configuration optimization model consists of parameters and decision variables. Design parameters define the problem, but decision variables are the quantities whose numerical values will be determined in the course of obtaining the optimal configuration. These decision variables are called the design variables. The list of decision variables are illustrated in
the table 3.9. The number of variables depends on the aircraft classification (Table 3.9), and as this number increases, so does the complexity of the solution.

<table>
<thead>
<tr>
<th>Design parameter</th>
<th>Cost</th>
<th>Performance</th>
<th>Flying qualities</th>
<th>Period of design</th>
<th>Beauty</th>
<th>Maintainability</th>
<th>Productivity</th>
<th>Weight</th>
<th>Disposability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>Cheap (1)</td>
<td>Worst (1)</td>
<td>Best (10)</td>
<td>Short (10)</td>
<td>Worst (1)</td>
<td>Best (10)</td>
<td>Best (10)</td>
<td>Light (10)</td>
<td>Better (8)</td>
</tr>
<tr>
<td>Retractable</td>
<td>Expensive (10)</td>
<td>Best (10)</td>
<td>Worst (1)</td>
<td>Long (1)</td>
<td>Best (10)</td>
<td>Worst (1)</td>
<td>Worst (1)</td>
<td>Heavy (1)</td>
<td>Worse (3)</td>
</tr>
<tr>
<td>Partially retractable</td>
<td>Middle (5)</td>
<td>Middle (5)</td>
<td>Middle (5)</td>
<td>Middle (5)</td>
<td>Middle (5)</td>
<td>Middle (5)</td>
<td>Middle (5)</td>
<td>Middle (5)</td>
<td>Middle (5)</td>
</tr>
</tbody>
</table>

Table 3.9. The relationship between landing gear design options and the design criteria

The configuration variables may be one of three types: 1. continuous, 2. discrete, 3. integer. A design variable is continuous if it is free to assume any value. When a design variable can only assume a fixed value, it is discrete. For example landing gear can only be fixed; or retractable; or partially retractable. This would be the case when, for example, number of engine can only be selected from a set of finite list (say, 1 or 2 or 3 or 4). In some situation, number of engines can only assume integer values; these design variables are known as integer variable.

Few policies must be established and followed in order to insure that the configuration design output is feasible and reliable. Every parameter is evaluated by a number between 0 and 1. The zero means that this design parameter has no influence (or least influence) on a design objective. Number one (1) means this design parameter has the highest influence on a design objective. The preference percentages are divided among all preferences such that their summation is 100% or one (see Table 3.7). Each objective index is the summation of the contribution of each configuration parameter:

\[ CI = \sum_{i=1}^{27} x_{C_i} \]  

(3.6)

\[ PI = \sum_{i=1}^{27} x_{P_i} \]  

(3.7)

\[ FI = \sum_{i=1}^{27} x_{F_i} \]  

(3.8)

\[ TI = \sum_{i=1}^{27} x_{T_i} \]  

(3.9)
where CI strands for cost index and \( X_{Ci} \) is the contribution of \( i \)th configuration parameter on the cost index. By the same token, other symbols are defined as: PI: Performance index, FI: Flying qualities index, TI: Period of design index, BI: Beauty (or scariness) index, MI: Maintainability index, RI: Producibility index, WI: Weight index, DI: Disposability index, SI: Stealth index.

Among ten design objectives, three objectives must be minimized, they are: Cost, Weight, and Period of design. Other seven design objectives must be maximized, they are: Performance, Flying qualities, Beauty (or scariness), Maintainability, Producibility, Disposability, and Stealth.

Each design option must be evaluated for features and requirements that are important to customers. It is a challenging task to compare the various design options, but the proposed methodology can simplify the task of selecting a best design. According to this methodology, a matrix (or table) is created between criteria of selection and design options as shown in Table 3.9. Each design option is rated on a scale from 1 to 10 for various selection criteria. The weight assigned to each criterion depends on its significance for the application. Each rating is multiplied by a weight and totaled for final selection. The design that yields the highest point is assumed as the best or optimum configuration.

