

FLIGHT VEHICLE DESIGN LABORATORY

LAB MANUAL

IV B. Tech I Semester

(2022-2023)

Prepared By

Associate Professor L Sushma

Department of Aeronautical Engineering



**MALLAREDDY COLLEGE OF ENGINEERING &
TECHNOLOGY**

(Autonomous Institution–UGC, Govt. of India)

Affiliated to JNTU, Hyderabad, Approved by AICTE-Accredited by NBA & NAAC-'A' Grade-ISO 9001:2015 Certified

Maisammaguda, Dhulapally (Post Via. Kompally), Secunderabad – 500100, Telangana State, India.

MRCET VISION

- Y To become a model institution in the fields of Engineering, Technology and Management.
- Y To have a perfect synchronization of the ideologies of MRCET with challenging demands of International Pioneering Organizations.

MRCET MISSION

To establish a pedestal for the integral innovation, team spirit, originality and competence in the students, expose them to face the global challenges and become pioneers of Indian vision of modern society.

MRCET QUALITY POLICY.

- Y To pursue continual improvement of teaching learning process of Undergraduate and Post Graduate programs in Engineering & Management vigorously.

To provide state of art infrastructure and expertise to impart the quality education.

PROGRAM OUTCOMES (PO's)

Engineering Graduates will be able to:

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design / development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply the set one's own work, as a member and leader in a team, to manage projects and in multi disciplinary environments.
12. **Life- long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

EDUCATIONAL OBJECTIVES – Aeronautical Engineering

1. **PEO1 (PROFESSIONALISM & CITIZENSHIP):** To create and sustain a community of learning in which students acquire knowledge and learn to apply it professionally with due consideration for ethical, ecological and economic issues.
2. **PEO2 (TECHNICAL ACCOMPLISHMENTS):** To provide knowledge based services to satisfy the needs of society and the industry by providing hands on experience in various technologies in core field.
3. **PEO3 (INVENTION, INNOVATION AND CREATIVITY):** To make the students to design, experiment, analyze, and interpret in the core field with the help of other multi disciplinary concepts wherever applicable.
4. **PEO4 (PROFESSIONAL DEVELOPMENT):** To educate the students to disseminate research findings with good soft skills and become a successful entrepreneur.
5. **PEO5 (HUMAN RESOURCE DEVELOPMENT):** To graduate the students in building national capabilities in technology, education and research

PROGRAM SPECIFIC OUTCOMES – Aeronautical Engineering

1. To mold students to become a professional with all necessary skills, personality and sound knowledge in basic and advanced technological areas.
2. To promote understanding of concepts and develop ability in design manufacture and maintenance of aircraft, aerospace vehicles and associated equipment and develop application capability of the concepts science to engineering design and processes.
3. Understanding the current scenario in the field of aeronautics and acquire ability to apply knowledge of engineering, science and mathematics to design and conduct experiments in the field of Aeronautical Engineering.
4. To develop leadership skills in our students necessary to shape the social, intellectual, business and technical worlds.

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

IV Year B. Tech, ANE-I Sem

L T/P/D C

(R18A2188) FLIGHT VEHICLE DESIGN LAB

- -/3/- 1.5

Objectives:

1. To learn conceptual aircraft design of a typical civil transport and fighter aircraft.
2. To use various tools (software) in flight vehicle design to meet given system requirements (performance and flying qualities).

LIST OF EXPERIMENTS:

1. Aircraft Conceptual sketching based on given system requirements. System requirements for a hypothetical transport and fighter aircraft will be formulated and given to the students.
2. Weight estimation of the fighter and transport aircraft defined in experiment number 1.
3. Estimating Wing Loading of transport and fighter aircraft identified in experiment no 1.
4. Wing design and estimation of aerodynamic (lift and Drag) and stability parameters to meet the system requirements defined in experiment number 1.
5. Design of Horizontal and vertical tail and control surfaces to meet system requirements.
6. Design of Crew and passenger cabin for the hypothetical aircraft identified in experiment no one.
7. Engine Sizing and performance estimation.
8. Design of landing gear for transport and military aircraft specified in experiment no 1.
9. Estimation of Nozzle characteristics
10. Demonstration of Hydraulic Test Rig.
11. Demonstration of Pneumatic Test Rig.
12. Estimation of flying qualities of designed aircraft in flight simulation.

Note: Minimum 10 experiments should be conducted.

Software Required: Microsoft Excel, MATLAB/SIMULINK Programming or Equivalent software

TEXT BOOKS:

1. AIRCRAFT DESIGN: A Conceptual Approach AIAA Book ISBN:0-930403-51-7 by Daniel P Raymer
2. MATLAB/SIMULINK Users' Guide.

Outcomes:

1. Student will be able to develop preliminary design of a given aircraft (transport and fighter aircraft) to meet given performance requirements.
2. Able to use various software tools in design & analysis of aircraft.

INTRODUCTION

Aircraft design is both arts and science and is a separate discipline of aeronautical engineering different from the analytical discipline such as aerodynamics, structure, control and propulsion. It is the intellectual engineering process of creating on paper a flying machine to

1) Meet certain specification

2) Certain pioneer innovative, new ideas and technology

Aircraft design is by its nature an iterative process. This means that estimates and assumptions have sometimes to be made with inadequate data. Such 'guesstimates' must be checked when more accurate data on the aircraft is available.

Requirements are set by prior design trade studies. Concepts are developed to meet requirement, design analysis frequently points towards new concepts and technologies, which can initiate a whole new design effort. All of these activities are equally important in producing a good aircraft concept.

The start of the design process requires the recognition of a 'need'. This normally comes from a 'project brief' or a 'request for proposals (RFP)'.

ii. Purpose and scope of aircraft design:

An airplane is designed to meet the functional and safety requirements. The actual process of design is a task involving

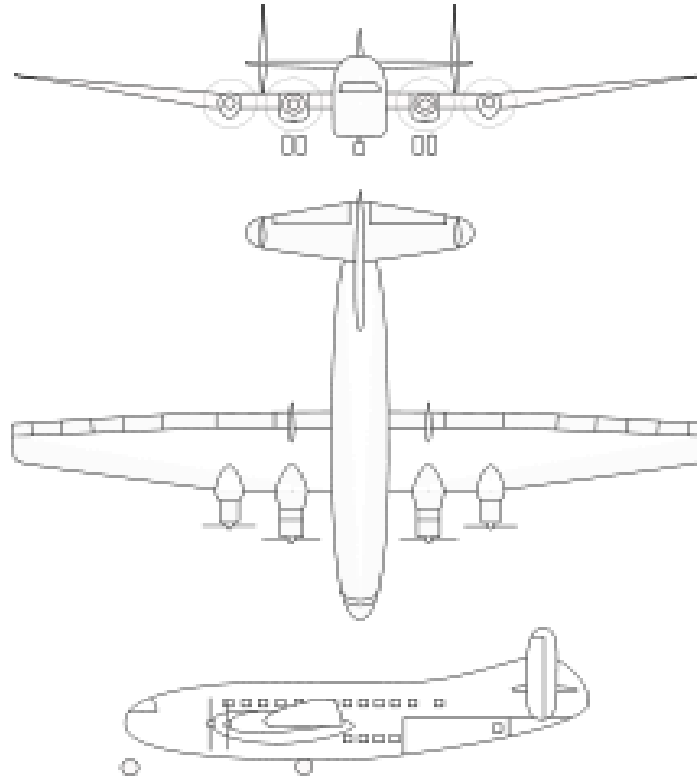
- a) Selection of airplane type and data
- b) Determination of the geometric parameter
- c) Selection of power plant
- d) Structural design and the analysis of various component
- e) Determination of airplane flight and operational characteristics

Designing a new airplane starts from development of a concept - a general idea for airplane.

The design of any aircraft starts out in three phases

1. Conceptual Design

The first design step, involves sketching a variety of possible aircraft configurations that meet the required design specifications. By drawing a set of configurations, designers seek to reach the design configuration that satisfactorily meets all requirements as well as go hand in hand with factors such as aerodynamics, propulsion, flight performance, structural and control systems. This is called design optimization. Fundamental aspects such as fuselage shape, wing configuration and location, engine size and type are all determined at this stage. Constraints to design like those mentioned above are all taken into account at this stage as well. The final product is a conceptual layout of the aircraft configuration on paper or computer screen, to be reviewed by engineers and other designers.

