



Design and Analysis of Turbo Jet Engine

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ABSTRACT

This project aims to design a turbojet engine using Catia software. The design was based on the research conducted by industry experts and researchers throughout the history of jet engines. The design methods were carefully selected to simplify the engine design process. The objective of the project was to create a functional turbojet engine. Air travel has become more accessible in today's world, allowing people to travel to any part of the world in a short amount of time. However, the aviation industry was not as advanced in the past, using Rotary Piston IC engines that had limited travel speed and distance, high fuel consumption, and increased transport costs. The development of turbojet engines, which are Rotary-Reaction Turbine Engines, was a significant breakthrough in the aviation industry. Compared to Rotary piston engines, turbojet engines are more efficient, and other engines such as turbofan, turboprop, and turbo shaft engines were developed as improvements over the turbojet engine.

Keywords: Turbo jet engine, Modelling, Analysis, probabilistic technique, simulation.

1. Introduction

Jet engines are widely used in various applications, including aviation and energy production. The design and construction of a jet engine require knowledge from multiple fields, including thermodynamics, fluid mechanics, and mechanical engineering. To build a modern jet engine, experienced professionals from all these fields are necessary. A modern jet engine is an engineering marvel, with features such as fine tolerances in space, resilience to high temperatures and stress. Over the years, the jet engine has undergone significant improvements in performance, efficiency, and reliability. The most commonly known jet engines are the turbojet engine, turboprop engine, turbofan engine, turboshaft engine, and ramjet engine. The basic principles underlying these engines are the same, and they operate according to similar concepts as the internal combustion engine: suck, squeeze, bang, and blow. The first part focuses on the inlet, where air is sucked in. The second part involves compressing the air to a higher pressure. The third part is the combustion chamber, where the compressed air is mixed with fuel and ignited to create high-velocity exhaust gases. The fourth part focuses on the outlet of the engine, where the exhaust gases exit the engine.

The history of the turbofan engine should be included in the beginning of the thesis, which dates back to the Wright Brothers and their aircraft. The Wright Brothers designed, built, and flew "The Flyer" in Carolina, which marked the beginning of powered flight. The 12-hp reciprocating intermittent combustion engine gave life to The Flyer, and until the late 1930s, this type of engine was used in all manned aircraft. The history of aircraft gas engines started in January 1930 with Frank Whittle's development of the turbojet engine based on the Brayton cycle. In 1936, a new turbojet engine was developed by von Ohain in Germany, which was the first engine to fly. In modern times, the development of gas turbine engines is still ongoing. The early turbojets were used as propulsion systems for high-speed fighter and reconnaissance aircraft. The turbojet was more suitable for these applications than traditional propeller engines, but fuel economy, reliability, and endurance were not characteristics of the turbojet. The first developments were about pressure ratios. By the early 1950s, the turbojets achieved a 10:1 pressure ratio, and by the 2000s, it had reached 40:1. The U.S. Air Force requested an engine capable of long-range subsonic speed operation, leading to the development of more efficient engines from the turbojet. The TF39 was the first turbofan engine made by General Electric under the leadership of Gerhard Neumann in 1965 for the Lockheed C5A.

The basic principle used in jet engines can be traced back to 150 BC, where the principle was used in the Aeolipile, a simple construction that uses a radial steam turbine. The steam exits through a nozzle, creating a spinning motion of a ball, according to Newton's third law. In 1791, John Barber filed a patent utilizing the same thermodynamic cycle as a jet engine, and the interest continued throughout the 1800s. However, it wasn't until Sir Frank Whittle of the Royal Air Force in the 1930s made the first patent for the jet engine and showed the possibilities through reliable energy conversion. He conducted the first static test in 1937. Two years later, in 1939, a German physicist named Hans von Ohain made the first jet-powered flight and demonstrated the possibilities of jet engines. The idea came about to improve the propeller-driven aircraft of the time, where the main problem was the speed of the aircraft. The aircraft of the time were closing in on the speed of sound, and sometimes getting too close, which would result in shockwaves being created, causing the propeller to shatter.

