AAE 538: Air-Breathing Propulsion

Lecture 10: Analysis of Ideal Engine Cycles (continued)

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PURDUE AERONAUTICS & ASTRONAUTICS

PURDUE PROPULSION

The Maximum Thrust Turbojet

- We can represent the turbine inlet temperature by a group of temperature ratios

$$\frac{T_{o,4}}{T_0} = \tau_r \tau_c \tau_b$$

We will define this parameter as:

Evidently, the minimum possible turbine inlet temperature is realized when no combustion takes place

Consequently, for a given, maximum allowable T.I.T., τ_b is limited by ______________________ ____. We just discussed this at length in accordance with the SFC vs M_0 and F/m vs. M_0 plots – the flight conditions and pressure ratio are very important to thrust and fuel consumption performance of the engine.

Using the definition of τ_λ, the specific thrust can be re-written as

The Maximum Thrust Turbojet

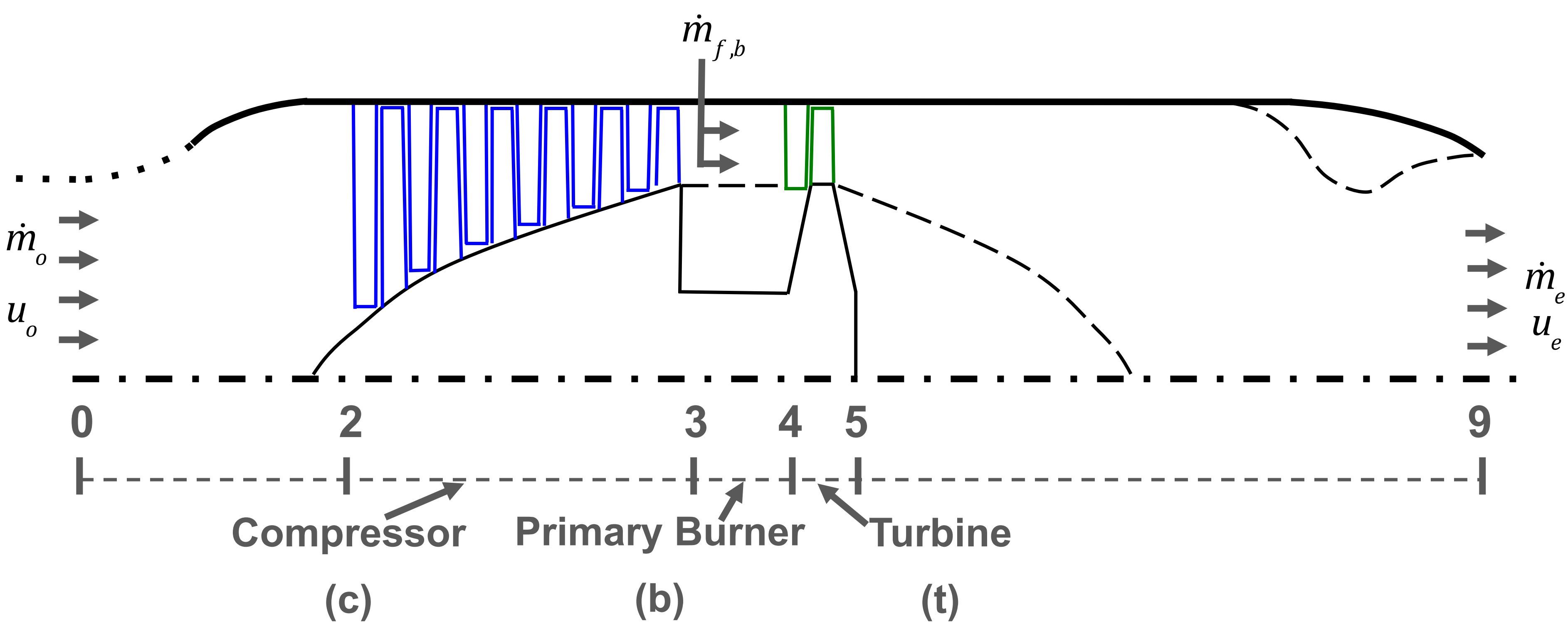
We note from this equation that, for a fixed $\tau_\lambda \tau_r$, there must be an optimal value of τ_c which maximizes (or minimizes) thrust.

