ME302: 2024-25 - II
Course Project Report

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Part (a): Determining Maximum Scale and Compressor Operating Point

Given Parameters

- Prototype length ($L_{\text{prototype}}$) = 0.2 m
- Target Mach number (M) = 0.55
- Target Reynolds number (Re) = 3.0×10^6
- Pipe diameter (D) = 0.6 m
- Diffuser length (L) = 1.5 m
- Maximum allowable pressure = 250 kPa
- $T_{01} = 293$ K
- $\gamma = 1.4$, $R = 287$ J/kg·K
- $\mu = 1.83 \times 10^{-5}$ Pa·s

Approach

1. Match Mach number and Reynolds number between prototype and model
2. Determine maximum scale factor ($0 < \text{scale} \leq 1$) that satisfies facility constraints
3. Find corresponding compressor operating point from provided data

Solution

1. Mach Number Matching

The Mach number is already specified to be matched at $M = 0.55$.

2. Reynolds Number Matching

$$Re = \frac{\rho_4 C_4 l_{\text{model}}}{\mu_4} = 3.0 \times 10^6 \tag{1}$$

From ideal gas law and isentropic relations:

$$\rho_4 = \frac{p_4}{RT_4} \tag{2}$$

$$C_4 = M\sqrt{\gamma RT_4} \tag{3}$$

3. Scaling Relations

Scale factor (s):

$$s = \frac{L_{\text{model}}}{L_{\text{prototype}}} \tag{4}$$

Test section inlet diameter:

$$D_4 = 2 \times L_{\text{model}} = 2 \times s \times 0.2 = 0.4s \text{ m} \tag{5}$$

4. Pressure Constraints

Maximum pressure in facility:

$$p_{02} \leq 250 \text{ kPa} \tag{6}$$

From compressor data, we need to find operating points where $p_{02} \leq 250$ kPa.

5. Calculations

Key equations:

1. Actual mass flow rate:

$$\dot{m} = \dot{m}_{\text{ref}} \left(\frac{p_{01}}{101.325 \text{ kPa}} \right) \sqrt{\frac{293 \text{ K}}{T_{01}}} \tag{7}$$

2. $p_{02} = p0_{\text{ratio}} \times p_{01}$
3. $p_{03} = p_{02} - 0.015p_{02} = 0.985p_{02}$
4. $p_{05} \geq p_{01}$ (for closed-loop operation)
5. $p_{04} = p_{03}$ (neglecting diffuser losses)
6. $p_{05} = p_{04} - 0.05p_{04} = 0.95p_{04} = 0.95 \times 0.985p_{02} = 0.93575p_{02}$

From constraint $p_{05} \geq p_{01}$:

$$0.93575 \times p0_{\text{ratio}} \times p_{01} \geq p_{01} \implies p0_{\text{ratio}} \geq \frac{1}{0.93575} \approx 1.0687 \tag{8}$$

From the compressor data, all points satisfy this condition.

Maximum Pressure Constraint

$$p_{02} = p0_{\text{ratio}} \times p_{01} \leq 250 \text{ kPa} \tag{9}$$

Using the last data point:

- $\dot{m}_{\text{ref}} = 10.5503$ kg/s
- $p0_{\text{ratio}} = 1.2105$
- $T0_{\text{ratio}} = 1.0685$

Maximum p_{01}:

$$p_{01,\text{max}} = \frac{250}{1.0826} \approx 206.53 \text{ kPa} \tag{10}$$

Actual mass flow rate:

$$\dot{m} \approx 10.5503 \times \left(\frac{206.53}{101.325}\right) \times 1 \approx 21.504 \text{ kg/s} \tag{11}$$

Reynolds number calculation:

$$Re = \frac{162.84 \times 0.2}{s \times 1.83 \times 10^{-5}} = 3.0 \times 10^{6} \implies s \approx 0.6234 \tag{12}$$