To combine all objective indices in a comparable quantity, design index (DI) is defined. All objectives that need to be minimized are grouped in one design index \( (DI_{\text{min}}) \) as found from the following equation:

\[
DI_{\text{min}} = CI \times P_C + WI \times P_W + TI \times P_T
\]  

(3.16)

All objective indices that need to be maximized are grouped in another design index \( (DI_{\text{max}}) \) as found from the following equation:  

\[
BI = \sum_{i=1}^{27} x_{Bi}
\]  

(3.10)

\[
MI = \sum_{i=1}^{27} x_{Mi}
\]  

(3.11)

\[
RI = \sum_{i=1}^{27} x_{Pi}
\]  

(3.12)

\[
WI = \sum_{i=1}^{27} x_{Wi}
\]  

(3.13)

\[
DI = \sum_{i=1}^{27} x_{Di}
\]  

(3.14)

\[
SI = \sum_{i=1}^{27} x_{Si}
\]  

(3.15)

Conceptual Design
\[ DI_{\text{max}} = PL \times P_r + FI \times P_e + BI \times P_b + MI \times P_M + RI \times P_R + DI \times P_D + SI \times P_S \]  
 \[ \text{where } \text{“P}_x \text{” represents the priorities of objective “x” in the design process and can be found from Table 2. The summations of the priorities of all objectives that need to be minimized are:} \]

\[ P_{\text{min}} = P_c + P_w + P_T \]  
\[ \text{The summations of the priorities of the objectives that need to be maximized are:} \]

\[ P_{\text{max}} = P_p + P_e + P_b + P_M + P_R + P_D + P_S \]  

In order to determine the optimum configuration, we will consider the configuration at which the design index (DI) is at the optimum value. First, two parameters of \( P_{\text{min}} \) and \( P_{\text{max}} \) must be considered. The design index at which the summation of the priorities of its objectives is higher is assumed as the criteria for configuration selection. There are eventually two configurations that yield the optimum design index. One configuration yields the lowest \( DI_{\text{min}} \), and one configuration yields the highest \( DI_{\text{max}} \).

If \( P_{\text{min}} \) is larger than \( P_{\text{max}} \), the configuration at which its \( DI_{\text{min}} \) is the lowest will be selected as the optimum configuration. If \( P_{\text{max}} \) is larger than \( P_{\text{min}} \), the configuration at which its \( DI_{\text{max}} \) is the highest will be selected as the optimum configuration. If the difference between \( P_{\text{min}} \) and \( P_{\text{max}} \) is not considerable (e.g. 51% and 49%), we need to follow the steps of systems engineering process. As an example application, the following example is introduced.

---

**Example 3.1**

**Problem statement:** A two seat fighter aircraft is ordered to be designed to fulfill a military mission and meet the following mission requirements:

- Maximum speed: at least Mach 1.8 at 30,000 ft
- Absolute ceiling: higher than 50,000 ft
- Radius of Action: 700 km
- Rate of climb: more than 12,000 fpm
- Take-off run: 600 m
- To be able to carry a variety of military stores with the mass of 8000 kg
- g limit: more than +9
- Highly maneuverable

Determine the optimum configuration for this aircraft.

**Solution:**
Initially, a baseline fighter configuration A is assumed as follows: Conventional configuration, Powered, Turbofan engine, Twin engine, Tractor engine, Fixed engine, Engines inside fuselage, One-wing, Fixed-wing, Tapered wing, Fixed sweep angle wing, Fixed setting angle, Low wing, Cantilever, Aft tail, Conventional tail, Twin Vertical Tail (VT) at the fuselage end, Retractable landing gear, Nose gear, Single long fuselage, Tandem seating, Cockpit, All moving horizontal tail, All moving vertical tail, Aileron and flap, Hydraulic power system, Full metal structure. For comparison, two alternative configurations, namely B and C, with arbitrary different variables are also considered. You may assume the features of other two configurations.

To find the design index, first the criteria index for each configuration variable is determined for all ten figures of merit or criteria (similar to what have been done in table 3.9). Then, the criteria index is calculated by summing up all indices for each criterion using equations 3.6 through 3.15 (the results are shown in the columns 5, 6, and 7 of Table 3.10). These indices must be compared with other configurations. Table 3.10 demonstrates a comparison between this baseline configuration (A) and two other configurations (B and C).

The next step is to use equations 3.16 and 3.17 to find two design indices. The design index $D_{I_{\text{min}}}$ for all three configurations are determined through equation 3.16 and the results are shown in row 5 of Table 3.10. The design index $D_{I_{\text{max}}}$ for all three configurations are also determined by applying equation 3.17 and the results are shown in the last row of Table 3.10.