2. Literature Review

These are references related to gas turbine engines and related technologies, including their history, design, modeling, and control:

1. L Jaw, J Mattingly - 2009: Provides an overview of gas turbine engines and their importance in aviation, including their efficiency and reliability.
2. JD Mattingly, KM Boyer, H von Ohain: A comprehensive textbook on gas turbine engines and rockets, covering the basic principles and advanced treatments of airbreathing propulsion.
3. C Rotaru, M Andres-Mihaila, PGMATEI: Discusses the modeling and simulation of combustion in a turbojet engine to find optimal characteristics of the burning process and combustion chamber design.
4. A Chelaru - 2013: Proposes a calculus model for an innovative Reaction Control System (RCS) that uses hybrid rocket engine technology, with several hybrid micro-thrusters controlled by a separate control system.
5. S Farokhi, John Wiley & Sons Inc., USA, 2009: A textbook on airbreathing propulsion that covers the basic principles and advanced topics in aircraft engine components and system integration, including new material on UAVs and design guidelines.
6. C Rotaru, I Sprințu-AIP Conference Proceedings, 2014: Explores the dynamic characteristics of the combined aircraft-engine system using the general theory of state variables for linear and nonlinear systems, with a focus on the longitudinal and lateral directional state variable models.
7. H Richter, Springer, 2012: Describes the operational performance requirements of commercial turbofan engines from a control systems perspective, including industry-standard methods and research-edge advances.

3. Methodology:

- All needed dimensions for components are extracted from turbo jet engine data and from standard data.
- 3D modeling of components is done using CATIA V5 and these individual parts are assembled/ integrated to entire the assembly.
- Stress analysis of turbo jet engine using analytical equations.
- The turbo jet engine analysis is simulated using ANSYS software and the results are observed.
- Comparison of analytical results with ANSYS results.

4. Design of Turbo jet engine:

Once you open the catia v5 you can see an interface. Now select start and create new part and now select any plane (xy,yz, zx),now a sketcher interface will appear for 2D sketching.

Select the line, spline commands and draw the profile of the turbo jet engine stator.

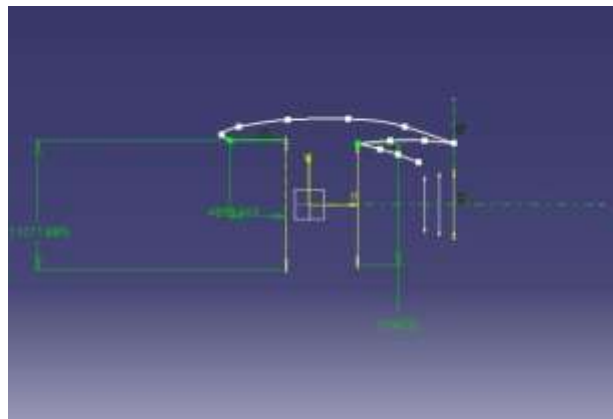


Fig. Stator casing in 3-D

Now exit from the sketcher work bench and by using sketch based features using of shaft command revolve the sketch then the material will be added and the 3Dmodel is created.

Now create the xy planes to sketch the curve profiles in sketcher work Bench .now exit from the sketcher work bench. Open the sketch based features and selects the pocket and removes the required material and one position in 3d model. Now select the sketch and draw a outline using the line, profile and spline command, then exit from the sketcher work bench and select the drawn profile and select shaft command and select the stator axis and revolve 360 d then the profile shape is created around the stator axis.

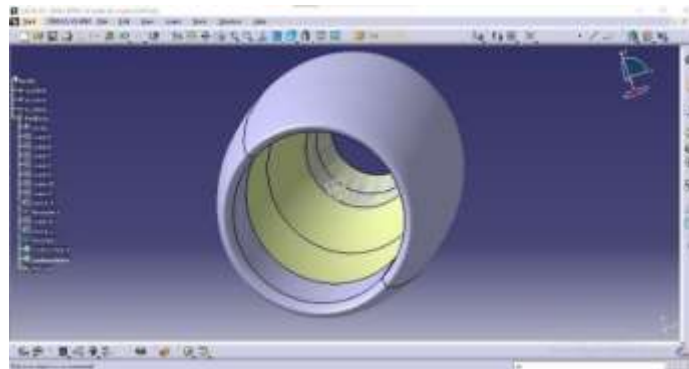
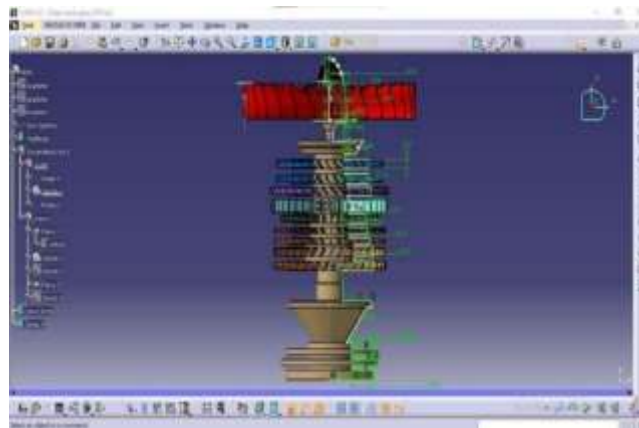