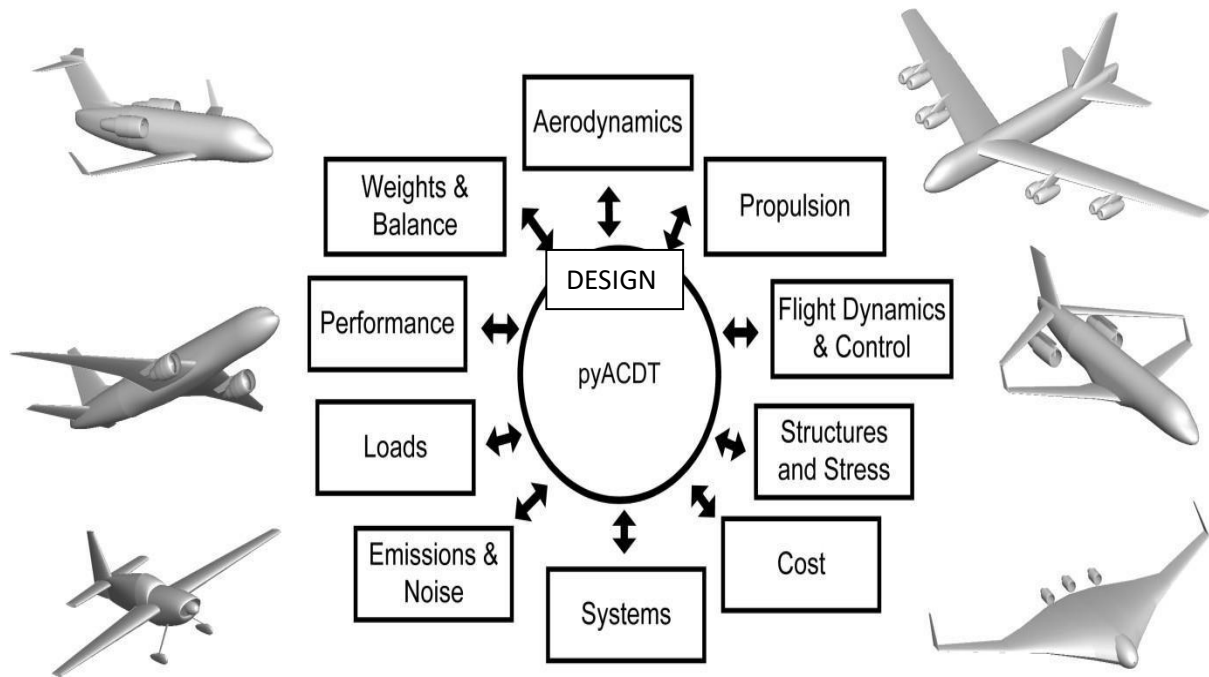


2. Preliminary design phase

The design configuration arrived at in the conceptual design phase is then tweaked and remodeled to fit into the design parameters. In this phase, wind tunnel testing and computational fluid dynamics calculations of the flow field around the aircraft are done. Major structural and control analysis is also carried out in this phase. Aerodynamic flaws and structural instabilities if any are corrected and the final design is drawn and finalized. Then after the finalization of the design lies the key decision with the manufacturer or individual designing it whether to actually go ahead with the production of the aircraft. At this point several designs, though perfectly capable of flight and performance, might have been opted out of production due to their being economically nonviable.

3. Detail design phase

This phase simply deals with the fabrication aspect of the aircraft to be manufactured. It determines the number, design and location of ribs, spars sections and other structural elements. All aerodynamic, structural, propulsion, control and performance aspects have already been covered in the preliminary design phase and only the manufacturing remains. Flight simulators for aircraft are also developed at this stage.



The concept defines ways, means and parameters that should provide high efficiency and competitiveness of a future airplane, its superiority in comparison with airplanes that are already exploited or designed.

The concept of a future airplane is determined by requirements for corresponding airplane functional and performance characteristics defined by a customer. Then a concept of a future airplane – its scheme and set of values for main parameters – is chosen.

All main parameters that will be chosen and determined at these stages should be based on statistics and take into account the aviation development dynamics by forecasting changes of the most important airplane features and characteristics with time. It requires knowledge of the latest achievements in the field of aviation science and technology - aerodynamics, engine, equipment, weapon and airframe engineering, constructional materials, airplane operation and etc.

Development of the airplane design concept while executing laboratory works, term and graduation design projects requires working up a list of new technical achievements in the field of aviation with estimation of its approximate positive influence on the main airplane parameters and characteristics: possible decrease of airframe mass, fuel and power plant; expected improvement of airplane performance. This list should contain specific technical innovations that should provide the improvement of efficiency ratios for the designed airplane.

For example, in aerodynamics it can be using new supercritical airfoils, utilizing tip vortex scatterers, wing boundary layer laminarization systems. Constructional perfection can be provided by decreasing the number of structural divisions, applying honeycomb structures, employing new materials such as aluminum, lithium and titanium alloys. While making a detailed list you may approximately estimate the influence of each innovation on corresponding airplane parameters and characteristics. This information

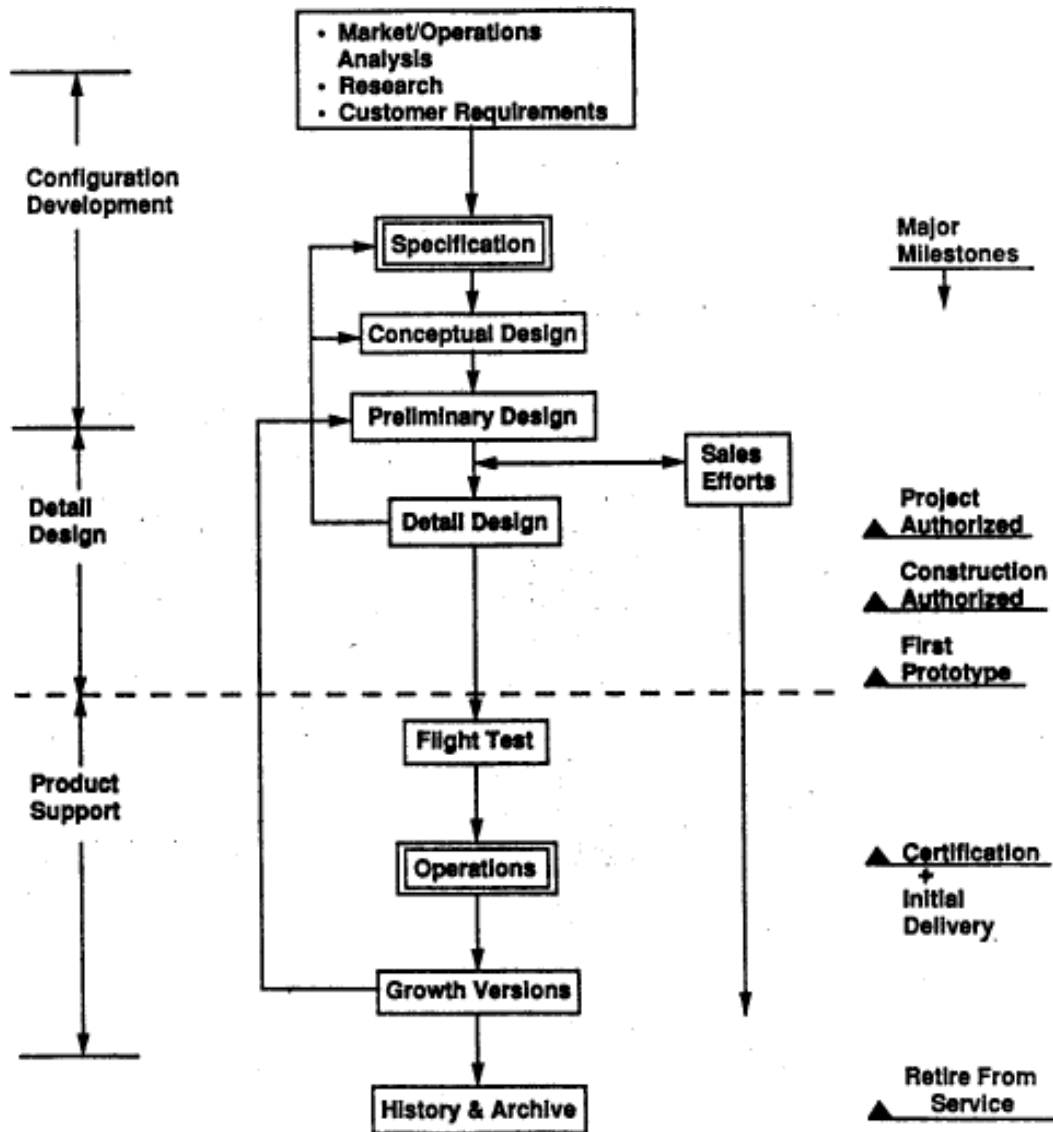
can usually be found in dedicated literature, and it is recommended to use it while executing this stage of your project. An example of such estimation of positive influence of state-of-the-art solutions on advanced airplane performance is the fifteen - year scientific and technical forecast made by one of the foreign airplane production companies.

According to it passenger planes designed and built with 2010th technologies have to weight on 23-35% less then airplanes of the year 1995. This significant take-off mass decrease is achieved by using following technological advances: wing boundary layer laminarization (4-6%), advanced aerodynamic schemes (6%), applying new materials (8–10%), advanced power plants (3%), equipment and systems (1%). These numbers are just an example, and now it can be a little out of date. Fresh forecasts can be found in new publications, especially periodic, combining it with gathering statistics.

ANALYZING THE DESIGN SITUATION

A design situation analysis is carried out on basis of statistics research and airplane development study. During this analysis the following problems should be solved:

- 1) Future demand for airplanes should be assessed with the required number of airplanes in the certain time, for example, 5-10 years. This information can be found in publication from periodical editions, describing the airplanes of a given type, and in review magazines dedicated to international air shows.
- 2) History of the development should be investigated, and achieved perfection degree of a given type of airplanes should be mentioned. The average statistical and maximum values of the most important performance parameters, geometric and weight parameters, the mileage rating and cost efficiency of these airplanes should be given. Also maintenance and operating features - airplane cost, traffic handling cost, an airplane life, reliability indexes, comfort ratios and etc. should be included.
- 3) Development prospects should be studied, and changes in main performance and relative airplane parameters should be forecasted for the near future. Thus, dynamic and static diagrams for the most important prototype parameters should be plotted using data from statistic tables; then their trend functions with an approximation errors should be figured out and forecasted (extrapolated) parameter values should be found
- 4) New engineering solutions that are expected to improve the value of each parameter should be mentioned.



