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Design and Analyze a Wing Structure of Narrow Body Aircraft

Rishi Patel¹, Rishabh Patel², Aniket Parmar³, Jayrajsinh Parihar⁴, Varun Jaiswal⁵, Meet Patel⁶

Students, Department of Aeronautical Engineering, Sardar Vallabhbhai Patel Institute of Technology, Gujarat, India^{1,2,3,4,5,6}

ABSTRACT: The ultimatum of this project is the wing design and analysis of a Narrow body aircraft with the desired specifications. This aircraft design project is nothing but designing our own imaginative aircraft with some help from Existing available data of similar types of aircrafts. This project boosts up the innovative and creative part of the mind. During the design process, the Existing theoretical formulae, concepts, basics are scrutinized to aid in the design process, thus developing one's mind and a better understanding capacity. This design process also helps in developing the potential in ourselves. This project is just a basic design with the use of basic formulae. However, designs based on these formulae have been found to comply to the desired specifications with minimal variations. This design process includes some of the airfoil selection, wing parameters and design, critical performance parameters and the power plant and finally the three-view diagram of the aircraft for which the design is being proposed.

KEYWORDS: Wing Design, Narrow Body Structure, Wing Structure, Aircraft Structure.

I. INTRODUCTION

Airplane design is both an art and a science. We can see by the name itself; airplane design involves Experience and practice rather than just a book. However, theory and Experimentation are interconnected, so we ought to go through the available books on design before starting a detailed design procedure. Airplane design is the intellectual process of creating on paper or on a computer screen a flying machine to meet certain specifications and requirements established by us, the designers or the concerned person or the firm for whom we are designing the aircraft. Airplane design is said to have started from the ages of Leonardo Da Vinci, Sir George Cayley, Otto Lilienthal, Alexander Mozhaiski, Felix Du Temple, Langley and the Wright brothers. In Indian Mythology, the demon king Ravan was believed to be fond of science. He is said to have designed an aircraft called the Pushpak Vaahan that he used to abduct Sita, the wife of lord Ram, the prince of Ayodhya. The design process is thus a process that does not stop. Even though, many modern configuration aircrafts Exist today and yet more are to come, the design process will never stop until the human desires of 100% efficiency, comfort, convenience and luxury are met.

PROBLEM STATEMENT:

Design and analyse a wing Structure of Narrow Body Aircraft with all the required data.

II. AIRCRAFT DESIGN

- ☞ First of all, the types of planes were discussed according to the engine type, wing configuration, range, passenger capacity, use, etc.
- ☞ Basics tools in Solidworks were taught and then the airfoil designing was done. Also one of the object was designed by the sir to teach us the basic tools usage.
- ☞ After designing the analysis was done in ANSYS.
- ☞ Geometry, meshing, problem setup, solution and results was done in the same airfoil.

THE DESIGN PROCESS:

☞ AIM:

To make a brief study of the airplane designing process to aid in the designing of narrow body aircraft.



☞ INTRODUCTION:

Those involved in design can never quite agree as to just where the design process begins. The designer thinks that it starts with a new airplane concept. The sizing specialist knows that nothing can begin until an initial estimate of weight is made. The customer feels that the design begins with requirements. They all are correct. The design process is actually an iterative process.

☞ STARTING A DESIGN PROCESS:

The start of the design process requires the identification of need. It is essential to understand at the start of the study where the project originated and to recognize what External factors are influential to the design before the design process is started. The design process never ends as the designers continuously provide many modifications to the aircraft to improve its safety and performance, services and any repairs, maintenance instructions etc. that are necessary to keep the Aircraft in an airworthy condition. Many airplanes never make it beyond the initial or preliminary design phase. In fact most don't. What happens beyond the preliminary design phase depends largely on the results obtained during the preliminary design and on the real or perceived market interest afterwards. If, because of the preliminary design studies a specific need can be met, then the full-scale development of the aircraft can follow. If, because of the preliminary design phase certain problem areas are discovered and then a research and development program can be initiated aimed at overcoming these problems. Eventually, with the problems solved which then can lead to a full-scale development.

