LMECA2550 Aircraft Propulsion Systems

Homework 2: Turbojet cycle analysis

Hand-out: Nov 24, 2025
Hand-in: Dec 15, 2025 at 23:59

Guidelines

Evaluation: The evaluation will consist in a written report which must present and analyse your results (a course summary is not needed). Emphasis will be placed on the clarity and the readability of your results, particularly the quality of the plots. Ensure that your plots are vectorized, feature a grid, proper labels and units, and relevant x and y axis limits.

Individual work: The homework is to be carried out alone.

Submission: Submit your **python code** and the **report** file (PDF) on the Moodle website. Name your files using the nomenclature : *"FIRSTNAME_HW2REPORT.pdf"* and *"FIRSTNAME_CODENAME.py"*. If you submit multiple codes, compress them in a single `.zip` archive.

Questions: Questions can be asked via the dedicated forum on Moodle.

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1 Turbojet optimum compressor ratio

Derive the expressions of the optimum pressure and temperature ratios $\pi_{c,(F/\dot{m})_{\max}}$ and $\tau_{c,(F/\dot{m})_{\max}}$ across the compressor of an ideal turbojet without after burner. These ratios are defined as those that maximize the engine specific thrust. Compare them to the expression of the optimum compression ratio for the standard Brayton cycle, what do you notice ?

2 Hybrid cycle after-burning turbojet

We study the behavior of the J-58 engine, (used in the SR-71 Blackbird). This is an afterburning turbojet which achieves a Combined Cycle conversion. At high Mach numbers, the engine can be converted into a ramjet : the compressor, burner and turbine are bypassed. The air flow goes directly to the afterburner.

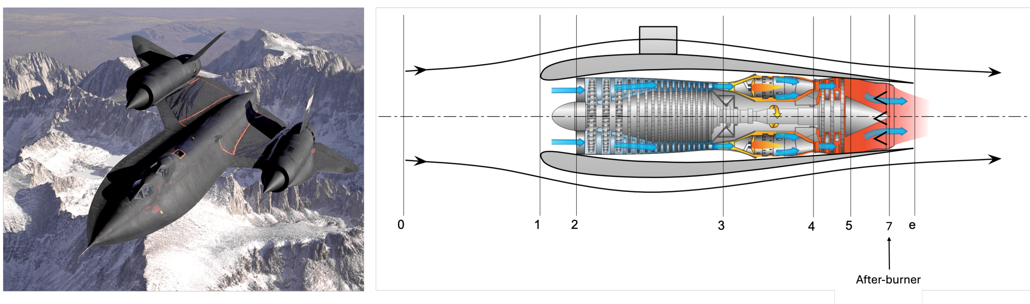

Figure 1: Lockheed-Martin SR-71 *Blackbird*

1. Carry out the cycle analysis for the after-burning turbojet to find the expression of its specific thrust. Note that, compared to the turbojet, you will now have to add the parameter $\tau_{\lambda,AB} = \frac{T_{t7}}{T_0}$ to enforce the maximum stagnation temperature in the after-burner. Also, losses are introduced in the parametric study, in the form of polytropic efficiencies e_c and e_t

2. Use your analysis from 2.1) to obtain the expression of the specific thrust when the engine works as a ramjet. (Hint : What is happening to τ_c, τ_t, τ_b, π_c, π_t, π_b ?)

3. Use these two expressions to deduce the condition on the Mach number at which one should transition from the after-burning turbojet to the ramjet mode. It is a somewhat simple function $M_{0,T}(\tau_c, \tau_t, \dots)$. Apply it to the flight conditions and engine parameters given below (Table. 1) to find the transition Mach number $M_{0,T}$.

4. Verify your formula : Apply your answers to questions 1 and 2 to Mach numbers M=[2, ..., $M_{0,T}(\tau_c, \tau_t, \dots)$ (your numerical answer to 2.3), ... 4]. Produce a plot of the specific thrust of each engine modes and comment your answer.

5. Can you give an interpretation of what happens to the cycles ? Plot the (T-s) diagrams and comment on them.

6. What happens to the thrust specific fuel consumption ?

Parameter	**Value**	**Units**
Altitude, z	20000	m
Pressure, p_0	5475	Pa
Temperature, T_0	216	K
Density, ρ_0	0.088	kg/m^3
Specific heat ratio, γ	1.4	
Flight Mach number, M_0	...	

Parameter	**Value**	**Units**
Compression ratio, π_c	20	
Turbine inlet temperature, T_{t4}	1400	K
Afterburner temperature, T_{t7}	2300	K
Polytropic efficiencies, e_c e_t	0.9	
Fuel lower heating value, LHV	43.19×10^6	J/kg

Table 1: SR-71 flight conditions and engine parameters

3 Off-design analysis

The transition Mach number obtained in 2.3) assumes that the turbojet operates at its on-design point. In reality, the engine is designed for a lower Mach number. Thus, operating at any other Mach number places the turbojet in an off-design condition.

Considering that the engine is designed to work at a given θ_{0R} :

1. Plot τ_c and τ_λ as a function of M_0 and comment.

2. Plot the associated specific thrust as a function of M_0 and compare it to the on-design case

3. Find the new transition Mach number. Is this new value tolerable? Plot the (T-s) diagrams for $M_0 = [2, \dots, M_{0,T}(\tau_c, \tau_t, \dots), \dots, 4]$ and use them to justify your answer. If the diagrams reveal problematic regions, suggest appropriate limits.

Parameter	**Value**
Design inlet total temperature ratio, θ_{0R}	1.3