Experiment 1: Aircraft Conceptual 3D sketching and Modeling

Aim: Write the request for proposal for the particular aircraft, Develop the conceptual sketch of the aircraft for given requirements.

Software's used: Catia / Engineering Drawing

Theory:

Conceptual design begins with a specific set of design requirements established from customer or a company-generated guess what future customers may need.

Design requirements include:

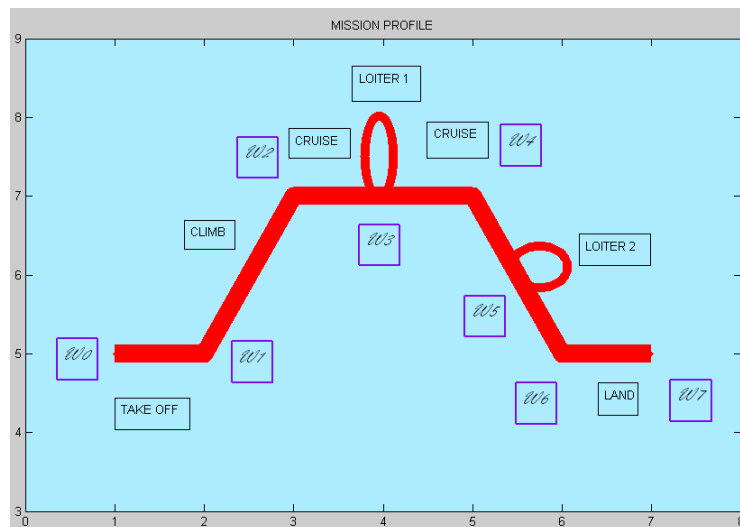
- a) Aircraft range
- b) Payload
- c) Take-off distance
- d) Landing distance
- e) Maneuverability and speed requirements

Design begins with innovative idea rather than as a response to a given requirement. Before design a decision is made to what technologies to incorporate, it must use only currently available technologies as well as existing engines and avionics. If designed to build in more distant future, then an estimate technological state of the art must be made to determine which emerging technologies will be ready for use at that time.

Design begins drawing with a conceptual sketch like shown in

Procedure:

1. Write the request for proposal for the given aircraft. It should be in the form of parameters and requirements for the aircraft.
2. Draw the conceptual sketch of the aircraft as explained in theory.
3. Draw the mission profile for the aircraft.



Validation:

1. Model 3D model of the given aircraft in catia / creo and obtain the 3 views compare with the hand sketch done.

Result:

1. The 3D views of given aircraft configuration by hand sketch and catia are done.

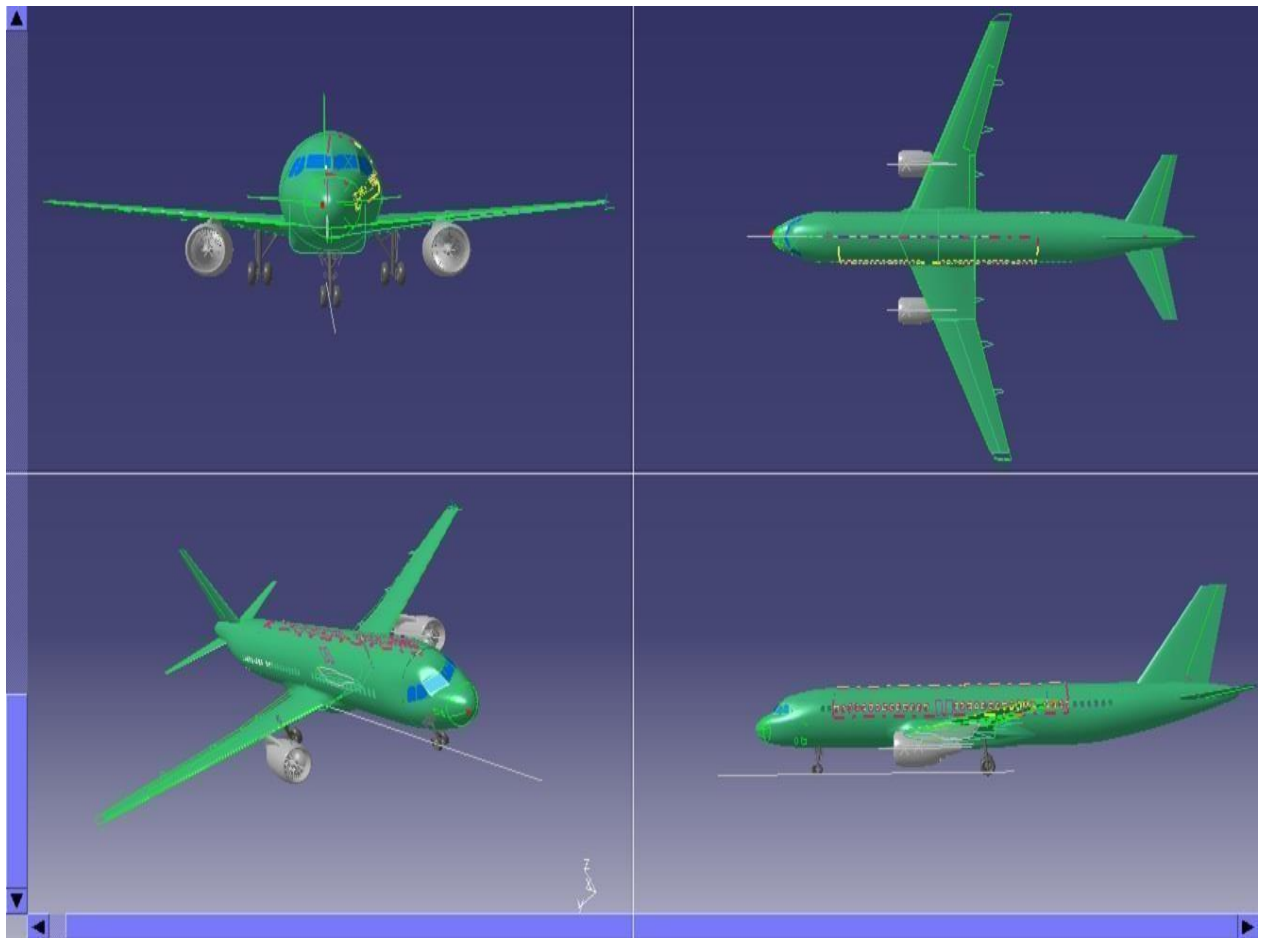
Catia 3D Views

Fig1. Example:

Experiment 2: Initial Sizing of a Transport aircraft

Aim: To estimate take-off gross weight for the given aircraft requirements and its mission profile using weight estimation algorithm.

Software used: Matlab

Theory:

Weight components of airplane explained as follows:

1) Crew weight (W_c):

The crew comprises the people necessary to operate the airplane in flight
e.g., Pilot, Co-pilot, Airhostess etc.

2) Payload weight (W_p):

The payload is what the airplane is mentioned to transport passengers, baggage, freight etc.
(Military use the payload includes bombs, rockets and other disposable ordnance).

3) Fuel weight (W_f):

This is the weight of the fuel in the fuel tanks. Since fuel is consumed during the course of flight.
 W_f is a variable, decreasing with time during the flight.

4) Empty weight (W_e):

This is weight of everything else-the structure engines (with all accessory equipment), electronic equipment landing gear, fixed equipment and anything else that is not crew, payload or fuel.

5) Gross weight (W_0):

The sum of these weights is the total weight of the airplane W_0 . Gross weight or total weight W_0 varies through the flight because fuel is being consumed. The design take off gross weight W_0 is the weight of the airplane at the instant it begins its mission. It includes the weight of the fuel.

$$W_0 = W_c + W_p + W_f + W_e$$

$$W_0 = W_c + W_p + \frac{W_f}{W_0} + \frac{W_e}{W_0} W_0$$

$$W_0 = \frac{(W_c + W_p)}{\left(1 - \frac{W_f}{W_0} - \frac{W_e}{W_0}\right)} \quad (1)$$

Estimation of empty weight fraction (W_e / W_0):

The empty weight fraction (W_e / W_0) can be estimated from data based on

- a) Historical data and tables
- b) Refined sizing data and tables

Estimation of fuel fraction (W_f / W_0):

The aircraft's fuel supply is available for performing the mission. The other fuel includes reserve fuel, trapped fuel (which is the fuel which cannot be pumped out of the tanks).

Fuel fraction (W_f/W_0) is approximately independently of aircraft weight. Fuel fraction will be estimated based on the mission to be flown.