Differentiation of the specific thrust relation with respect to τ_c and setting the result to zero gives:

Substitution back into the specific thrust equation gives the maximum specific thrust:

Ideal Turbojet Example

Compute the Specific Thrust and the Specific Fuel Consumption of an ideal turbojet engine operating with the following parameters:



Ideal Turbojet Example

Find: $T/\dot{m}$, S

Ideal Turbojet Example

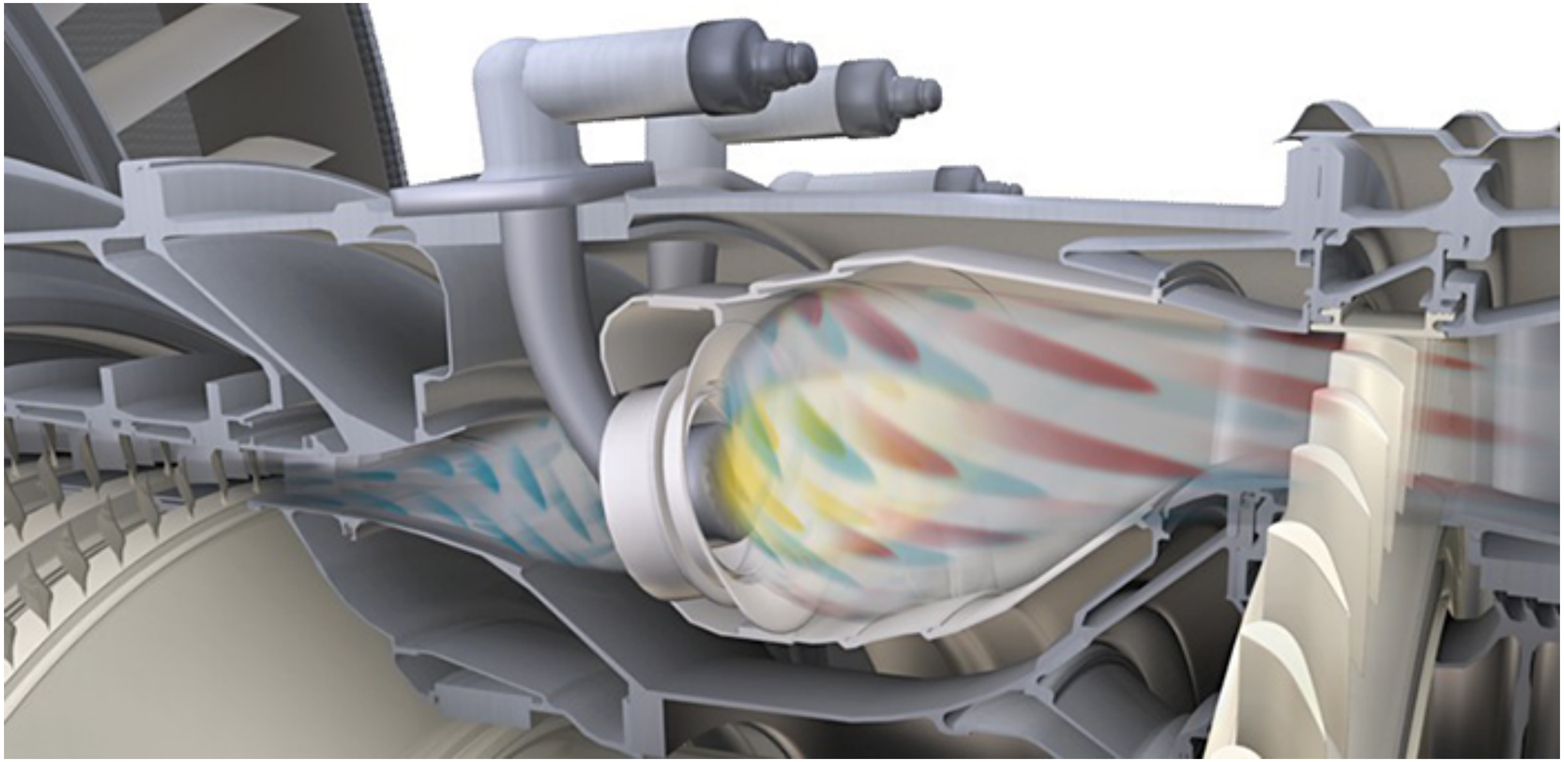
Ideal Turbojet Example

Ideal Turbojet Example

Ideal Turbojet Example

The Ideal Turbojet with Afterburning

- Because the global equivalence ratio in the combustor is always fuel-lean, we know that the combustion product flow will contain excess oxygen: ________________________________.
  - It it therefore possible to add additional energy by combusting additional fuel downstream of the turbine in a device called an **afterburner**.