☞ PHASES OF AIRCRAFT DESIGN:

The complete design process involves three distinct phases that are carried out in sequence. The phases are,

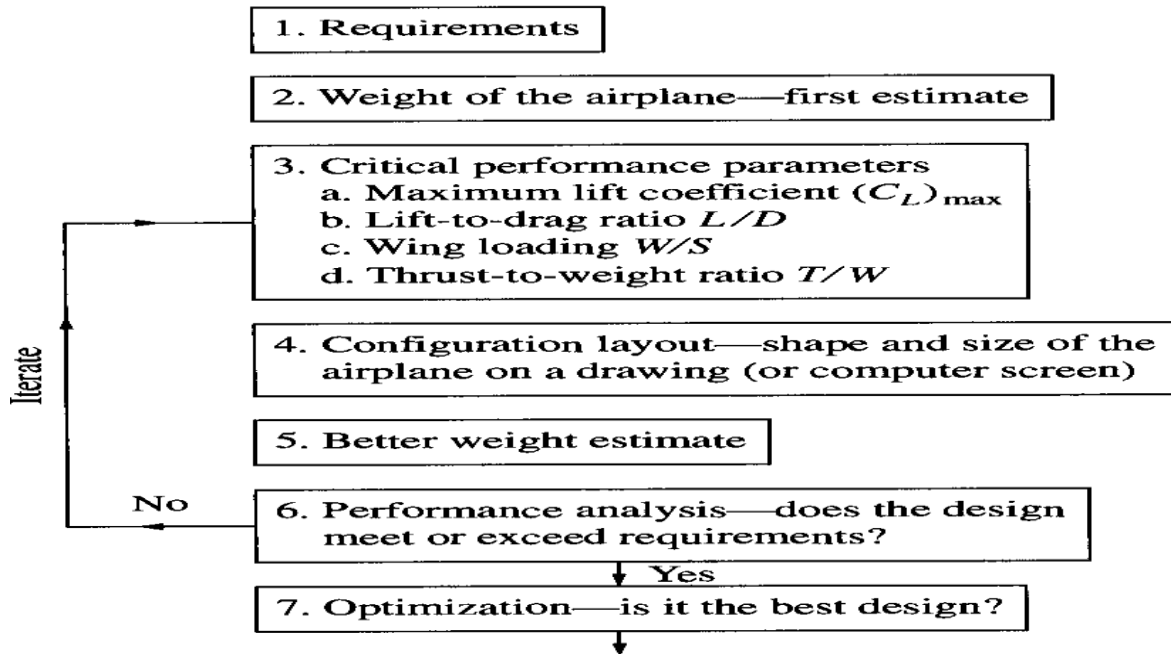
- ☞ Conceptual Design
- ☞ Preliminary Design
- ☞ Detail Design

☞ CONCEPTUAL DESIGN:

Usually, the design process starts with a set of preliminary requirements or specifications for the new airplane or with the desire to introduce some innovative ideas and technology. In this the overall shape, weight size and performance of the new design are determined. The result of conceptual design is the layout on a sheet of paper or on the computer screen of the airplane configuration. However, these drawings have to be visualized as flexible lines as they are prone to modifications during the second phase of the design process. It gives out some data like the wing and tail dimensions, position and type of the engine etc. During the conceptual design phase, the designer is influenced by qualitative aspects such as the increased structural loads imposed by a high horizontal T-tail versus a conventional tail location through the fuselage, and the difficulties associated with the cut outs in the wing structure if the landing gears are to retract into the wing rather than the fuselage or engine nacelle.



The Seven Intellectual Pivot Points for Conceptual Design



❏ **PRELIMINARY DESIGN:**

Minor changes are made to the configuration layout from the conceptual design in this preliminary design process. It is in this process serious structural and control system analysis and design takes place. In addition, during this phase substantial wind tunnel testing will be carried out and CFD (Computational Fluid Dynamics) calculations of the complete flow over the airplane configuration will be made. These tests will uncover some undesirable aerodynamic interference, or some Expected stability problems. At the end of preliminary design, the airplane configuration is fixed. It will not undergo any further modifications. The drawing process called lofting is carried out that mathematically models the precise shape of the outer skin of the airplane, making sure that all the sections of the aircraft properly fit together. The future of the design rests in the result of the preliminary design process whether to commit to the manufacture of the airplane or not.