Mission profiles:

Typical mission profiles for various types of aircraft are shown in Fig1. The simple cruise mission is used for many transport and general aviation designs, including home built. Following are the briefly explained the terms that are used in mission profiles:

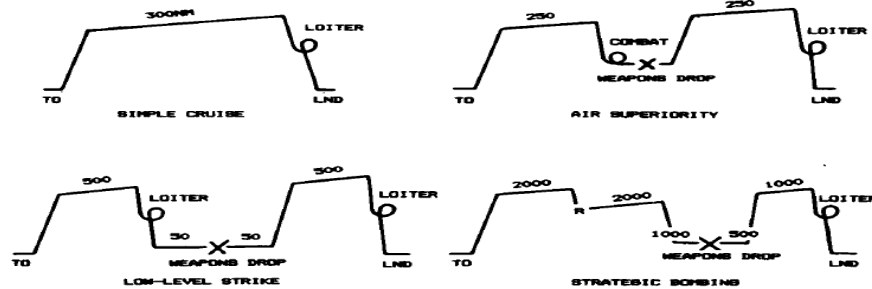


Fig. 1 Typical mission profiles for sizing.

Warm Up and Take-Off:

Warm Up is the engine start up for the airplane kept idling for some time to warm up. Take Off is the point where aircraft is made lift off from ground. It is the motion after warm up i.e., moving of airplane after starting and till it lifts off from the ground.

Climb:

It is between take-off (TO) and cruise (stead level flight with constant speed) Increase in height until airplane achieves steady level flight.

Cruise:

It is the steady level flight to cover the mission distance. The mission distance is called Range.

Loiter:

Represent the airplane spending in air for some fixed number of minutes near airport before getting the clearance from airport signal or simple spending some time to collect data of some mission (Terrain data).

Dash:

It is the mission that must be flown at just a few hundred numbers of feet of the ground for low level strike.

Landing:

It is the aircraft landing on the runway till stopping of engine.

Estimation of mission segment weight fractions:

The various mission segments (legs) are numbered starting from zero denoting, the start of the mission. Mission leg one is usually engine warm up and take-off. The remaining legs are sequentially numbered. For example in the simple *cruise mission* the legs could be numbered as (0) warm-up and take-off, (1) climb (2) cruise (3) loiter and (4) landing.

Similarly, the aircraft weight at end of each mission is denoted by W_i . Denoting “i”-th segment as mission segment weight

W_0 = Beginning airplane weight (“Take –off gross weight”)

W_1 = Weight of the airplane at end of warm-up and take-off

W_2 = Weight of the airplane at end of climb.

W_3 = Weight of the airplane at end of cruise

W_4 = Weight of the airplane at end of loiter.

W_5 = Weight of the airplane at end of landing.

$$\frac{W_x}{W_0} = \frac{W_5}{W_0} = \frac{W_1}{W_0} \frac{W_2}{W_1} \frac{W_3}{W_2} \frac{W_4}{W_3} \frac{W_5}{W_4}$$

So in general it can be written as

$$\frac{W_x}{W_0} = \frac{W_i}{W_0} = \frac{W_1}{W_0} \frac{W_2}{W_1} \frac{W_3}{W_2} \frac{W_4}{W_3} \dots \frac{W_i}{W_{i-1}}$$

Table 1 Empty weight fraction vs W_0

$W_e/W_0 = A W_0^C K_{us}$	A	C
Sailplane—unpowered	0.86	– 0.05
Sailplane—powered	0.91	– 0.05
Homebuilt—metal/wood	1.19	– 0.09
Homebuilt—composite	0.99	– 0.09
General aviation—single engine	2.36	– 0.18
General aviation—twin engine	1.51	– 0.10
Agricultural aircraft	0.74	– 0.03
Twin turboprop	0.96	– 0.05
Flying boat	1.09	– 0.05
Jet trainer	1.59	– 0.10
Jet fighter	2.34	– 0.13
Military cargo/bomber	0.93	– 0.07
Jet transport	1.02	– 0.06

K_{us} = variable sweep constant = 1.04 if variable sweep
= 1.00 if fixed sweep

Given warm-up/take-off, climb and landing weight fractions from historical trends: The warm-up, take-off and landing weight fractions can be estimated historically from Table2.

Table 2 Historical mission segment weight fractions

	(W_i/W_{i-1})
Warmup and takeoff	0.970
Climb	0.985
Landing	0.995

Requirements:

Aircraft type, engine type, wing sweep type, mission profile, crew weight, payload weight, specific fuel consumption, L/D ratio.

Procedure:

Estimation of gross weight, calculated using following steps:

1) Calculate the mission weight fraction of individual segment:

Mission weight fractions of following individual segments:

1) Take-off (W_1/W_0): This is taken from Table2.

2) Climb (W_2/W_1): This is taken from Table2.

3) Landing (W_5/W_4): This is taken from Table2.

4) Cruise:

Weight fraction for cruise segment is found using Breguet range formula.

$$R = \frac{V}{C} \frac{L}{D} \ln \left(\frac{W_{i-1}}{W_i} \right) \quad \text{Where } R = \text{range, } C = \text{specific fuel consumption}$$

$$\frac{W_i}{W_{i-1}} = \exp \left(\frac{-C}{V} \left(\frac{L}{D} \right) R \right)$$

V = velocity, L/D = lift to drag ratio

5) Loiter

Weight fraction for loiter segment is found using Endurance formula.

$$E = \frac{L/D}{C} \ln \left(\frac{W_{i-1}}{W_i} \right)$$

$$\frac{W_i}{W_{i-1}} = \exp \left(\frac{-EC}{L/D} \right) \quad \text{Where } E = \text{endurance or loiter time, } C = \text{specific fuel consumption,}$$

V = velocity, L/D = lift to drag ratio

6) Empty Weight fraction: The empty weight fraction can be estimated from Table1 based on the aircraft type and wing sweep.

2) Calculate gross weight of the aircraft from following equation which is function of W_0 .

$$W_0 = \frac{(W_e + W_f)}{1 - \frac{W_f}{W_0} - \frac{W_e}{W_0}} \quad (1)$$

W_e/W_0 is function of W_0 , W_f/W_0 is also a function of W_0 . W_0 is calculated from equation(1) through process of iteration. W_0 has to be assumed, then RHS value of equation(1) is calculated which should match the value of assumed, if it doesn't, increment the assume by some value and iterate it. This process is continued till the absolute difference of RHS value and assumed value is the least and that iteration step will be your nearest solution.

This is done using following iteration table.

Iteration. No	Guess weight	Empty weight	Fuel weight	Calculated weight	Difference= guess-cal

3) Plot graph for calculated weight, guess weight versus iteration number from above table results and compare them in a single graph.

Validation:

1. Perform the analytic equations and obtain the results and validate with your code results

Result: The Gross takeoff weight of the given aircraft is _____

Sample Matlab output

```
'S_no'  'MISSION_SEGMENT'  'VALUE'
[ 1]  'Takeoff_condition' [ 0.9700]
[ 2]  'Climb_condition'  [ 0.9850]
[ 3]  'Cruise_condition' [ 0.8986]
[ 4]  'Loiter_condition'  [ 0.9277]
[ 5]  'Cruise_condition' [ 0.8986]
[ 6]  'Loiter_condition'  [ 0.9917]
[ 7]  'Landing_condition' [ 0.9950]
[ 8]  'FUEL FRACTION'     [ 0.3113]
[ 9]  'WO CALCULATED'     [7.8172e+004]
```

Experiment 2: Weight Estimation of Fighter Aircraft

Aim: Perform rubber engine sizing of a given fighter aircraft requirements

Software used: Matlab

Theory:

Table 6.1 Empty weight fraction vs W_0 , A , T/W_0 , W_0/S , and M_{\max}

	$W_e/W_0 = (a + bW_0^{C1}A^{C2}(T/W_0)^{C3}(W_0/S)^{C4}M_{\max}^{C5})K_{us}$						
	a	b	$C1$	$C2$	$C3$	$C4$	$C5$
Jet trainer	0	4.28	-0.10	0.10	0.20	-0.24	0.11
Jet fighter	-0.02	2.16	-0.10	0.20	0.04	-0.10	0.08
Military cargo/bomber	0.07	1.71	-0.10	0.10	0.06	-0.10	0.05
Jet transport	0.32	0.66	-0.13	0.30	0.06	-0.05	0.05

K_{VS} = variable sweep constant = 1.04 if variable sweep
= 1.00 if fixed sweep

Given warm-up/take-off, climb and landing weight fractions from historical trends: The warm-up, take-off and landing weight fractions can be estimated historically from Table2.

$$W_1/W_0 = 0.97-0.99$$

Requirements:

Aircraft type, engine type, wing sweep type, mission profile, crew weight, specific fuel consumption, L/D ratio, different range values, different payload weight values.