<table>
<thead>
<tr>
<th>No</th>
<th>Criteria</th>
<th>Must be</th>
<th>Priority (%)</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>1</td>
<td>Cost minimized</td>
<td>9</td>
<td>115</td>
<td>183</td>
</tr>
<tr>
<td>2</td>
<td>Weight minimized</td>
<td>4</td>
<td>136</td>
<td>163</td>
</tr>
<tr>
<td>3</td>
<td>Period of design minimized</td>
<td>7</td>
<td>190</td>
<td>176</td>
</tr>
<tr>
<td></td>
<td>$D_{I_{\text{min}}}$</td>
<td>20</td>
<td>20.1</td>
<td>35.3</td>
</tr>
<tr>
<td>4</td>
<td>Performance maximized</td>
<td>40</td>
<td>210</td>
<td>195</td>
</tr>
<tr>
<td>5</td>
<td>Flying qualities maximized</td>
<td>15</td>
<td>183</td>
<td>87</td>
</tr>
<tr>
<td>6</td>
<td>Scariness maximized</td>
<td>1</td>
<td>87</td>
<td>124</td>
</tr>
<tr>
<td>7</td>
<td>Maintainability maximized</td>
<td>5</td>
<td>95</td>
<td>83</td>
</tr>
<tr>
<td>8</td>
<td>Producability maximized</td>
<td>6</td>
<td>215</td>
<td>184</td>
</tr>
<tr>
<td>9</td>
<td>Disposability maximized</td>
<td>2</td>
<td>246</td>
<td>254</td>
</tr>
<tr>
<td>10</td>
<td>Stealth maximized</td>
<td>11</td>
<td>65</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>$D_{I_{\text{max}}}$</td>
<td>80</td>
<td>142</td>
<td>116.5</td>
</tr>
</tbody>
</table>

Table 3.10. Evaluation of three presumptive configuration alternatives for a fighter

On the other hand, two parameters of $P_{\text{min}}$ and $P_{\text{max}}$ are calculated (equations 3.18 and 3.19) as shown in column 4 (rows 5 and 13) of table 3.10. The summations of the priorities of all objectives that need to be minimized ($P_{\text{min}}$) is 20%. Also, the summations of the priorities of all objectives that need to be minimized ($P_{\text{max}}$) is 80%. Since $P_{\text{max}}$ is larger than $P_{\text{min}}$, the configuration at which its $D_{I_{\text{max}}}$ is the highest (142) is selected as the optimum configuration that
is Configuration A. Thus, when the optimization methodology is carried out, the design may move from a baseline configuration to an optimized configuration. The details of the calculation has not been shown here.

In practice, this methodology requires large numbers of evaluations of the objectives and the constraints. The disciplinary models are often very complex and can take significant amounts of time for the evaluation. The solution can therefore be extremely time-consuming.

Example 3.2

Figure 3.12 illustrates the photos of four aircraft: Boeing 747 (Transport), McDonnell Douglas F-15C Eagle (Fighter), Stampe-Vertogen SV-4C (GA), Rutan 33 VariEze (GA). By using these photos and other reliable sources (such as [18]), identify configuration parameters of these aircraft.

1. *Boeing 747 (Courtesy Anne Deus)*
2. *Stampe-Vertogen (Courtesy Jenny Coffey)*

3. *Rutan 33 VariEze (Courtesy Jenny Coffey)*
4. *F-15C Eagle (Courtesy Antony Osborne)*

*Figure 3.12. Four aircraft to be used in Example 3.2*

**Solution:**

By using photos in figure 3.12 and also [18], the configuration parameters of these aircraft are identified as provided in Table 3.11.
Table 3.11. The configuration features for four aircraft of Example 3.2

