In The Name Of God

Sharif University of Technology – Department of Aerospace Engineering

Fundamentals of Air-Breathing Propulsion

Instructor: Kaveh Ghorbanian (ghorbanian@sharif.edu)

Course Project

1) Scope of Project

The goal of this project is the preliminary design of a single-spool turboshaft engine with an output shaft power of 1 MW ± 5%.

The main engine requirements at SLS are listed in the below table:

Engine Data Requirements at SLS

Maximum Power (required at takeoff and excluding the offtake power):	P_{max} = 1000 kW
Offtake Power (for accessories & avionics):	$P_{offtake}$ = 50 kW
Mass Flow Offtake (at the compressor exit for any operating condition):	5% of $\dot{m}_{\text{total}}$
Turbine material is a Nickel-based superalloy with no need to cooling:	$T_{critical} = T_{melting} - 35K$ $TIT = T_{critical} - 50K$
Maximum Allowable Turbine Pressure Ratio (per each turbine stage):	$TPR_{max} = 3.5$
Fuel Type is JP4	
Efficiencies (only for real cycle analysis):	$\eta_{AC} = 0.8$, $\eta_{CT} = 0.85$, $\eta_{PT} = 0.89$ $\eta_{combustor} = 0.97$ $\eta_{nozzle} = 0.99$ $\eta_{inlet} = 0.98$

PART – A: Cycle Analysis

For both the **ideal** and **real** cycles, determine the followings and make always a **comparison**:

1) Plot the variation of SFC with specific power P/ṁ (for variable CPR and TIT) at SLS and M=0.
2) Identify the $CPR_{optimum}$ and the corresponding ṁ.
3) Redo the above for $M_0 = [0.05 \div 0.5]$ and $H = [0 \div 7{,}000\ \text{m}]$ (this is your off-design analysis).
4) Identify "**your best**" specific power which satisfies the design requirement for the above "Engine Data". Explain it why you have selected this value.
5) Tabulate CPR, TIT, P/ṁ, $\dot{m}_{air}$, $\dot{m}_{fuel}$, FAR , η_{thermal}, $\eta_{\text{propulsive}}$, η_{overall}, at SLS (this is your design point).
6) Tabulate CPR, TIT, P/ṁ, $\dot{m}_{air}$, $\dot{m}_{fuel}$, FAR , η_{thermal}, $\eta_{\text{propulsive}}$, η_{overall}, at SLS (this is your cruise condition).
7) Draw the H-S diagrams for both cycles (ideal & real) at your design point and cruise condition.
8) Tabulate the total enthalpy drop and the preliminary estimated number of stages for the air compressor (AC), the compressor-turbine (CT), and the power-turbine (PT).

Note: As mentioned, you have to perform all the above tasks for both the ideal cycle and the real cycle.

PART – B: Air Compressor (AC) Design

In this part, the preliminary design of an axial compressor is of interest.

The main requirements for the axial compressor at SLS are listed in the below table:

Compressor Data Requirements at SLS

Axial compressor rotational speed:	N = 50,000 RPM
Compressor blade tip speed:	350 – 450 m/s
Compressor axial velocity:	150 – 200 m/s

1) Design your best constant-tip axial compressor at SLS and for the ideal engine cycle from Part-A.
   - tabulate your assumptions.
   - tabulate the number of stages and number of blades in each row.
   - tabulate and plot the velocities and angles at the hub, mean, and tip of each row.
   - tabulate and plot the Mach numbers at the hub, mean, and tip of each row.
   - tabulate and plot the loading coefficient, flow coefficient, and degree of reaction at the hub, mean, and tip of each row.
   - tabulate and plot De-Haller number and diffusion factor at the hub, mean, and tip of each row.
   - tabulate and plot the total-to-static and total-to-total efficiencies.
2) Repeat task 1) at 70%, 80%, and 90% RPM.
3) Repeat the above tasks 1) and 2) by considering the real engine cycle from Part-A.
   - tabulate your equation for losses along with the corresponding references.
4) Provide a rough estimate on the size and weight of the following components of the compressor for both the ideal cycle and the real cycle:
   - Shaft
   - Disks & Blades
   - Casing

PART – C: Compressor Turbine (CT) Design

In this part, the preliminary design of an axial compressor turbine (CT) is of interest.