Procedure:

1. Draw the mission profile as per the given aircraft requirements, and decide the weight fractions in the mission.
2. Calculate the value of take off weight from table 1 as per your aircraft requirements
3. Calculate the climb weight fraction by considering the following equation

Subsonic: $W_i/W_{i-1} = 1.0065 - 0.0325M$

Supersonic: $W_i/W_{i-1} = 0.991 - 0.007M - 0.01M^2$

4. Calculate the value for cruise weight segment

Jet: $\frac{W_i}{W_{i-1}} = \exp \frac{-RC}{V(L/D)}$

5. Calculate the loiter weight fraction by using

Jet: $\frac{W_i}{W_{i-1}} = \exp \frac{-EC}{L/D}$

6. Calculate the combat weight fraction

$$W_i/W_{i-1} = 1 - C(T/W)(d)$$

7. Calculate the Descent weight segment

$$W_i/W_{i-1} = 0.990 \text{ to } 0.995$$

8. Calculate the Landing weight segment

$$W_i/W_{i-1} = 0.992 \text{ to } 0.997$$

9. Calculate Fuel weight fraction

$$\frac{W_f}{W_0} = 1.06 \left(1 - \frac{W_x}{W_0} \right)$$

10. Calculate the gross takeoff weight and empty weight fraction

$$W_0 = \frac{W_{\text{crew}} + W_{\text{payload}}}{1 - (W_f/W_0) - (W_e/W_0)}$$

- 11.11. W_e/W_0 is function of W_0 , W_f/W_0 is also a function of W_0 . W_0 is calculated from equation(1) through process of iteration. W_0 has to be assumed, then RHS value of equation(1) is calculated

which should match the value of assumed, if it doesn't, increment the assume by some value and iterate it. This process is continued till the absolute difference of RHS value and assumed value is the least and that iteration step will be your nearest solution.

12. This is done using following iteration table.

Iteration. No	Guess weight	Empty weight fraction	Fuel weight fraction	Calculated weight	Difference= guess-cal

Validation:

2. Perform the analytic equations and obtain the results and validate with your code results

Result: The Gross takeoff weight of the given aircraft is _____

Experiment 3: Estimation of Wing Loading

Aim: To determine the wing loading of an aircraft for different mission segments

Software used: Matlab

Equations Required:

Stalling speed , V stall	=	117	Knots	
C l max for airfoil	=	2.7		
Cruise speed , M	=	0.9		
Typical cruise speed	=	470	Knots	
Allowable landing distance	=	2000	fts	
e	=	0.85		
AR	=	10		
Sa	=	1000	fts	(airliner aircraft)
		600	fts	(general aviation)

1 STALL CONDITION

FORMULAE :-

W/S	=	$1/2 * \rho * (V_{stall})^2 * C_{L\max}$
C L max	=	$0.9 * C_{l\max}$

Since, ρ at sea level = $0.23769 * 10^{-2}$ slugs/ft³

CALCULATIONS

∴

C L max	=	
W/S	=	lbs/ft ²

2 TAKEOFF CONDITION

FORMULAE :-

W/S	=	$\frac{(TOP) * (\sigma) * (C_{LTO})}{(T/W)}$
C L TO	=	$C_{l\max} * (V_{stall} / V_{TO})^2$
V TO	=	$1.15 * V_{stall}$
T/W	=	$a * (M_{\max})^c$

Since, TOP = 450 , at 10,000 ft
 σ = 1 , at sea level
a = 0.267
c = 0.363

3 CLIMB CONDITION

FORMULAE :-

W/S	=	$\frac{(T/W) + ((T/W)^2 - ((4 * n^2 * C_{D,o}) / (\pi * A * e)))^{1/2}}{(2 * n^2) / (q * \pi * A * e)}$
-----	---	---

$(T/W)^c$	=	1	+	V
-----------	---	---	---	---

	vertical
$(L/D)c$	V climb

V vertical	=	R/C	,	V climb	=	1.2 * V stall
-------------------	---	------------	---	----------------	---	----------------------

C D,o	=	$\frac{S_{\text{wetted}}}{S_{\text{ref}}} * C_{fe}$	S
--------------	---	---	----------

q	=	$(1/2)*(\rho)*(V_{\text{climb}})^2$, at 1500 ft
----------	---	-------------------------------------	--------------

Since , $n = 1$, $\rho = 0.2274 * 10^{-2}$ slugs/ft³

$(L/D) c = 18$

$V_{\text{vertical}} = 2940$ ft/min

4 **CRUISE CONDITION**

FORMULAE :-

W/S	=	$q*(\pi*A*e*C_{D,o}/3)^{(1/2)}$	
q	=	$(1/2)*(\rho)*(V_{\text{cruise}})^2$, at 42,000 ft

Since, $\rho = 0.5337 * 10^{-3}$ slugs/ft³

$V_{\text{cruise}} = 470$ knots

CALCULATIONS

\therefore

q =

W/S = **lbs/ft²**

5 **LOITER CONDITION**

FORMULAE :-

W/S	=	$q*(\pi*A*e*C_{D,o})^{(1/2)}$	
q	=	$(1/2)*(\rho)*(V)^2$, at 5000 ft
V	=	1.3 * V stall	

Since , $\rho = 0.1496*10^{-2}$ slugs/ft³

CALCULATIONS

\therefore

6 **LANDING CONDITION**

FORMULAE :-

W/s = $((S_{\text{landing}}) - (S_a)) * (\sigma) * (C_{L \text{ max}})/80$

Since, $C_{L \text{ max}} = 2.43$

$S_a = 1000$ fts

$S = 2000$ fts

$$\sigma = 1$$

Procedure:

1. Calculate q, V for various segments by using above equations.
2. Calculate W/S stall condition by using the equation = $\frac{1}{2} \rho (V_{stall})^2 C_{Lmax}$.
3. Calculate W/S takeoff condition by using the equation = $(TOP) * (\sigma) * (C_{LTO}) * (T/W)$
4. Calculate W/S climb condition by using the equation =
$$\frac{(T/W) + ((T/W)^2 - ((4 * n^2 * C_{D,o}) / (\pi * A * e)))^{1/2}}{(2 * n^2) / (q * \pi * A * e)}$$
5. Calculate W/S cruise condition by using the equation = $q * (\pi * A * e * C_{D,o} / 3)^{1/2}$
6. Calculate W/S loiter condition by using the equation = $q * (\pi * A * e * C_{D,o})^{1/2}$
7. Calculate W/S landing condition by using the equation = $((S_{landing}) - (S_a)) * (\sigma) * (C_{Lmax}) / 80$

Validate:

1. Perform analytical calculations and compare with matlab results

Result: Wing loading of various mission segments are obtained as follows

Sl.No:	MISSION SEGMENT	(W/S)
1	Stall condition	lbs/ft ²
2	Takeoff condition	lbs/ft ²
3	Climb condition	lbs/ft ²
4	Cruise condition	lbs/ft ²
5	Loiter condition	lbs/ft ²
6	Landing condition	lbs/ft ²

Matlab result

```

'S_no' 'MISSION_SEGMENT' '(W/S)' 'Units'

[ 1] 'Stall_condition' [112.6162] 'lbs/ft^2'

[ 2] 'Takeoff_condition' [212.4831] 'lbs/ft^2'

[ 3] 'Climb_condition' [442.8376] 'lbs/ft^2'

[ 4] 'Cruise_condition' [ 67.3742] 'lbs/ft^2'

[ 5] 'Loiter_condition' [ 34.1761] 'lbs/ft^2'

[ 6] 'Landing_condition' [ 30.3750] 'lbs/ft^2'

```

Experiment 4: Wing design and Drag estimation

Aim: Design wing according to the given data and plot the graph for α Vs C_L and C_L Vs C_D

Software used: Matlab

Requirements: Wing area, aspect ratio, drag polar, span efficiency factor.

Theory:

The induced drag coefficient of moderate angle of attack is proportional to square of the lift coefficient with a proportionality factor called the “*drag-due-to-lift-factor or K*”

$$C_D = K C_L^2 \quad (1)$$

Following are the two methods to estimate “drag-due-to-lift-factor or K”:

- 1) Oswald’s span efficiency method
- 2) Leading edge suction method

1) Oswald’s span efficiency method:

According to classical wing theory, the induced drag coefficient of 3D-Wing with an elliptical lift distribution equals the square of lift coefficient divided by πA (A = Aspect Ratio or Effective Aspect Ratio)

$$K = \frac{1}{\pi A e} \quad (2)$$

A = Aspect Ratio

$A_{effective}$ = Effective Aspect Ratio

e = Oswald’s span efficiency (The value of e varies from 0.7 to 0.85)

Effective Aspect Ratio for

$$\text{End-plates: } A_{effective} = A(1 + 1.9h/b) \quad (3)$$

h = height of Endplate

$$\text{Winglets: } A_{effective} \cong 1.2A \quad (4)$$

Straight wing aircraft:

$$e = 1.78(1 - 0.045A^{0.68}) - 0.64 \quad (5)$$

Swept wing aircraft:

$$e = 4.61(1 - 0.045A^{0.68})(\cos \Lambda_{LE})^{0.15} - 3.1 \quad (6)$$

Supersonic aircraft:

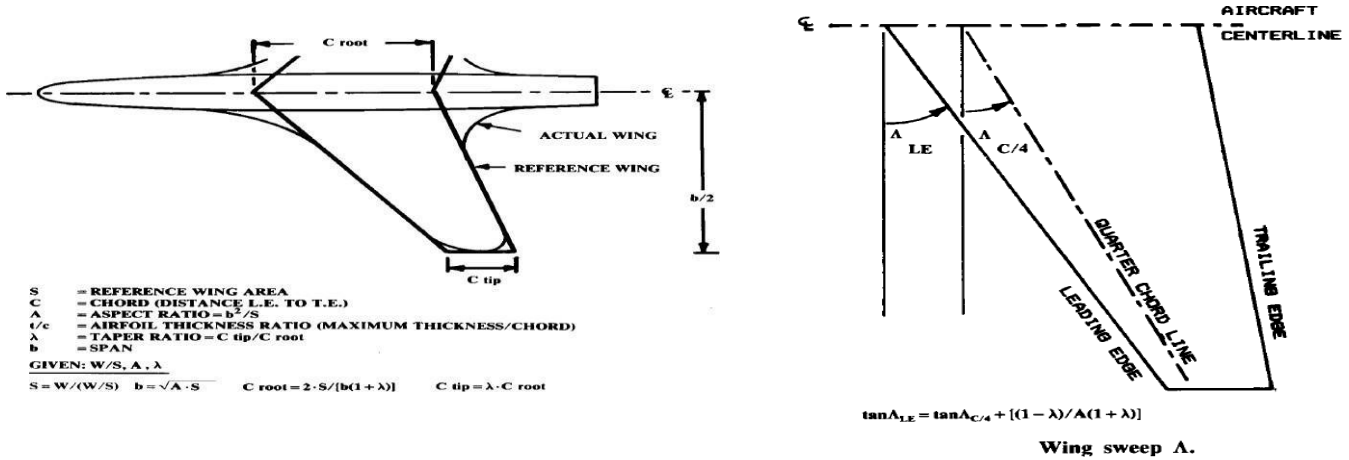
$$e = \frac{A[M^2 - 1]}{4A(\sqrt{M^2 - 1}) - 2} \cos \Lambda_{LE} \quad (7)$$

Λ_{LE} = Sweep angle of leading edge

Disadvantages of Oswald span efficiency method:

- 1) Ignores the variation of K with lift coefficient.
- 2) This doesn't include the effects of the change in viscous separation as lift coefficient is changed.

Wing Details



2) Leading Edge Suction Method:

This is a semi-empirical for estimation of K allows for the variation of K with lift coefficient and Mach number. Due to the rapid curvature at the leading edge, there creates a pressure drop on the upper part of the leading edge. The reduced pressure exerts a suction force on the leading edge in a forward direction. This “*leading edge suction*” force S is in the direction perpendicular to the normal force N .

$$K = SK_0 + (1 - S)K_{100}$$

(8)

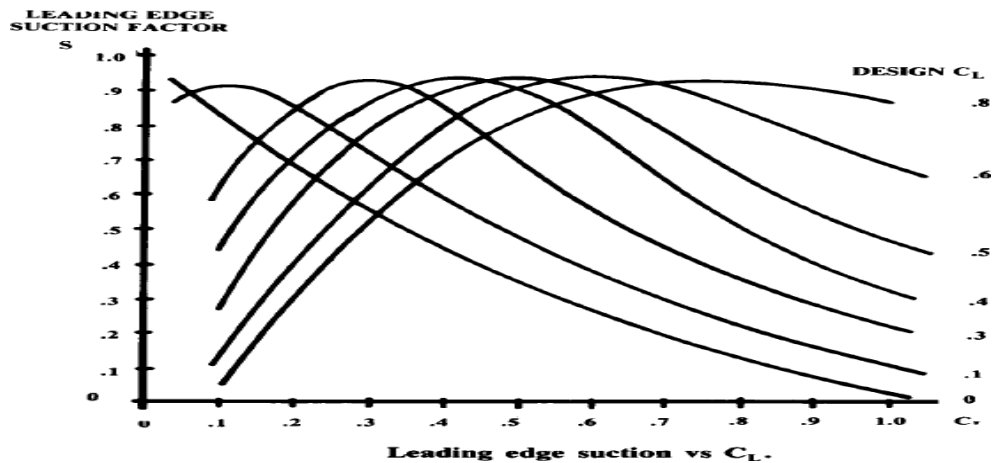
K = drag-due-to-lift-factor

$$K_{100} = \frac{1}{\pi A}$$

$$K_0 = \frac{1}{C_{l\alpha}}$$

$C_{l\alpha}$ = slope of the lift curve, angle taken in radians

S = Leading edge suction factor



Equations Used:

* **AIRFOIL DATA : 2414**

$C_{l \max}$	=	1.5
$C_{l \alpha}$	=	$0.11 / 1^\circ$
Aerodynamic Centre	=	$0.25 C$
α_{oL}	=	-1.33
$C_{d,o}$	=	0
r_{LE}	=	0
C_l at minimum drag	=	0.1 - 0.3
$t/c \max$	=	0.15

* **DESIGN PARAMETER :**

M at Cruise	=	0.9	
S	=	$\frac{W_{\text{cruise}}}{(W/S)_{\text{cruise}}}$	fts
W cruise	=	$(W_2 + W_3) / 2$	lbs
Λ_{LE}	=	25°	
λ	=	0	
$C_{L \text{ start cruise}}$	=	$W_2 / (S \cdot q)$	=
$C_{L \text{ end cruise}}$	=	$W_3 / (S \cdot q)$	=

* **AIR PROPERTIES :**

Cruise Altitude	=	42,000	ft
Velocity at Cruise	=	470	knots
ρ	=	$0.5337 \cdot 10^{-3}$	sl/ft ³
q	=	167.92	
v	=	$0.5564 \cdot 10^{-3}$	ft ² /s
μ	=	$0.2969 \cdot 10^{-6}$	sl/ft/s

Procedure:

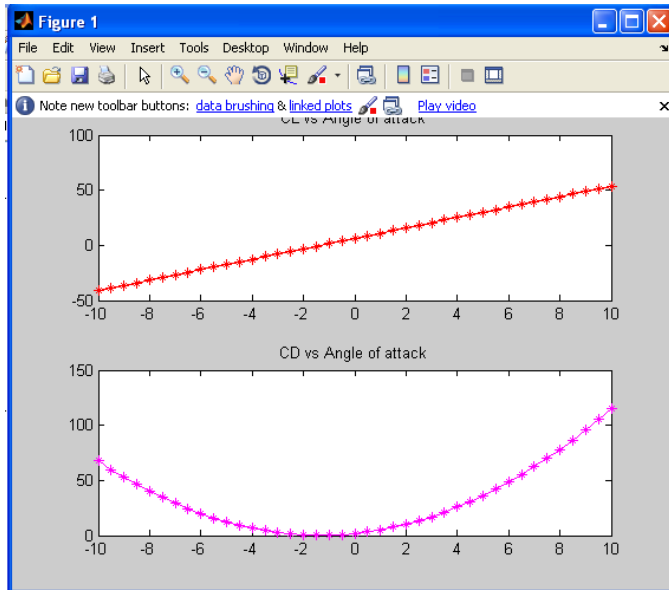
1. Calculate K , C_D , C_r , b , $\Lambda_{t/c}$, M_{eff} , β from the equations mentioned.
2. Calculate C_L at $\alpha=0$, $dC_L/d\alpha$, C_L from the given equations.
3. Consider switch case to find area for your prompted wing shape.
4. Consider a for loop to find drag for the given wing chord length by considering it as a flat plate
5. Calculate C_f , S_{wet} , F , $C_{D,o}$
6. Consider for loop for various α values
7. Plot α Vs C_L and C_L Vs C_D .

Tabulation:

α	C_L	C_D	L	D

Result: The variation of C_L and C_D for various angle of attack are obtained

Matlab plot



Experiment 5: Design of Horizontal and vertical Tails

Aim: To design horizontal and vertical tails for a jet transport aircraft

Software used: MATLAB

Theory: Tails provide for trim, stability, and control. There are horizontal and vertical tails

Inputs:

1. Wing data: $b = 32.2 \text{ ft}$; $mac = 21.5 \text{ ft}$; $S = 519$; $M = 0.9$; $\Lambda LE = 62^\circ$; $t/c = 0.04$; $\lambda = 0$.
2. Vertical tail data : $C_{vt} = 0.07$; $L_{vt} = 40$; $\Lambda LE = 63^\circ$; $\lambda = 0.3$; $A_{vt} = 1.1$; $t/c = 0.04$
1. Horizontal tail data: $C_{ht} = 0.11$; $L_{ht} = 50$; $\Lambda LE = 63^\circ$; $\lambda = 0.35$; $A_{ht} = 2$; $t/c = 0.04$

Equations used:

$$b = (A_{vt} * S_{vt})^{(1/2)}$$

C_r	=	$\frac{2 * S_{vt}}{b * (1 + \lambda)}$
-------	---	--

C_t	=	$\lambda * C_r$
-------	---	-----------------

S_{vt}	=	$C_{vt} * \frac{b w * S_w}{L_{vt}}$
----------	---	-------------------------------------

$m.a.c$	=	$\frac{2 * C_r}{3} \frac{1 + \lambda + (\lambda^2)}{1 + \lambda}$
---------	---	---

b	=	$(A_{ht} * S_{ht})^{(1/2)}$
-----	---	-----------------------------

C_r	=	$\frac{2 * S_{ht}}{b * (1 + \lambda)}$
-------	---	--

C_t	=	$\lambda * C_r$
-------	---	-----------------

S_{ht}	=	$C_{ht} * \frac{(m.a.c) w}{L_{ht}}$
----------	---	-------------------------------------

$m.a.c$	=	$\frac{2 * C_r}{3} \frac{1 + \lambda + (\lambda^2)}{1 + \lambda}$
---------	---	---