GE TAPS Lean Combustion Technology

The Ideal Turbojet with Afterburning

- With no turbomachinery protruding into the hot-gas path downstream of the turbine, the afterburner can operate at flow temperatures well-above the turbine inlet temperature, which restricts the amount of fuel that can be added to the main combustor.
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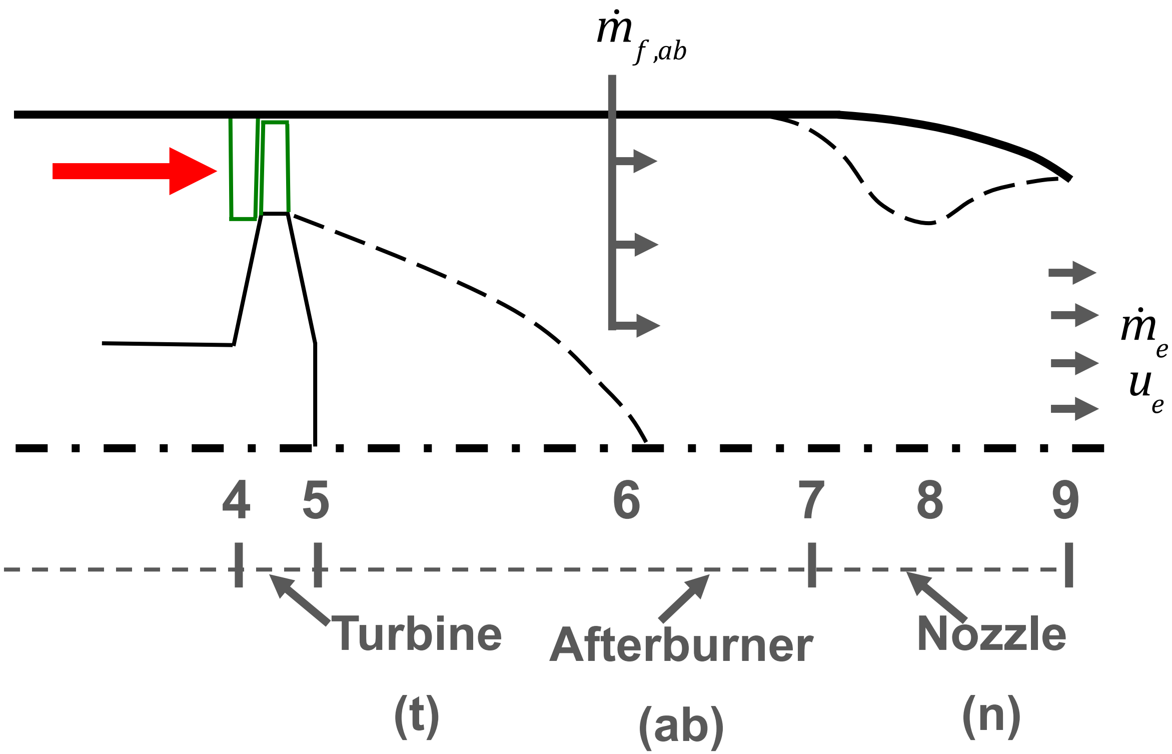
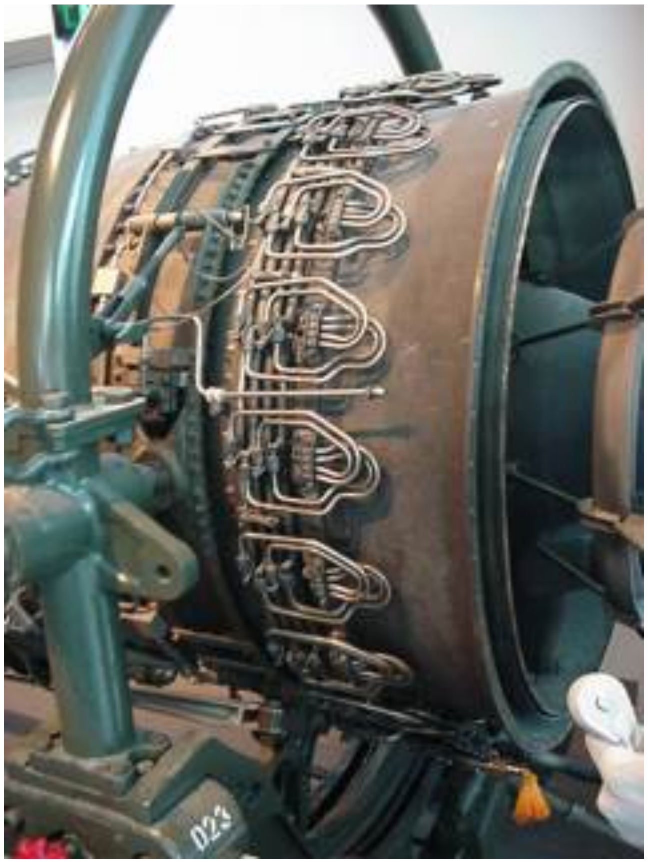
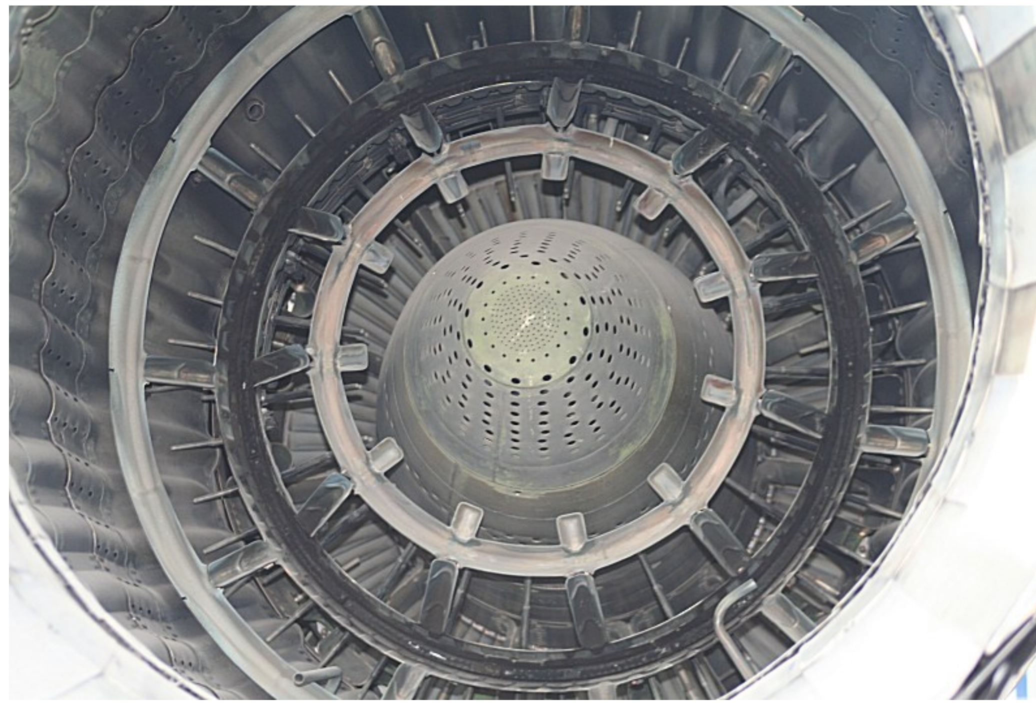