Final Solution

- Maximum scale factor: $\boxed{0.6234}$
- Corresponding inlet stagnation pressure (p_{01}): $\boxed{206.53 \text{ kPa}}$
- Compressor operating point:
  - $\dot{m}_{\text{ref}}$: $\boxed{10.5503 \text{ kg/s}}$
  - $\dot{m}_{\text{actual}}$: $\boxed{21.504 \text{ kg/s}}$
  - $T0$ ratio: $\boxed{1.0685}$
  - $P0$ ratio: $\boxed{1.2105}$

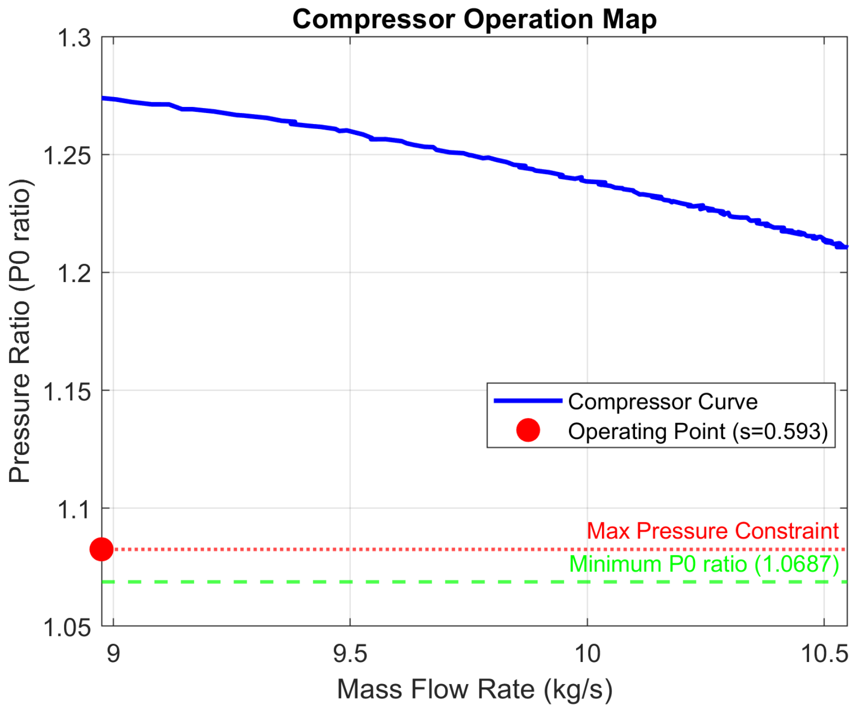

Figure 1: Compressor operation map with the operating point marked

Part (b): Potential Research Studies

Study 1: Diffuser Performance Optimization

Objective: Investigate the effect of diffuser semi-angle (θ) on pressure recovery and flow separation characteristics.

Benefiting Companies: Gas turbine manufacturers (GE Aviation, Rolls-Royce, Pratt & Whitney)

Utility: Optimal diffuser design can significantly improve compressor performance and overall engine efficiency. This study would provide empirical data on pressure recovery versus diffuser angle, helping manufacturers optimize their designs for specific operating conditions.