<table>
<thead>
<tr>
<th>No</th>
<th>Attribute</th>
<th>Boeing 747</th>
<th>McDonnell Douglas F-15C Eagle</th>
<th>Stampe-Vertongen</th>
<th>Rutan 33 VariEze</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Standard</td>
<td>FAR 25</td>
<td>MIL-STD</td>
<td>Homebuilt</td>
<td>Nonconventional</td>
</tr>
<tr>
<td>2</td>
<td>Runway</td>
<td>Land</td>
<td>Land</td>
<td>Land</td>
<td>Land</td>
</tr>
<tr>
<td>3</td>
<td>Materials</td>
<td>Mostly metal</td>
<td>Metal</td>
<td>Metal</td>
<td>Composite materials</td>
</tr>
<tr>
<td>4</td>
<td>Manufacture</td>
<td>Modular</td>
<td>Modular</td>
<td>Modular</td>
<td>Kit-form</td>
</tr>
<tr>
<td>5</td>
<td>Engine type</td>
<td>Turbofan</td>
<td>Turbofan</td>
<td>Piston-prop</td>
<td>Piston-prop</td>
</tr>
<tr>
<td>6</td>
<td>Seating (in a row)</td>
<td>10 seat</td>
<td>single seat</td>
<td>Two tandem seats</td>
<td>Two tandem seats</td>
</tr>
<tr>
<td>7</td>
<td>Landing gear type</td>
<td>Multi-gear</td>
<td>Tricycle</td>
<td>Tail-gear</td>
<td>Tricycle</td>
</tr>
<tr>
<td>8</td>
<td>Fixed or retractable</td>
<td>Retractable</td>
<td>Retractable</td>
<td>Fixed</td>
<td>Partially retractable</td>
</tr>
<tr>
<td>9</td>
<td>Pusher or tractor</td>
<td>Pusher</td>
<td>Pusher</td>
<td>Tractor</td>
<td>Pusher</td>
</tr>
<tr>
<td>10</td>
<td>Engine location</td>
<td>Under wing</td>
<td>Inside fuselage</td>
<td>Fuselage nose</td>
<td>Rear fuselage</td>
</tr>
<tr>
<td>11</td>
<td>Number of engines</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Flap</td>
<td>Triple slotted flap</td>
<td>Plain flap</td>
<td>Plain flap</td>
<td>Plain flap</td>
</tr>
<tr>
<td>13</td>
<td>Door</td>
<td>10 cabin door</td>
<td>Cockpit</td>
<td>No door</td>
<td>Cockpit</td>
</tr>
<tr>
<td>14</td>
<td>Tail or canard</td>
<td>Aft tail</td>
<td>aft</td>
<td>Aft tail</td>
<td>Canard</td>
</tr>
<tr>
<td>15</td>
<td>Number of wings</td>
<td>Monoplane</td>
<td>Monoplane</td>
<td>Biplane</td>
<td>Monoplane</td>
</tr>
<tr>
<td>16</td>
<td>Wing location</td>
<td>Low wing</td>
<td>High wing</td>
<td>Low + parasol</td>
<td>Mid-wing</td>
</tr>
<tr>
<td>17</td>
<td>Wing attachment</td>
<td>Cantilever</td>
<td>Cantilever</td>
<td>Strut-braced</td>
<td>Cantilever</td>
</tr>
<tr>
<td>18</td>
<td>Tail configuration</td>
<td>Conventional</td>
<td>Conventional</td>
<td>Conventional</td>
<td>Conventional + twin VT</td>
</tr>
<tr>
<td>19</td>
<td>Wing fixed or ...</td>
<td>Fixed-wing</td>
<td>Fixed-wing</td>
<td>Fixed-wing</td>
<td>Fixed-wing</td>
</tr>
<tr>
<td>20</td>
<td>Wing configuration</td>
<td>Swept back</td>
<td>Swept back</td>
<td>Elliptic</td>
<td>Swept back</td>
</tr>
<tr>
<td>21</td>
<td>Tail attachment</td>
<td>Adjustable</td>
<td>All moving</td>
<td>Fixed</td>
<td>Fixed</td>
</tr>
<tr>
<td>22</td>
<td>Control surfaces</td>
<td>Elevator-aileron-rudder</td>
<td>Elevator-aileron-rudder</td>
<td>Elevator-aileron-rudder</td>
<td>Elevator-aileron-rudder</td>
</tr>
<tr>
<td>23</td>
<td>Power transmission</td>
<td>Hydraulics</td>
<td>Hydraulics</td>
<td>Mechanical</td>
<td>Mechanical</td>
</tr>
<tr>
<td>24</td>
<td>Fuel tank</td>
<td>Inside wing and fuselage</td>
<td>Inside wing and fuselage</td>
<td>Inside fuselage</td>
<td>Inside fuselage</td>
</tr>
<tr>
<td>25</td>
<td>Vertical tail</td>
<td>A VT</td>
<td>Twin VT</td>
<td>A VT</td>
<td>Twin VT on wingtip</td>
</tr>
<tr>
<td>26</td>
<td>Spoiler/tab</td>
<td>Spoiler and 3 tabs</td>
<td>No tab</td>
<td>No tab</td>
<td>No tab</td>
</tr>
</tbody>
</table>

Example 3.3

A university conceptual design team for a small remote controlled aircraft is to participate in an AIAA student competition. The aircraft has to be able to carry a payload of 7 lb with different payload combinations; and also the size limitation is 4 ft by 5 ft. The performance requirements are as follows:

- Stall speed: 15 knot
- Maximum speed: 40 knot
- Take-off run: 80 ft
- Endurance: 5 minutes

The airplane must fly empty while carrying all payload restraint components. The objective is to complete the course profile as many times as possible within 5 minutes, while minimizing battery weight. You are a member of the wing design group and is required to decide on the wing configuration, to investigate monoplane, biplane, “x”-wing (tri-wing or higher), and a blended wing body.