Procedure:

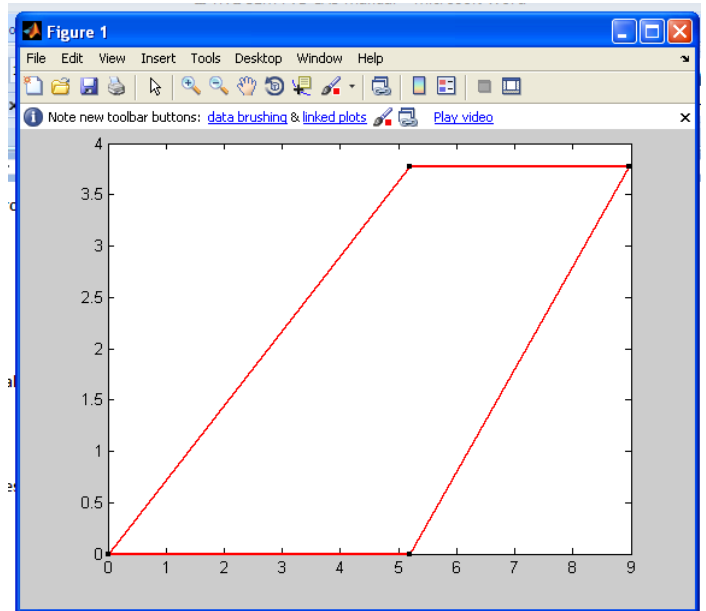
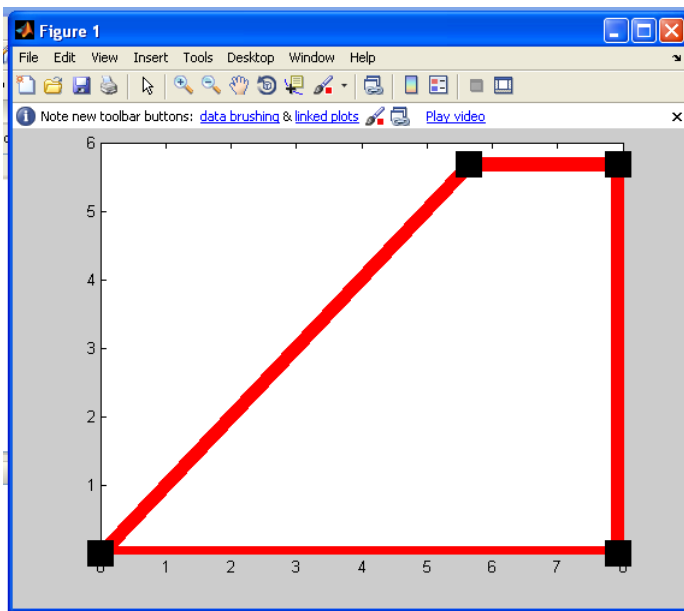
1. Calculate b , Cr , Ct , S_{ht} , mac for horizontal tail with the given equations.
2. Plot the coordinates to obtain horizontal tail configuration.
3. Calculate b , Cr , Ct , S_{ht} , mac for vertical tail with the given equations.
4. Plot the coordinates to obtain vertical tail configuration.
5. Develop 3D model in catia

Validation:

1. Develop 3D model in Catia with the given coordinates points.
2. Compare with theoretical calculations and graph

Result: Horizontal and vertical tail are generated configurations are generated and 3D modeling is done

Matlab output



Experiment 8: Engine Sizing

Aim: To estimate the total drags on an aircraft.

Software used: MATLAB

Theory: To develop the propulsion system it is necessary to know the actual dimensions and installation requirements of the engine and as well as its supporting equipment like inlet, nozzle or propellers

Equations used:

Experiment 7: Engine Sizing

Aim: To estimate the total drags on an aircraft.

Software used: MATLAB

Theory: To develop the propulsion system it is necessary to know the actual dimensions and installation requirements of the engine and as well as its supporting equipment like inlet, nozzle or propellers

Equations used:

Nonafterburning engines:

$$W = 0.084 T^{1.1} e^{(-0.045 \text{ BPR})}$$

$$L = 2.22 T^{0.4} M^{0.2}$$

$$D = 0.393 T^{0.5} e^{(0.04 \text{ BPR})}$$

$$\text{SFC}_{\max T} = 0.67 e^{(-0.12 \text{ BPR})}$$

$$T_{\text{cruise}} = 0.60 T^{0.9} e^{(0.02 \text{ BPR})}$$

$$\text{SFC}_{\text{cruise}} = 0.88 e^{(-0.05 \text{ BPR})}$$

Afterburning engines:

$$W = 0.063 T^{1.1} M^{0.25} e^{(-0.81 \text{ BPR})}$$

$$L = 3.06 T^{0.4} M^{0.2}$$

$$D = 0.288 T^{0.5} e^{(0.04 \text{ BPR})}$$

$$\text{SFC}_{\max T} = 2.1 e^{(-0.12 \text{ BPR})}$$

$$T_{\text{cruise}} = 1.6 T^{0.74} e^{(0.023 \text{ BPR})}$$

$$\text{SFC}_{\text{cruise}} = 1.04 e^{(-0.186 \text{ BPR})}$$

where

W = weight

T = takeoff thrust

BPR = bypass ratio

M = max Mach number

Cruise is at 36,000 ft and $0.9M$.

Procedure:

2. Calculate the weight, thrust, lift and drag from the given equations.
3. Calculate the exit pressure and mach number for the given nozzle configurations

Validation: Check with the theoretical calculations

Result: The engine with given specifications is designed and nozzle exit conditions are calculated

Experiment 10: Operation of Hydraulic test rig

Aim: Operate the hydraulic test rig to deflect the control system.

Equipment Required:

1. Hydraulic test rig

Theory:

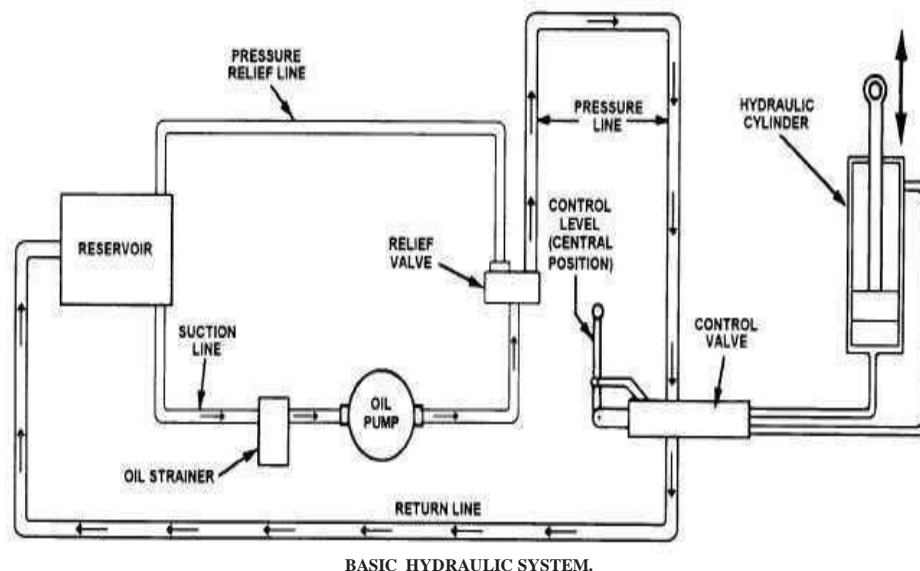
A **hydraulic drive system** is a drive or transmission **system** that uses pressurized **hydraulic fluid** to power **hydraulic machinery**. The term hydrostatic refers to the transfer of energy from flow and pressure, not from the kinetic energy of the flow.