❏ **DETAILED DESIGNED:**

The detail design is literally the nuts-and-bolts phase of the airplane design. The aerodynamics, propulsion, structures and flight control analyses all have been finished with the preliminary design phase. In this, the airplane is simply a machine waiting to be fabricated. The precise design of each individual component like the ribs, spars, section of skin etc., takes place. The size, number and location of fasteners are determined. Manufacturing tools and jigs are designed. The flight simulators for the aircraft are developed. At the end of this phase, the aircraft is ready to be fabricated.

III. COMPARATIVE STUDY

❏ **AIM:**

To do a comparative study on similar types of existing aircrafts and to prepare a comparative data sheet.

❏ **INTRODUCTION:**

The comparative study consists of preparing a comparative data sheet using data collected from Existing aircrafts similar to the aircraft that is to be designed. The data sheet focuses attention on some of the important parameters of the aircraft like,

- ❏ Empty weight
- ❏ Fuel weight
- ❏ MTOW
- ❏ Thrust
- ❏ Powerplant



- ✂ Maximum speed
- ✂ Range
- ✂ Service ceiling
- ✂ T/W ratio
- ✂ Wing loading
- ✂ Passengers and crew
- ✂ Wing area
- ✂ Wingspan

We are considering three aircrafts for our comparative study. They are,

Name of the aircraft	Manufacturer	Country
Airbus A220-100	Airbus	USA
Boeing 737(500)	Boeing	USA
Comac ARJ21-900	Comac	China

✂ **COMPARATIVE DATA SHEET:**

GENERAL DESCRIPTION OF AIRCRAFT			
NAME OF AIRCRAFT	Airbus A220-100	Boeing 737(500)	Comac ARJ21-900
TYPE OF AIRCRAFT	Regional Airliner	Regional Airliner	Regional Jet
MANUFACTURER	Airbus	Boeing	Comac
SEATING CAPACITY	120	130	95-105
TYPE OF ENGINE	Jet Engine	Turbofan	Jet Engine
NAME OF ENGINE	Pratt & Whitney PW1500G	CFM56-3B-1	General Electric CF34-10A
NO. OF ENGINES	2	2	2
AIRCRAFT DIMENSIONS			
LENGTH (m)	35	31	36.4
HEIGHT (m)	11.5	11.1	8.4
FUSELAGE DIAMETER (m)	3.7	3.7	3.54
WING SPAN (m)	35.1	28.9	27.3
WING CHORD (m)	3.2	3.15	2.92
ASPECT RATIO	10.97	9.17	9.32
WING AREA (m*2)	112.3	91.04	79.9
WING SWEEP (deg)	nil	35	25
PERFORMANCE			
CRUISING ALTITUDE (m)	10700 - 11600	nil	10500 - 11400
SERVICE CEILING (m)	12497	11900	11900
RANGE (km)	6297	3770	3300
CRUISING SPEED (km/hr)	829	828	828
MAX SPEED (km/hr)	870	876	871
MAX THRUST (KN)	103.6	78.2	82
DESIGN WEIGHT			
MAX TAKEOFF WEIGHT (kg)	54930	42800	47182
EMPTY WEIGHT (kg)	50580	26000	26770
WING LOADING (kg/m*2)	489.136	575	590.51
LANDING DISTANCE(m)	1350	1400	1700

This comparative data sheet will help us in determining the main parameters and limits for our aircraft.