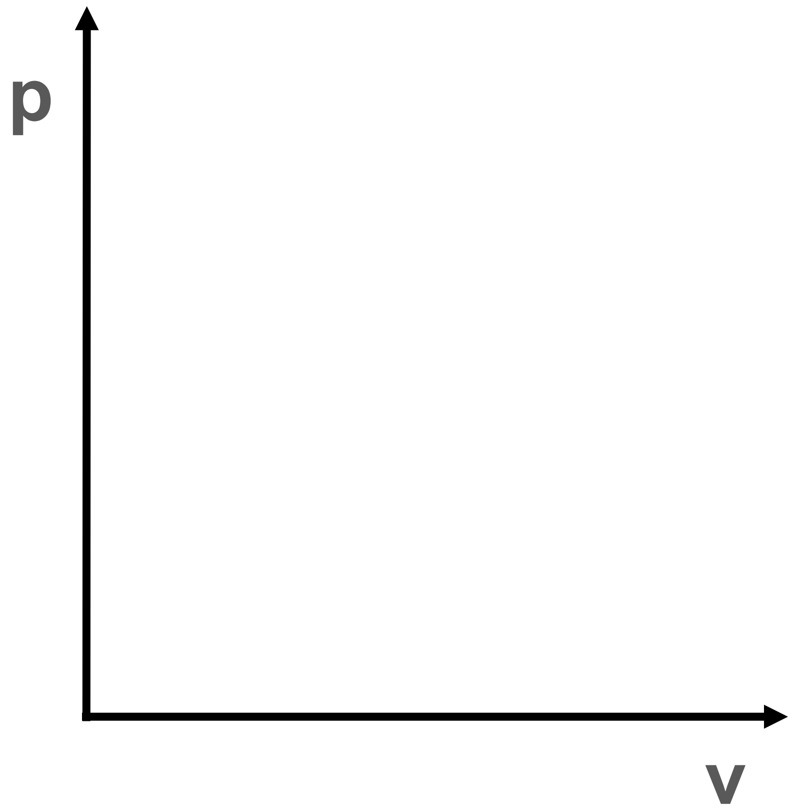
The Ideal Turbojet with Afterburning

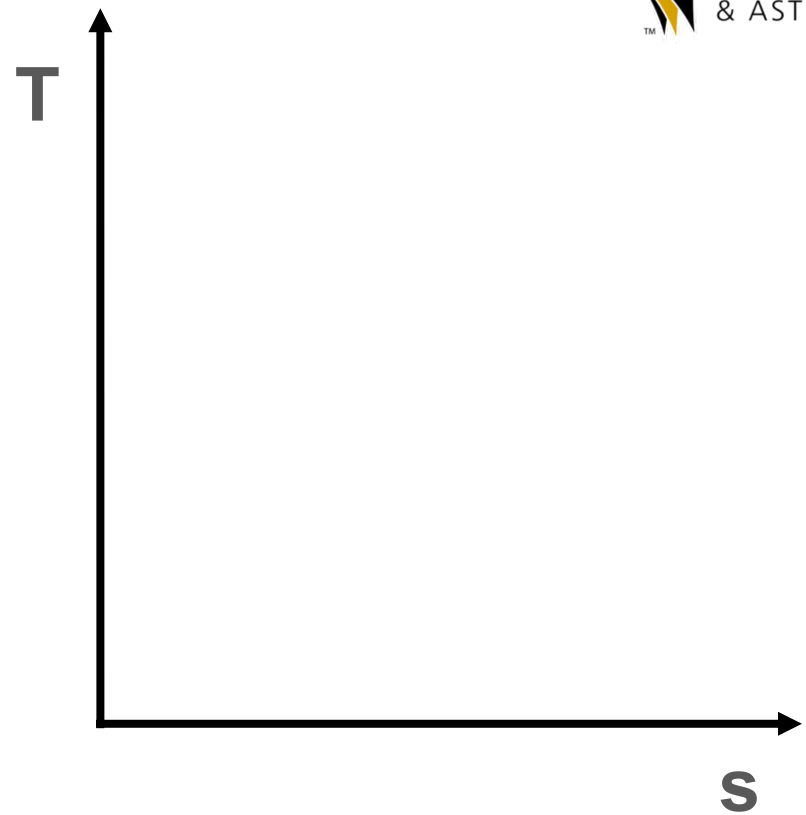
- Typical design of an afterburner involves fuel injection and some flame-holder device





The Ideal Turbojet with Afterburning





- Very large change in specific volume incurred due to the constant pressure combustion within the afterburner.

The Ideal Turbojet with Afterburning

- As in the ideal main burner, we will assume that there is no stagnation pressure loss in the afterburner.

$$\pi_{ab} =$$

While the energy addition in the device is characterized by the temperature ratio:

$$\tau_{ab} =$$

- If we assume that the fuel-air ratio in the afterburner is much less than unity, then we can write the specific thrust, as before:

As before, we can express the velocity ratio as:

The Ideal Turbojet with Afterburning

To solve for the velocity ratio, we again write the stagnation temperature and pressure at the nozzle exit as:

Now, since recovery, compression, and turbine expansion are isentropic, and since $p_0 = p_9$, we can write the expression for the total pressure ________________________ ____.