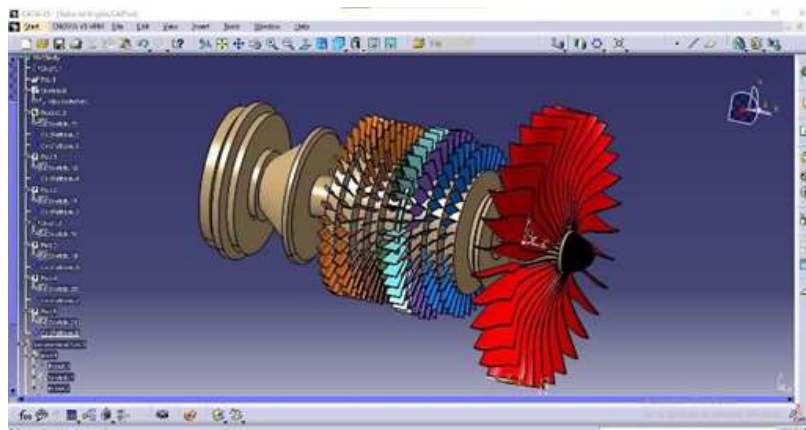
Fig. Turbo jet casing

Once you open the CatiaV5 you can see an interface. Now select start and create new part and now select any plane (xy, yz ,zx), now a sketcher interface will appear for 2D sketching. Select the line, spline, profile commands and draw the profile of the turbo jet engine rotor.Now exit from the sketcher work bench and select the drawn profile and open the sketch based features and select the shaft command and select the central axis. Now revolve 360 , then the material will be added and 3D model is created in Catia. Now create a plane to draw the blades profiles.



Select the xy plane to draw the curve of the blade after drawing curve exit from the sketcher work bench and create another plane (xz plane) and select the xz plane now draw the rectangular profile, after drawing exit from the sketch. Now by using rib command select that curve and rectangular profile, then the material is added and the aerospace shape 3D blade is created. Now select that single blade and open the transformation features then select the circular pattern then a multiple blades are created around the axis. Now by using the pocket command obtain the required aero space shaped by removing the material.

5. Actual project design:



6. Formation of a mesh:

You can use the Mesh component system to create and/or open geometry or mesh files. The Mesh component system contains a Mesh system header and two cells.

You can create a Mesh component system using any of these methods:

Double-click the Mesh system template in the Tool box.

Drag-and-drop the Mesh system template onto the Project Schematic.

Drag-and-drop a .meshdat or .cmb file from Windows Explorer onto the Project Schematic.

Choose File>Import or click the Import button from ANSYS Workbench and select a file of type .meshdat or .cmb

Object Name	Solid
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Material	Structural Steel
Stiffness Behavior	Flexible
Nonlinear Material Effects	Yes
Bounding Box	

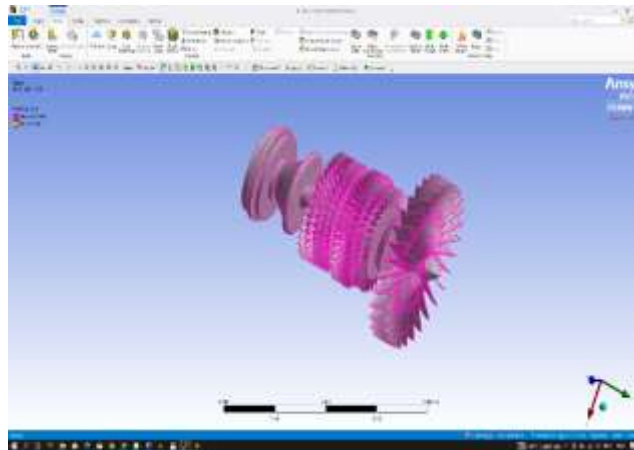


Fig. Meshing model

Steps required to perform analysis:

Step 1: Open ANSYS workbench. Now open Steady- State Thermal module.

Step 2: In Engineering Data Aluminum Alloy should be selected.