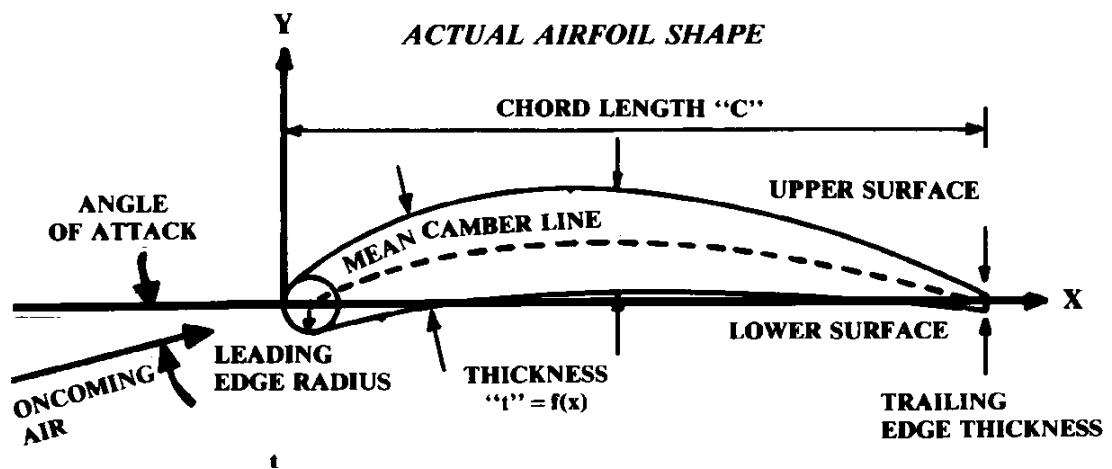
IV. SECTION OF MAIN PARAMETER

AIM:
To fix or select primary requirements for our aircraft.

INTRODUCTION:
Before designing the aircraft, the main parameters of the aircraft have to be selected. The customer provides them in case the aircraft is being designed for him. The main parameters are simply the aircraft’s requirements. They are as follows,

Criteria	Value
Payload-Passengers	116 at 100 kg
Payload-Baggage	20 kg each
Crew	2 pilots, 4 crew
Range	4445 km
Cruise altitude	12000 m (≈40000 ft)
Cruise Mach no.	0.8
Powerplant	2 turbojets
Landing distance	1400 m
Estimated weight	38000 kg
Thrust	85 kN

Thus, the primary parameters required for our aircraft were selected with help from the comparative data sheet.



V. SELECTION OF AIRFOIL

AIM:
To study different types of airfoils and select an appropriate airfoil for the wing design.

INTRODUCTION:
After the estimation of weight, a compatible airfoil for the type of aircraft that would be able to generate enough lift to overcome the weight efficiently has to be selected. First, a study of the Existing airfoils is suggested before proceeding to airfoil selection. NACA provides a wide variety of airfoils, each having its own different merits and demerits.

AIRFOIL FAMILY NACA FOUR-DIGIT SERIES:
Around 1932, NACA tested a series of airfoil shapes known as the four-digit sections. The four-digit airfoil geometry is defined, as the name implies, by four digits; the first gives the maximum camber in percent of chord, the second the location of the maximum camber in tenths of chord, and the last two the maximum thickness in percent of chord. For Example, the 2412 airfoil is a 12% thick airfoil having a 2% camber located 0.4 from



the leading edge.

ADVANTAGES:

- ⊗ Good stall characteristics
- ⊗ Small centre of pressure movement across large speed range
- ⊗ Roughness has little effect

DISADVANTAGES:

- ⊗ Low CL_{max}
- ⊗ Relatively high drag
- ⊗ High pitching moment

NACA FIVE-DIGIT SERIES:

The NACA five-digit series developed around 1935 uses the same thickness distribution as the four-digit series. The numbering system for the five-digit series is not as straightforward as for the four-digit series. The first digit multiplied by $3/2$ gives the design lift coefficient of the airfoil. The next two digits are twice the position of maximum camber in percent of chord. The last two digits give the percent thickness. For Example, the 23012 airfoil is a 12% thick airfoil having a design Cl of 0.3 and a maximum camber located 15% of c back from the leading edge.

ADVANTAGES:

- ⊗ Higher CL_{max}
- ⊗ Low pitching moment
- ⊗ Roughness has little effect

DISADVANTAGES:

- ⊗ Poor stall behaviour
- ⊗ Relatively high drag

NACA 1-SERIES (SERIES 16):

The NACA 1-series of wing sections developed around 1939 was the first series based on theoretical considerations. The most commonly used 1-series airfoils have the minimum pressure located at the 1.6 And are referred to as series-16 airfoils. The camber line for these airfoils is designed to produce a uniform chord wise pressure difference across it. In the thin airfoil theory to follow, this corresponds to a constant chord wise distribution of vortices.

Operated at its design Cl , the series-16 airfoil produces its lift while avoiding low-pressure peaks corresponding to regions of high local velocities.

Thus, the airfoil has been applied extensively to both marine and aircraft propellers. In the former application, Low-pressure regions are undesirable from the standpoint of cavitation (the formation of vaporous cavities in a flowing liquid). In the latter, the use of series-16 airfoils delays the onset of deleterious effects resulting from shock waves being formed locally in regions of high velocities.