The Ideal Turbojet with Afterburning

Here we can solve for M_9^2 to give

And we can also substitute back into the stagnation temperature equation to give us an expression for the temperature ratio across the engine (at our control surfaces)

Substitution of all of these relations back into the equation for specific thrust gives:

Where the power balance between the compressor and the turbine is unaffected by the operation of the afterburner, therefore the turbine temperature ratio can be specified with the same equation as before:

$$\tau_t = 1 - \frac{\tau_c - 1}{\tau_c \tau_b}$$

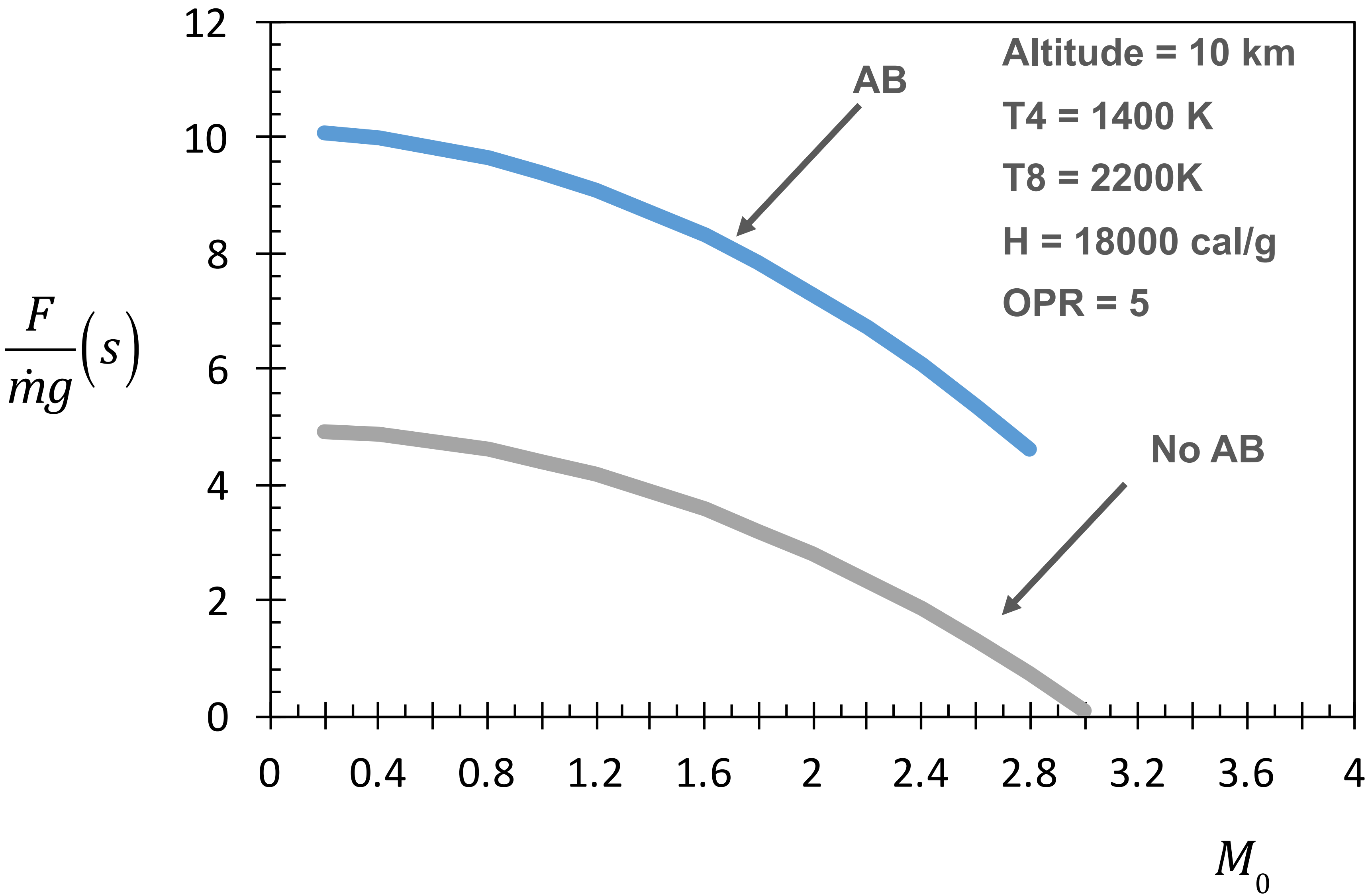
The Ideal Turbojet with Afterburning

- The specific fuel consumption for the device requires consideration of the energy equation. Across the afterburner, we know that

  Such that the fuel-air ratio for the afterburner can be written as:

  And we define the total fuel-air ratio as the sum of the two fuel-air ratios corresponding to the main burner and afterburner, where

Ideal Turbojet with Afterburning



Ideal Turbojet with Afterburning

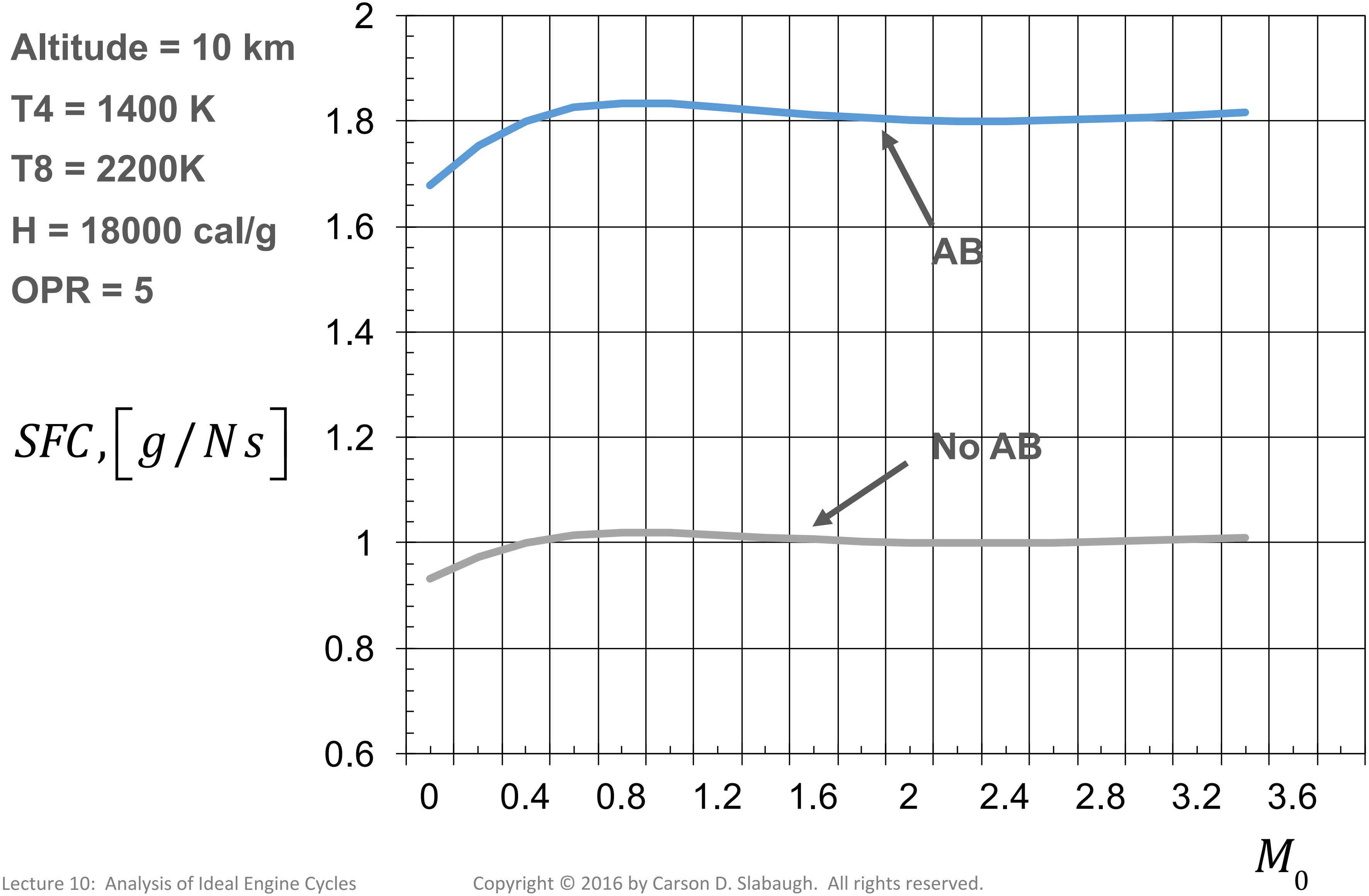
Altitude = 10 km

T4 = 1400 K

T8 = 2200K

H = 18000 cal/g

OPR = 5



Ideal Turbojet with Afterburning

$$\frac{dT}{ds} = \frac{(1-n)T}{c_p\left(1-\frac{n}{\gamma}\right)}$$