1) Design your best constant-mean axial turbine at SLS and for the ideal engine cycle from Part-A.
   - tabulate your assumptions.
   - tabulate the number of stages and number of blades in each row.
   - tabulate and plot the velocities and angles at the hub, mean, and tip of each row.
   - tabulate and plot the Mach numbers at the hub, mean, and tip of each row.
   - tabulate and plot the loading coefficient, flow coefficient, and degree of reaction at the hub, mean, and tip of each row.
   - tabulate and plot the total-to-static and total-to-total efficiencies.
2) Repeat task 1) at 70%, 80%, and 90% RPM.
3) Repeat the above tasks 1) and 2) by considering the real engine cycle from Part-A.
   - tabulate your equation for losses along with the corresponding references.
4) Compare the $\dot{m}_{air}$, $\dot{m}_{corrected}$, and the power consumption for the AC at the design point and off-design points for both the ideal cycle and the real cycle and compare it with the corresponding values by the CT.

PART – D: Power Turbine (PT) Design

In this part, the preliminary design of an axial compressor turbine (PT) is of interest.

5) Design your best constant-mean axial turbine at SLS and for the ideal engine cycle from Part-A.
   - tabulate your assumptions.
   - tabulate the number of stages and number of blades in each row.
   - tabulate and plot the velocities and angles at the hub, mean, and tip of each row.
   - tabulate and plot the Mach numbers at the hub, mean, and tip of each row.
   - tabulate and plot the loading coefficient, flow coefficient, and degree of reaction at the hub, mean, and tip of each row.
   - tabulate and plot the total-to-static and total-to-total efficiencies.
6) Repeat task 1) at 70%, 80%, and 90% RPM.
7) Repeat the above tasks 1) and 2) by considering the real engine cycle from Part-A.
   - tabulate your equation for losses along with the corresponding references.

2) Team Organization

Students work in teams of 4 to perform the project and each team must submit a team charter (including the role assignment of each student) before 14/08/1405. Each team should have:

- a "**cycle analysis**" leader,
- an "**air compressor (AC)**" leader,
- a "**turbine (CT & PT)**" leader, and
- a "**team**" leader, responsible for component sizing and matching, trade-study/optimization, analysis, documentation, and presentation.

3) Grading Scheme & Assessment

While the project is team-based, each student will be assessed both individually and as a team member. The final project grade of each student will be based in two parts as follows:

Weight	Description
80%	Student's technical responsibility as outlined in "Team Charter"
20%	Team overall assessment

Hence, contributions may adjust an individual's performance grade by up to ±80%.

4) Deliverables & Due Dates

Deliverables are due on:

Topic	Description	Due Date
Team Charter	Team charter of 4 (including the role assignment of each student)	14/08/1405
Report No. 1	PART – A: Cycle Analysis	06/09/1405
Report No. 2	PART – B: Air Compressor (AC) Design	20/09/1405
Report No. 3	PART – C: Compressor Turbine (CT) Design	27/09/1405
Report No. 4	PART – D: Power Turbine (PT) Design	04/10/1405
Presentation	Joint Report and 10 minutes presentation with 5 minutes Q&A	14/10/1405

There will be NO credit for late reports and there will be NO time extension.

NOTE:

A report should be prepared for each part of the project with the following sections:

- Introduction
- Method of Approach (i.e., equations, derivations, assumptions, etc.)
- Results (data, tables, and figures)
- Conclusion (discussion, suggestions, and lessons learned
- References
- Source Code (in MATLAB format)

The report should be turned in as a hard copy as well as on a CD (along with the code).

Students must form teams of four. The designated team leader should email this table to me by no later than 14/08/1405 and ensuring that the email is also copied (CC'd) to the other team members.

If the registered students fail to submit this table by 14/08/1405, the instructor will randomly assign their names to a table and notify them accordingly.

Name of the Team		
Name of Student	**Student ID Number**	**Role Assignment**
1)		PART – A: Cycle Analysis
2)		PART – B: Air Compressor (AC) Design
3)		PART – C: Compressor Turbine (CT) Design
4)		PART – D: Power Turbine (PT) Design