Series-1 airfoils are also identified by five digits as, for Example, the NACA 16212 section. The first digit designates the series; the second digit designates the location of the minimum pressure in tenths of chord. Following the dash, the first number gives the design Cl in tenths. As for the other airfoils, the last two digits designate the maximum thickness in percent of chord.

ADVANTAGES:

- ⊗ Avoids low pressure peaks
- ⊗ Low drag at high speed

DISADVANTAGES:

- ⊗ Relatively low lift

NACA 6 SERIES:

The 6 series airfoils were designed to achieve desirable drag, compressibility, and Cl , performance. These requirements



are somewhat conflicting, and it appears that the motivation for these airfoils was primarily the achievement of low drag. The chord wise pressure distribution resulting from the combination of thickness and camber is conducive to maintaining Extensive laminar flow over the leading portion of the airfoil over a limited range of G values. Outside of this range, Cd and Clm values are not too much different from other airfoils.

The mean lines used with the 6-series airfoils have a uniform loading back to a distance of $x/c = 2$. Aft of this location the load decreases linearly.

The = 1 mean line corresponds to the uniform loading for the series-16 airfoils.

There are many perturbations on the numbering system for the 6 series airfoils. The later series is identified, for Example, as

NACA 651-212 a = 0.6

Here 6 denotes the series; the numeral 5 is the location of the minimum pressure in tenths of chord for the basic thickness and distribution; and the subscript 1 indicates that low drag is maintained at Cl, values of 0.1 above and below the design Cl, of the 0.2, denoted by the 2 following the dash. Again, the last two digits specify the percentage thickness. If the fraction, a, is not specified, it is understood to equal unity.

ADVANTAGES:

- ⊗ High C_{Lmax}
- ⊗ Very low drag over a small range of operating conditions
- ⊗ Optimized for high speed

DISADVANTAGES:

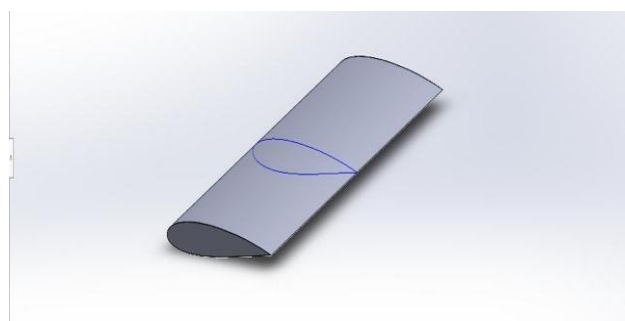
- ⊗ High drag outside of optimum range of operating conditions
- ⊗ Higher pitching moment
- ⊗ Poor stall behaviour
- ⊗ Very susceptible to roughness

Design Objectives	Eppler-361(12%)	Lockheed c-141(13%)	Boeing 737(12.5%)
C_{dmin}	0.005	0.005	0.01
C_{m0}	0.004	- 0.04	- 0.01
α_s	16	16	15
α_0	.015	0.25	0.1
$(Cl/Cd)_{max}$	84	72	87
$Cl\alpha$	0.25	1	0.1

VI. WING DESIGN

⊗ AIM:

To design wing section in solid works using previously selected airfoils.



