Department of Mechanical Engineering
Erich Gemballa
Gavin Geiger
Brendan Savelli
Abdullah Abdulghafour
Hamad Almutairi
ME-476C - 02

To: David Willy: Professor, Client

CC: Amy Swartz: Teaching Assistant

From: Team 1B Thermodynamics Demo Unit

Date: March 16, 2018

Re: Analysis Memo

I. *Introduction*

The purpose of this memo is to establish what specifics the team will be researching for their individual analytical reports. Through approval of the client, the team has decided to breakdown the project into three sections: turbine blade design, compressor blade design, and implementation of heat exchanger. Each team member will address their technical roles along with their methodology and approach to their analytical report.

II. Roles and Responses

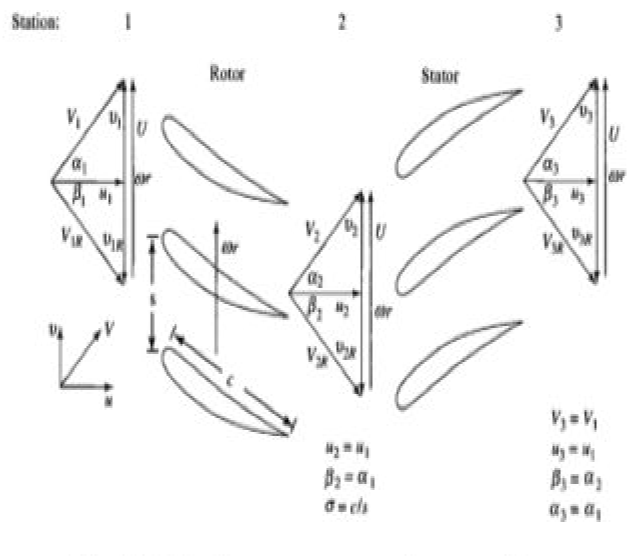
1. Erich Gemballa: Axial Turbine Blade Design
2. The purpose of designing an axial turbine blade is to maximize rotation of the turbine to capture most of the kinetic energy and transfer it into usable shaft work.
3. Utilizing Turbomachinery textbooks to optimize the outward velocity from the tips of the turbine blade.
4. Assumptions going into the model:
    a. Adiabatic boundary conditions
    b. Uniform properties at inlet and outlet
    c. Inviscid flow
    d. Air as working fluid
5. The results of the analysis should produce an operating turbine blade design that follow the principles set but turbomachinery design. Designing blades that optimize the lift to drag ratio will determine the angle of attack necessary to produce such results.

6. The results of an axial turbine blade will be one of two designs created for the project. By having two members construct a turbine blade it is possible to maximize the efficiency of the blade by creating two unique designs.

1-Hamad Almutairi: Axial compressor Blade Design

2-The Purpose of the axial compressor blade design is to design compressor blade with an adequate stall margin that could compress the fluid with minimum possible pressure loss

3-The Design and analysis of compressor starts with solving velocity triangle which gives different parameters required for calculation of required design parameters



By law of steady one-dimensional flow, we have

$$\rho_l A_1 = \rho_2 A_2 = \rho_3 A_3$$

Repeating-row constraint: Since β2 = α1, then

$$V_{2R} = V_1 = \omega r -- V_2$$

Also, since $\beta_3 = \alpha_2$, then $V_{3R} = V_2$ and $V_3 = V_1$; thus, the stage exit conditions are indeed identical to those at the stage entrance.

Diffusion factor then be calculated as

$$D = 1- +$$

Degree of Reaction

For repeating stage and repeating row degree of reactions must be 0.5

Moreover, An important geometrical cascade parameter is the solidity σ, which is defined as the ratio of chord-to spacing. A high solidity blading is capable of a higher net turning angle than a low solidity blading. Consequently, a high solidity cascade is less susceptible to stall. the modern compressor and fan design utilizes a high solidity blading (σt ≅ 1).

Analysis

For blade design, we need to estimate the following angles:

➢ Incidence angle

➢ Deviation Angle

The incidence angle is estimated at the location of minimum loss, from cascade data that is known as $i_{optimum}$.

Typically, optimum incidence angle is ~−5◦ to +5

The deviation angle is first estimated from the simple Carter's rule:

$$\delta* \approx \Delta\beta /4 \sqrt{\sigma}$$

which is based on the net flow turning and the coefficient "m" in Carter's formula which is taken to be 0.25. Also, based on the inlet and exit flow angles, we may use the (NACA 65-series) cascade correlation data of Mellor to identify a suitable 65-series cascade geometry that gives an adequate stall margin. Note that the front and aft stages of a multistage compressor or fan face different stall challenges; for example, the front stages are more susceptible to positive stall and the aft stages are more susceptible to negative stall. Therefore, we may choose the design point to be farther away from the two stall boundaries for front and aft stages.

4-Assumption

1. Repeating Rows
2. Repeating Stages
3. Two-Dimensional flow (i.e. no variation of velocity vector perpendicular to the page)
4. Constant mean Radius
5. Polytropic efficiency representing stage losses
6. Flow is steady
7. Flow is inviscid

5-Expected Results

➢ Optimum Incidence Angle
➢ Appropriate Cascade Geometry at an adequate stall margin.