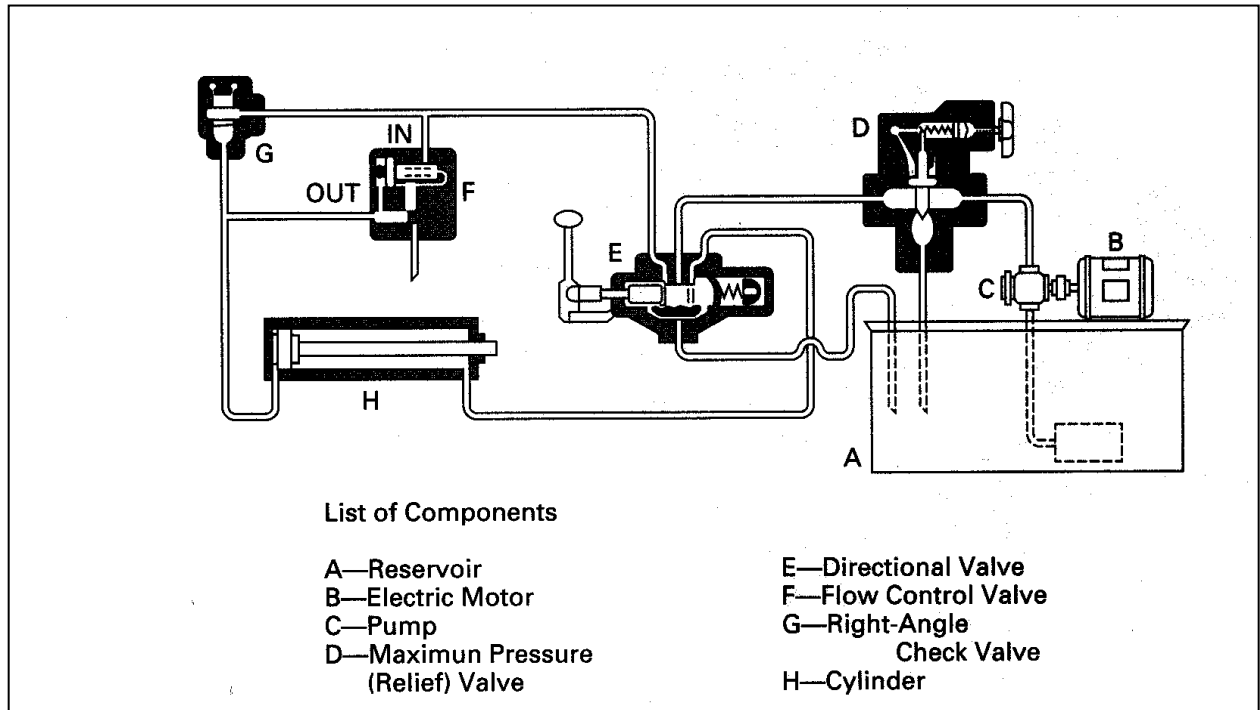
Common hydraulic fluids are based on **mineral oil** or water. Examples of equipment that might use hydraulic fluids include excavators and backhoes, hydraulic brakes, power steering systems, transmissions, garbage trucks, aircraft flight control systems, lifts, and industrial machinery.

The Basic Idea

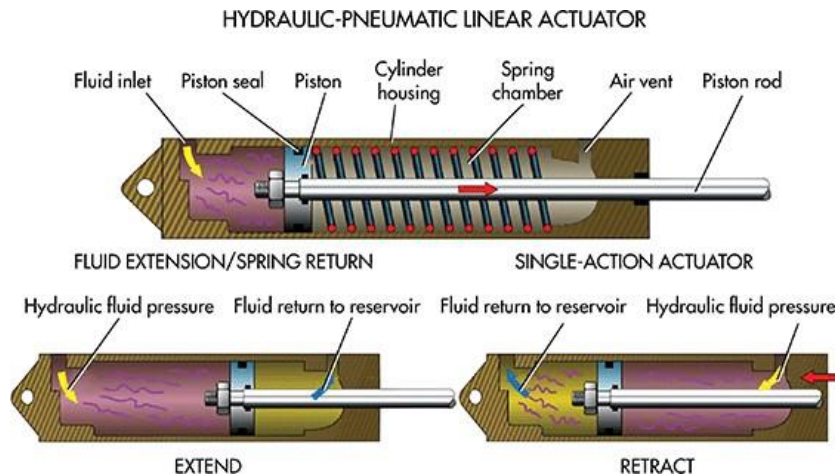
The basic idea behind any hydraulic system is very simple: **Force that is applied at one point is transmitted to another point using an incompressible fluid**. The fluid is almost always an oil of some sort. The force is almost always multiplied in the process. The picture below shows the simplest possible hydraulic system

A **hydraulic pump** is a mechanical source of power that converts mechanical power into **hydraulic energy** (hydrostatic energy i.e. flow, pressure). It generates flow with enough power to overcome pressure induced by the load at the **pump outlet**.





- Pneumatic linear actuators consist of a piston inside a hollow cylinder. Pressure from an external compressor or manual pump moves the piston inside the cylinder. As pressure increases, the cylinder moves along the axis of the piston, creating a linear force. The piston returns to its original position by either a spring-back force or fluid being supplied to the other side of the piston.
- Hydraulic linear actuators operate similarly to pneumatic actuators, but an incompressible liquid from a pump rather than pressurized air moves the cylinder.
- An electric linear actuator converts electrical energy into torque. An electric motor mechanically connected turns a lead screw. A threaded lead or ball nut with corresponding threads that match those of the screw is prevented from rotating with the screw. When the screw rotates, the nut gets driven along the threads. The direction the nut moves depends on which direction the screw rotates and also returns the actuator to its original position.



The top image shows a spring return actuator. The maximum spring compression pushes back on the piston and the hydraulic fluid exits the cylinder and returns to its starting position. The bottom image is a double-acting cylinder where fluid enters either side of the piston depending on the desired motion.

Hydraulic Actuators

Advantages

- Hydraulic actuators are rugged and suited for high-force applications. They can produce forces 25 times greater than pneumatic cylinders of equal size. They also operate in pressures of up to 4,000 psi.
- Hydraulic motors have high horsepower-to-weight ratio by 1 to 2 hp/lb greater than a pneumatic motor.
- A hydraulic actuator can hold force and torque constant without the pump supplying more fluid or pressure due to the incompressibility of fluids
- Hydraulic actuators can have their pumps and motors located a considerable distance away with minimal loss of power.

Disadvantages

- Hydraulics will leak fluid. Like pneumatic actuators, loss of fluid leads to less efficiency. However, hydraulic fluid leaks lead to cleanliness problems and potential damage to surrounding components and areas.
- Hydraulic actuators require many companion parts, including a fluid reservoir, motors, pumps, release valves, and heat exchangers, along with noise-reduction equipment.

Result: The hydraulic test rig is operated

Experiment 11: Operation of Pneumatic Test Rig

Aim: Operate the pneumatic test rig to deflect the control system.

Equipment Required:

1. Pneumatic test rig

Theory: A pneumatic system is a system that uses compressed air to transmit and control energy.

Pneumatic systems are used in controlling train doors, automatic production lines, mechanical clamps, etc (Fig).



(a) Automobile production lines



(b) Pneumatic system of an automatic machine

Fig. 1 Common pneumatic systems used in the industrial sector

(a) The advantages of pneumatic systems

Pneumatic control systems are widely used in our society, especially in the industrial sectors for the driving of automatic machines. Pneumatic systems have a lot of advantages.

(i) High effectiveness

Many factories have equipped their production lines with compressed air supplies and movable compressors. There is an unlimited supply of air in our atmosphere to produce compressed air. Moreover, the use of compressed air is not restricted by distance, as it can easily be transported through pipes. After use, compressed air can be released directly into the atmosphere without the need of processing.

(ii) High durability and reliability

Pneumatic components are extremely durable and can not be damaged easily. Compared to electromotive components, pneumatic components are more durable and reliable.

(iii) Simple design

The designs of pneumatic components are relatively simple. They are thus more suitable for use in simple automatic control systems

(iv) High adaptability to harsh environment

Compared to the elements of other systems, compressed air is less affected by high temperature, dust, corrosion, etc.

v) Safety

Pneumatic systems are safer than electromotive systems because they can work in inflammable environment without causing fire or explosion. Apart from that, overloading in pneumatic system will only lead to sliding or cessation of operation. Unlike electromotive components, pneumatic components do not burn or get overheated when overloaded

(vi) Easy selection of speed and pressure

The speeds of rectilinear and oscillating movement of pneumatic systems are easy to adjust and subject to few limitations. The pressure and the volume of air can easily be adjusted by a pressure regulator.

vii) Environmental friendly

The operation of pneumatic systems do not produce pollutants. The air released is also processed in special ways. Therefore, pneumatic systems can work in environments that demand high level of cleanliness. One example is the production lines of integrated circuits.

(viii) Economical

As pneumatic components are not expensive, the costs of pneumatic systems are quite low Moreover, as pneumatic systems are very durable, the cost of repair is significantly lower than that of other systems

(b) Limitations of pneumatic systems

Although pneumatic systems possess a lot of advantages, they are also subject to many limitations.

i) Relatively low accuracy

As pneumatic systems are powered by the force provided by compressed air, their operation is subject to the volume of the compressed air. As the volume of air may change when compressed or heated, the supply of air to the system may not be accurate, causing a decrease in the overall accuracy of the system.

ii) Low loading

As the cylinders of pneumatic components are not very large, a pneumatic system cannot drive loads that are too heavy

(iii) Processing required before use Compressed air must be processed before use to ensure the absence of water vapour or dust Otherwise, the moving parts of the pneumatic components may wear out quickly due to friction

(iv) Uneven moving speed

As air can easily be compressed, the moving speeds of the pistons are relatively uneven.

(v) Noise

Noise will be produced when compressed air is released from the pneumatic components

(c) Main pneumatic components

Pneumatic components can be divided into two categories

1. Components that produce and transport compressed air.
2. Components that consume compressed air.

All main pneumatic components can be represented by simple pneumatic symbols. Each symbol shows only the function of the component it represents, but not its structure. Pneumatic symbols can be combined to form pneumatic diagrams. A pneumatic diagram describes the relations between each pneumatic component, that is, the design of the system

2 The production and transportation of compressed air

Examples of components that produce and transport compressed air include compressors and pressure regulating components

(a) Compressor

A compressor can compress air to the required pressures. It can convert the mechanical energy from motors and engines into the potential energy in compressed air (Fig. 2). A single central compressor can supply various pneumatic components with compressed air, which is transported through pipes from the cylinder to the pneumatic components. Compressors can be divided into two classes: reciprocatory and rotary



Result: The Pneumatic test rig is operated