Figures of Merit includes: weight, strength, span, take-off capability, stability, control, manufacturability, reparability, and familiarity.
If the weight of each figure of merit is:
  - Weight: 20%
  - Strength: 20%
  - Span: 10%
  - Take-off capability: 10%
  - Stability and control: 10%
  - Manufacturability: 10%
  - Reparability: 5%
  - Familiarity: 5%

Determine the optimum wing configuration.

**Solution:**

A summary of the investigation is outlined in Table 3.12. In this table 3 numbers (1, 0, and -1) are employed. The number “0” indicates that this configuration does not have any influence on a particular figure of merit. The number “1” indicates that this configuration does have a positive influence on a particular figure of merit. The number “-1” indicates that this configuration does have a negative influence on a particular figure of merit.

<table>
<thead>
<tr>
<th>Figure of Merit</th>
<th>Weight (%)</th>
<th>Monoplane</th>
<th>Biplane</th>
<th>X-wing</th>
<th>Blended wing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>20</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>Strength</td>
<td>20</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Span</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Take-off Capability</td>
<td>10</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Stability &amp; Control</td>
<td>10</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>Interference</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>Manufacturability</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>Reparability</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>Familiarity</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>0.4</strong></td>
<td><strong>0.45</strong></td>
<td><strong>0.25</strong></td>
<td><strong>0.3</strong></td>
</tr>
</tbody>
</table>

*Table 3.12. Wing Figures of Merit*

As indicated in Table 3.12, the monoplane or biplane configuration met the design requirements at the highest level. While the monoplane would be lighter, the biplane
configuration would be more structurally sound. Additionally, given the dimension restriction, more wing area could be gained (without aspect ratio penalties) by employing a biplane configuration. For a given wing area, the biplane configuration employs a smaller wing span, leaving more distance longitudinally for a tail arm to increase aircraft stability.
Problems

1. The following (Figure 3.13) is an image of utility transport Canadian aircraft Vickers PBV-1A Canso A. Identify 15 different configuration parameters from this image.

![Figure 3.13. Canadian Vickers PBV-1A Canso A (Courtesy of Jenny Coffey)](image)

2. The following (Figure 3.14) illustrates an image of WWII fighter aircraft P-51D Mustang. Identify 12 different configuration parameters from this image.

![Figure 3.14. Commonwealth CA-18 Mustang (Courtesy of Jenny Coffey)](image)

3. The following (Figure 3.15) is a photo of transport aircraft Antonov An-140. Identify 12 different configuration parameters from this photo.

![Figure 3.15. Antonov An-140 (Courtesy of Antony Osborne)](image)
4. The figure 3.16-1 illustrates an image of the transport aircraft McDonnell Douglas MD-11. Identify 15 different configuration parameters from this 3-view.

5. The figure 3.16-2 illustrates a photo of the WWII fighter aircraft De Havilland Vampire T11 (DH-115). Identify 15 different configuration parameters from this image.

6. By referring to Reference [18], identify four aircraft that have unconventional configuration.

7. By referring to Reference [18], identify five aircraft that have canard.

8. By referring to Reference [18], identify five aircraft that their engines are installed above fuselage.

9. By referring to Reference [18], identify five transport aircraft that their engines are installed beside aft-fuselage.

10. By referring to Reference [18], identify three aircraft that have pusher engines plus canard.

11. By referring to Reference [18], identify two aircraft that have their landing rear is partially retractable.

12. The figure 3.17 illustrates a cutaway of the GA aircraft Saab MFI-17 Supporter (T-17). Identify 15 different configuration parameters from this cutaway.

13. The figure 3.18-1 illustrates a 3-view of the fighter aircraft F/A-18 Hornet. Identify 15 different configuration parameters from this 3-view.

14. The figure 3.18-2 illustrates a 3-view of the trainer aircraft Pilatus PC-7. Identify 15 different configuration parameters from this 3-view.