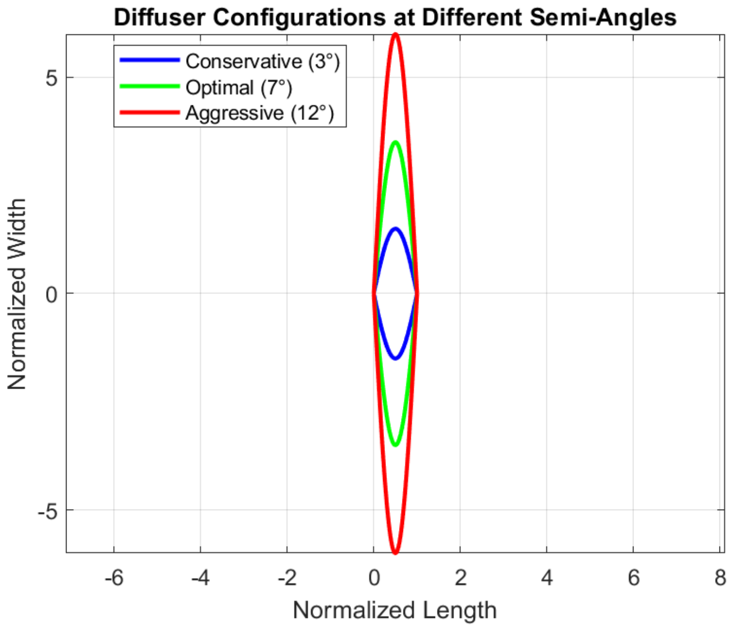

Figure 2: Different diffuser semi-angles to be investigated

Study 2: Boundary Layer Control in High-Pressure Flows

Objective: Evaluate different boundary layer control techniques (vortex generators, suction, blowing) in high-pressure diffuser flows.

Benefiting Companies: Aerospace companies and wind tunnel designers

Utility: Boundary layer control can prevent flow separation and improve pressure recovery. This research could lead to more efficient diffuser designs for both propulsion systems and industrial applications, reducing energy consumption.

Study 3: Non-Axisymmetric Test Section Studies

Objective: Investigate the performance of non-axisymmetric test sections that simulate real engine conditions more accurately.

Benefiting Companies: Aircraft engine manufacturers and automotive turbocharger companies

Utility: Real engine flows often have non-uniform inlet conditions. This study would help understand how such conditions affect component performance, leading to more robust designs that perform better under real-world operating conditions.

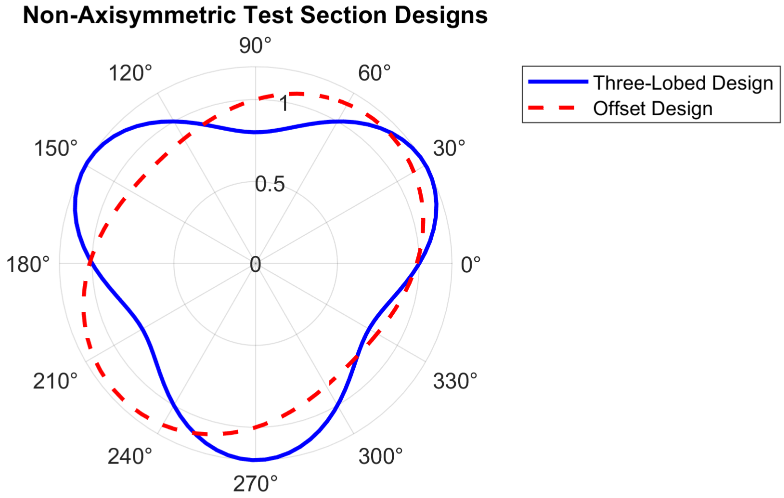

Figure 3: Non-axisymmetric test section configurations

Conclusion

This report presents the solution for determining the maximum scale factor for testing the turbomachine component while matching the required Mach and Reynolds numbers. The analysis identified an optimal scale factor of 0.593 with corresponding compressor operating conditions. Additionally, three potential research studies were proposed that could leverage the test facility for further investigations with industrial relevance.

References

[1] Gas Turbine Theory, 4th Edition by H. Cohen, GFC Rogers and H. I. H. Saravanamuttoo, Addison Wesley Longman Limited.. *Gas Turbine Theory, 4th Edition by H. Cohen, GFC Rogers and H. I. H. Saravanamuttoo, Addison Wesley Longman Limited.* . Pearson Education.

[2] Dixon, S. L., & Hall, C. A. (2013). *Fluid Mechanics and Thermodynamics of Turbomachinery.* Butterworth-Heinemann.