6-The results obtained can be first validated with pre existing literature then the optimized values are used to select the most appropriate design

1. Gavin Geiger - Axial compressor blade design
2. Designing the compressor blades need to make sure that the flow leaving the compressors has a much higher pressure than the flow entering the compressor. This will be done through calculations with angle of attack and drag/lift.
3. The equations will be found through researching textbooks such as turbomachinery and aerodynamics. The end goal of the compressor is simple, slow down and compress fluid moving through the compressor blades.
4. Assumptions going into the model:
    a. Adiabatic boundary conditions
    b. Uniform properties at inlet and outlet
    c. Inviscid flow
    d. Air as working fluid
    e. Incompressible flow
5. Fluid that enters the compressor blades will be expected to be compressed and slowed down as designed. This will be accomplished through the blades being designed such that the fluid is spinning long distances around the shaft in order to properly be compressed.
6. Once the fluid is properly compressed, the fluid will be heated up in the combustion chamber and then run through the turbine. The end result is to have the turbine shaft spin in order to generate power that can be displayed in order to teach students about the Brayton cycle.

1.Abdullah Abdulghafour - Axial turbine blade design

2.Designing the turbine blade requires a high blade rotation to generate power.

3.The professor recommended the principles of turbomachinery, Korpela textbook. So, this reference will be helped in the calculation of velocity triangle.

4. Assumptions going into the model:

a. Adiabatic boundary conditions
b. Uniform properties at inlet and outlet
c. Inviscid flow
d. Air as working fluid

5.The maximum rotation of blade will generate a power.

6.After the air (fluid) ran through the compressor and heat exchanger it will run through the turbine. The air will rotate the blades then the power will be created. So, that will teach the thermodynamics II students about Brayton Cycle.

1. student's name and technical role

Brendan Savelli- Combustion chamber

2.

How much energy can be safely added to combustion chamber without breaking the turbine blades?

How much energy do we need to add to the combustion chamber to power the compressor, generate electricity and thrust?

The goal is to safely add as much heat to the combustion chamber as possible without heating the ABS beyond its glass transition temperature of 105°C. Since this will not produce enough expansion through the turbine to power the compressor, produce electricity and thrust, external bottled compressed air will be used to increase the change in pressure between the P_0 *and* P_3 iso bars **(figure 1)**. Safely maximizing both the Δ P and ΔT will produce the most power but may not be necessary for the purposes of this model.

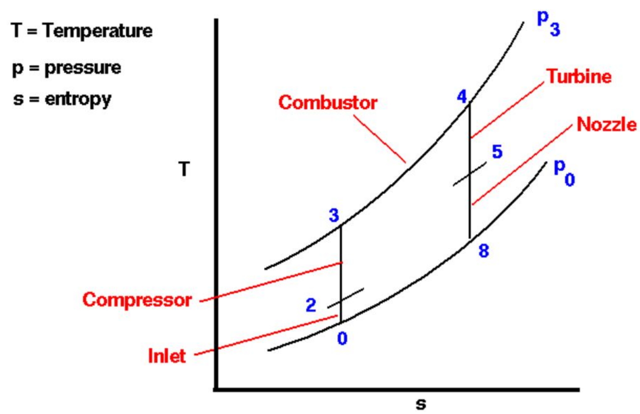


Figure 1: T-S diagram

1. What model/methodology will you be using?

The maximum energy added to the combustion chamber through a combination of heating coils,bottled compressed air and the turbofan compressor will be dictated by the strength of the turbine blades. The blades will be tested by heating the combustion chamber to 104°C and gradually increasing the flow of compressed air until the first blade fails. The working pressure will be reduced to achieve FS= $\frac{p_{failar}}{p_{working}}$ >1.5 which is standard for the aerospace industry.

The minimum energy input will be dictated by a combination of the power needed to light a bulb, Power needed to run the compressor and produce a realistic brayton cycle for an in class demonstration..

2. 4. What assumptions and inputs will go into the model?

We are assuming the glass transition temperature of the particular ABS we are using is actually 105°C. We are also assuming that we will be able to manufacture models for testing and actual use that will have similar strength characteristics.

3. 5. What results do you expect from your analysis?

Analysis will help determine the ideal amount of energy added in the combustion chamber to produce a safe and realistic model of a turbofan brayton cycle.

4. 6. How will these results inform your design?

These results will help us determine the upper and lower limits of energy input for the model. It may also impact the design of the turbine blades if we determine a particular turbine blade design it isn't strong enough to withstand the minimum required pressure.

III. Conclusion

This memo has outlined analytic methods that will be used to evaluate and design a TurboFan engine that will be used for in class brayton cycle deminstations. Technical roles have been assigned to team members to determine the relevant analysis techniques that can be used to optimize individual components of the model. . Assumptions that may impact analysis have been identified and now can be vetted for accuracy if the results of our analysis are unexpected. The design implications of analysis have been identified and can be used to improve and evaluate individual components by a rigorous process.   The research conducted has focused the teams design efforts and will be crucial for successful completion of the project.