15. The figure 3.18-3 illustrates a 3-view of the military transport aircraft Lockheed C-130 Hercules. Identify 15 different configuration parameters from this 3-view.
Figure 3.17. Saab MFI-17 Supporter (Courtesy of SAAB)

Figure 3.18. F/A-18 Hornet, Pilatus PC-7, and Lockheed C-130 Hercules
16. A 19 seat transport aircraft with the following design requirements is ordered to be designed:

- Maximum speed: at least 250 knot at 20,000 ft
- Absolute ceiling: higher than 25,000 ft
- Range: 700 km
- Rate of climb: more than 2,000 fpm
- Take-off run: 1000 m

Determine the optimum configuration for this aircraft. Then sketch its 3-view by hand.

17. The figure 3.19 illustrates an image of the solar powered aircraft Solar Impulse with its revolutionary design. Identify 10 different configuration parameters from this 3-view.

![Figure 3.19. Solar Impulse (Courtesy of Vladimir Mykytarenko)](image)

18. The authorities of Ground Canyon National Park has ordered a touring aircraft with the following design requirements:

- Maximum speed: greater than 100 knot at 2,000 ft
- Stall speed: less than 40 knot
- Absolute ceiling: higher than 12,000 ft
- Range: 300 km
- Rate of climb: more than 4,000 fpm
- Take-off run: 500 m

The aircraft is required to carry a pilot and a tourist. Determine the optimum configuration for this aircraft. Then sketch its 3-view by hand.

19. A civil trainer aircraft with the following design requirements is desired to be designed:

- Maximum speed: greater than 200 knot at 20,000 ft
- Stall speed: less than 50 knot
- Absolute ceiling: higher than 30,000 ft
- Range: 500 km
- Rate of climb: more than 3,000 fpm
- Take-off run: 400 m
The aircraft is required to carry an instructor and a student. Determine the optimum configuration for this aircraft. Then sketch its 3-view by hand.

20. A cargo aircraft with the following design requirements is desired to be designed:

- Maximum speed: greater than 250 knot at 30,000 ft
- Stall speed: less than 80 knot
- Absolute ceiling: higher than 35,000 ft
- Range: 10000 km
- Rate of climb: more than 2,500 fpm
- Take-off run: 1,500 m

The aircraft is required to carry 20 blocks of cargo each has a volume of $3 \times 3 \times 3$ m. Determine the optimum configuration for this aircraft. Then sketch its 3-view by hand.

21. You are a member of a design team to perform the conceptual design phase of an unmanned aircraft with the following design requirements:

- Maximum speed: greater than 200 knot at 30,000 ft
- Stall speed: less than 70 knot
- Absolute ceiling: higher than 60,000 ft
- Range: 30,000 km
- Rate of climb: more than 2,000 fpm
- Take-off run: 1,000 m

The aircraft is required to carry communication and surveillance equipments. Determine the optimum configuration for this aircraft. Then sketch its 3-view by hand.

22. You are a member of a design team to perform the conceptual design phase of a human-powered aircraft. The aircraft is required to carry communication and surveillance equipments. Determine the optimum configuration for this aircraft. Then sketch its 3-view by hand.

23. You are a member of a design team to perform the conceptual design phase of a sailplane with the following design requirements:

- Glide speed: 40 knot at 10,000 ft
- Stall speed: less than 30 knot
- Take-off run (when towed by another aircraft): 300 m
- Endurance (when flight begins from 10,000 ft): 2 hours

The aircraft is required to have two seats. Determine the optimum configuration for this aircraft. Then sketch its 3-view by hand.

24. Sketch by hand a four seat aircraft with the following configuration features:
   Monoplane, high wing, canard, pusher piston-prop engine, fixed tail gear, tapered wing, tip-tank

25. Sketch by hand a two seat aircraft with the following configuration features:
Monoplane, low wing, T-tail, twin turboprop engines on the wing, retractable nose gear, rectangular wing

26. Sketch by hand a cargo aircraft with the following configuration features:
   High rectangular wing, conventional tail, four turboprop engines on the wing, retractable multi-gear landing gear

27. Sketch by hand a transport aircraft with the following configuration features:
   Low swept back wing, T-tail, two turbofan engines beside rear fuselage, retractable tricycle landing gear

28. Sketch by hand a single seat fighter aircraft with the following configuration features:
   Monoplane, low wing, canard, twin vertical tail, single turbofan engine inside fuselage, retractable tricycle landing gear, variable sweep
References

4. www.faa.gov
18. Jackson P., *Jane's All the World's Aircraft*, Jane’s information group, Various years