Step 3: Then the geometry should be imported which we have drawn in CATIA software and update project should be for model update.

Step 4: Meshing should be done with normal considerations.

Step 5: In the setup, Temperature loads and Heat flux are inserted.

Step 6: For the results insert Temperature, Total heat flux, Directional Heat flux

Step 7: Click on Solve for the results.

$$w_c = \dot{m}_3 * c_p * (T_3 - T_2)$$

Step 8: Now insert Static-Structural (SAMCEF), and connect with Steady State Thermal Creating Static Structural standalone and connecting it with Steady State thermal.

$$T_c = \beta_c * T_3 + (1 - \beta_c) * T_2$$

Step 9: Apply the Loads i.e. Axial, Radial, and Tangential. And fix the base.

Step 10: Now for results insert total deformation, Von-Mises Stress, Normal Stress, Shear Stress.

Step 11: Click on solve for results.

The structural analysis results are given below.

The below figure shows the Total Deformation of the Blade.

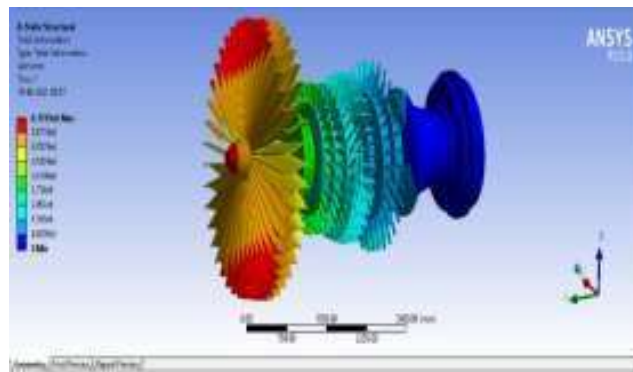


Fig. Total deformation

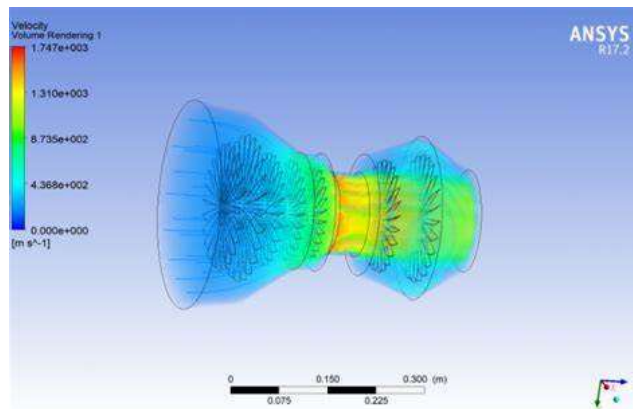


Fig. Velocity-volume rendering

Calculations:

Turbojet engine thrust equation:

$$\text{Thrust} = \dot{m}_e v_e - \dot{m}_0 v_0$$

Inlet: $T_2 = T_0$

$$P_2 = \eta_1 * P_0$$

Pressure recovery in the diffuser is calculated using the Nigeria Air force standard

$$\eta_1 = 1.0 \text{ if } M \leq 1$$

$$\eta_1 = 1.0 - 0.075 * [(M-1)1.35] \text{ if } M > 1$$

Compressor: Where, $\gamma_a = 1.4$ and $\gamma_g = 1.33$

Work done by the compressor to increase the pressure and temperature of the air can be calculated from the expression.

$$T_2 = T_1 \left[1 + \frac{\left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1}{\eta_{b, comp}} \right]$$

Continuity equation:

$$w_c = \dot{m}_3 * c_p * (T_3 - T_2)$$

$$T_c = \beta_c * T_3 + (1 - \beta_c) * T_2$$

Energy equation:

$$\frac{d}{dt}(w_3) = \dot{m}_3 - \dot{m}_3 - Bld$$

$$\frac{d}{dt}(T_3) = \frac{1}{w_3 c_v} \left\{ \left[\dot{m}_3 * (C_p T_3 - C_v T_3) \right] - \left[(\dot{m}_3 + Bld) * R * T_3 \right] \right\}$$

Ideal Gas equation:

$$P_3 = \frac{w_3 * R * T_3}{V_3}$$

Pressure drop in the combustor:

$$\dot{m}_b = \dot{m}_3 = \sqrt{\frac{P_3 - P_4}{R_b}}$$

Combustor volume dynamics:

Continuity equation:

$$\frac{d}{dt}(w_4) = \dot{m}_b - \dot{m}_f - \dot{m}_4$$

Energy balance:

$$\frac{d}{dt}(T_4) = \frac{1}{w_4 c_{vb}} \left\{ \left[\dot{m}_3 * (C_{pb} T_b - C_{vb} T_4) \right] - \left[\dot{m}_f * (HVF * \eta_b - C_{vb} T_4) \right] \left[\dot{m}_4 * R * T_4 \right] \right\}$$

Ideal Gas equation:

$$P_4 = \frac{w_4 * R * T_4}{V_4}$$

Turbine:

$$T_5 = T_4 * \left[1 - \eta_{t, com} * \left[1 - \frac{1}{\left(\frac{P_3}{P_2} \right)^{\frac{\gamma}{\gamma}} \right]} \right]$$

Nozzle:

Mass flow rate in the nozzle,

$$\dot{m}_s = \frac{P_s}{\sqrt{RT_s}} A_{nz} \left[\frac{P_e}{P_s} \right]^{\frac{1}{\gamma_b}} \sqrt{\frac{2\gamma_b}{\gamma_b - 1} \left[1 - \left(\frac{P_e}{P_s} \right)^{\frac{\gamma_b - 1}{\gamma_b}} \right]}$$

Mass flow rate in the nozzle,

$$\dot{m}_s = \frac{P_s}{\sqrt{RT_s}} A_{nz} \sqrt{\gamma_b \left(\frac{\gamma_b}{\gamma_b + 1} \right)^{\frac{\gamma_b}{\gamma_b - 1}}}$$

Thrust produced,

$$Thrust = c_v \dot{m}_s \sqrt{2c_p T_s \left[1 - \left(\frac{P_e}{P_s} \right)^{\frac{\gamma_b - 1}{\gamma_b}} \right]} + A_{nz} [P_{cr} - P_e]$$

Jet velocity at the exit of the nozzle,

$$V_e = \sqrt{\frac{2\gamma_b}{\gamma_b - 1} RT_s \left[1 - \left(\frac{P_e}{P_s} \right)^{\frac{\gamma_b - 1}{\gamma_b}} \right]}$$

7. Conclusion:

In this work turbo-jet engine is designed by referring some of the commercial engines which are currently using nowadays. Design is done by using Catia V5 and the analysis is done by using ANSYS R15. For analysis we given structural steel material for the turbo jet machine. The structural modal analysis and the structural static analysis is conducted for this design. The frequencies which are obtained from the modal analysis are shown in table 1. In static analysis we got values of deformation, stresses, strains, strain energy. Here the maximum equivalent stress produced is 3.6178e12 pa, the maximum equivalent strain produced here is 18.36 and the maximum strain energy produced her is 1.682e8 Joules. In practice nickel and titanium alloys are used here we tried structural steel instead of those to check the how it will behave to the maximum temperature and pressure. As we saw in the results steel will react more quickly and it is affected more than the other alloys. On this topic there are very less literature available so we conducted this work to check the modal analysis results and static behaviour of the engine which done by using steel material, people who are working or doing research on turbo jet engine can go through this work. Here ANSYS gives relatively good results.

The following conclusions are drawn from the structural and thermal analysis of jet turbine engine subjected to structural and thermal boundary conditions as specified.

The total heat flux distribution between different materials is compared and it clearly shows the heat treated alloy shows better heat distribution characteristics than aluminum alloy and titanium alloy.

The total deformations for different materials is compared which clearly showed that heat treated alloy is able to withstand heavy loads resulting in lower deflections.

The Equivalent Von-Moses Stresses induced in different materials is compared and the trend clearly indicated that lower stresses are induced in heat treated alloys which are good for implementation.

The normal stress distribution comparison between different materials is shown and it clearly showed the heat treated alloys are better than other materials.

8. Future scope:

Detailed economic study of configurations should be worked out to estimate the specific capital cost as well as plant capital cost which may help to choose configuration on the basis of better efficiency and specific work as well as on the cost.

Detailed feasibility study for each configuration considering all practical aspects.

Optimization of individual elements of different configurations can be attempted.

Better mathematical models for every component may be developed for real situation.

Better cooling model may be developed.

Other type of blade cooling technique can be investigated.

More sophisticated cycle configurations leading to higher plant efficiency may be considered and studied.

Level of NO_x, SO_x in the exhaust gas can be investigated.

The effect inlet air-cooling through fogging and refrigeration system may be studied.

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