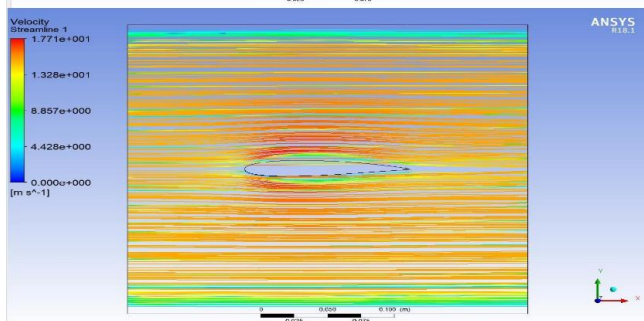
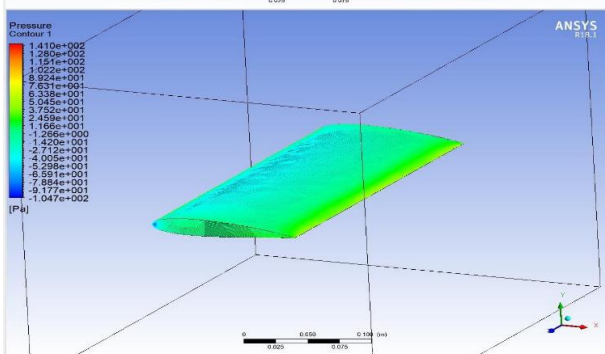
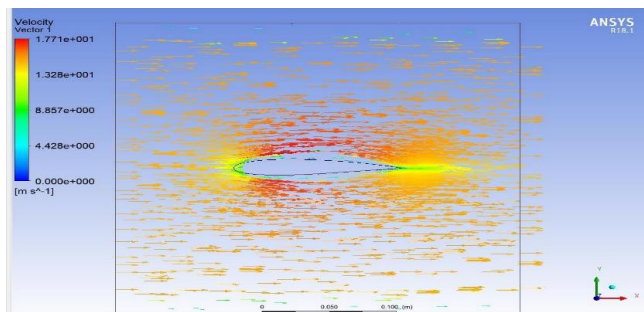
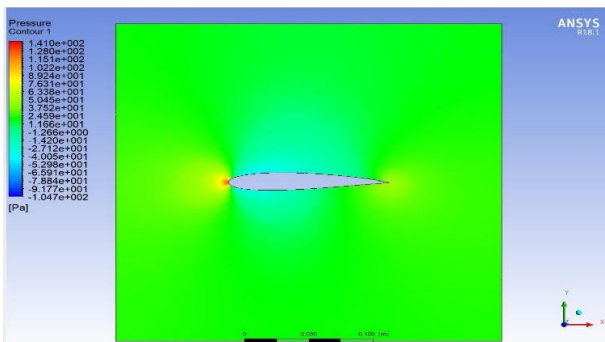
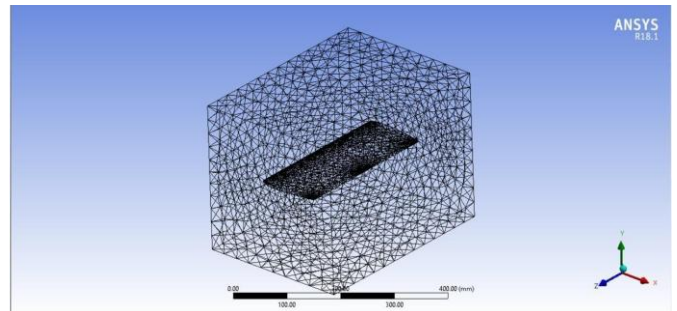
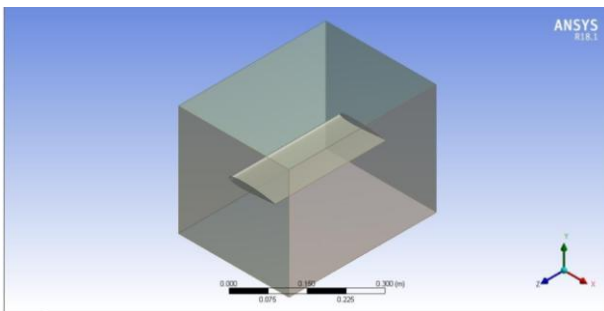
The design of Lockheed c-141 13% airfoil in SolidWorks by taking coordinates from airfoiltools.com. Steps:

- 1) Insert curve through x-y coordinate.
- 2) Extrude by mid plane option
- 3) Creating rectangle around it for domain.
- 4) Extrude domain rectangle.

VII. RESULT AND ANALYSIS

AIM:

To analyze the designed wing section in Ansys



VIII. CONCLUSION

The design of the selected wings of narrow-bodied aircraft was done in a step-by-step method sticking to the basic rules. Calculations were performed with respect to data and formulae obtained from available design books. Some problems aroused during the process. However, they were solved by good teamwork. The conceptual design done in this project meets the initial requirements that were set by us... It also helped us to understand some basic things about the aircraft and its design. We saw how the airfoil of an aircraft plays an important role in the design process. All the other following parameters vary with weight. The design of wing from the selected airfoil was a very crucial step and was also interesting. Then followed by the estimation and analysis. Then the estimation of some critical performance



parameters to finalize the conceptual design process and selection of an appropriate powerplant. Finally, it ended with the three-view diagram and results. We would like to conclude saying that the experience that we got during the process will be helpful and the moments will always be remembered by us.

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