General Dynamics F-16 Pratt & Whitney Engine Nozzle

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Qualitative description of the device or system:

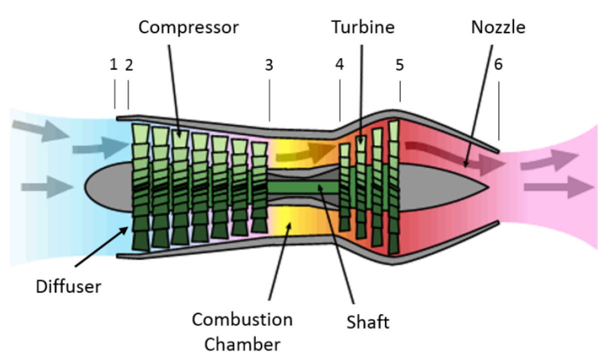
Device: The F-16 is the greatest fighter jet of all time. The jet features a Pratt and Whitney F100-PW-200/220/229. We are analyzing the nozzle at the rear of the jet as a control volume device.

The nozzle serves the function of controlling the flow of burning fuel (exhaust) and air to maximize thrust and propel the jet forward at high speeds. The change in cross-sectional area of the nozzle causes the flow of gases inside to accelerate, generating thrust as they are forced out the back of the plane. The nozzle is designed to maximize efficiency and power, which is ensured by controlling all of the gas that passes through and diverting the stored energy towards as much kinetic energy as possible.

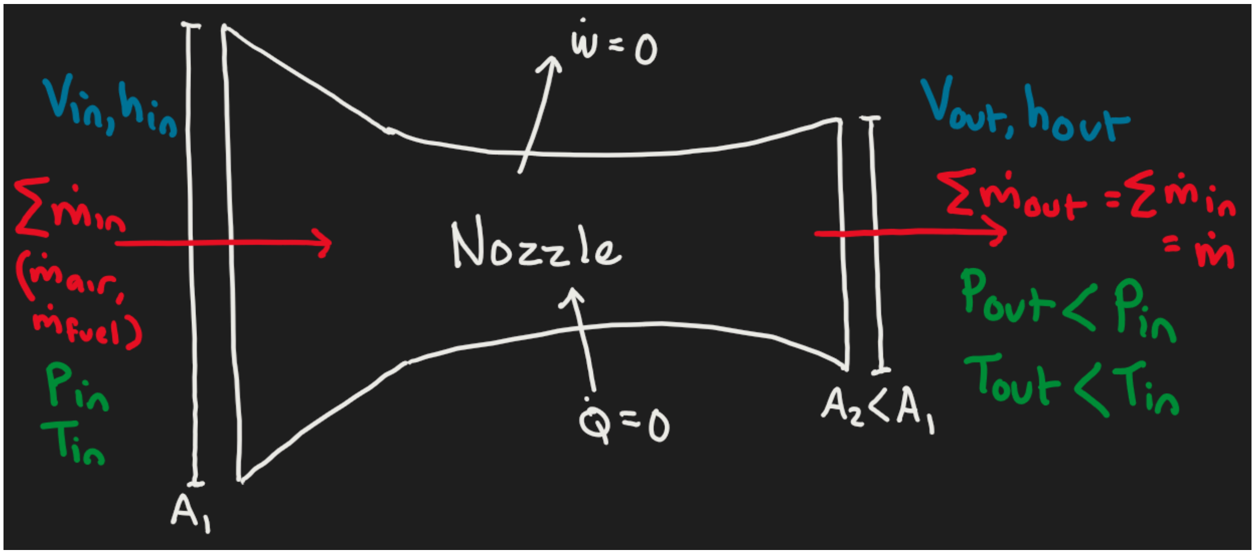
Assumptions:

- Steady state - The jet is cruising at a constant velocity
- Adiabatic - This is probably not a great assumption, but assuming an ideal model makes calculations much easier
- No potential energy change - The jet is cruising at a constant altitude
- Isentropic - Friction and heat transfer are ideally negligible
- Reversible (ideal jet engine) - Assume no mixing, free expansion, heat transfer, etc.
- Ideal gas (air) - In reality, the flow is an air/fuel mixture, but we are assuming that this causes a negligible change

Photos and schematics of the device or system:



A system diagram of the device or system operating (either CV or CM), showing work and heat transfer interactions as well as any relevant mass flows:



Relevant equations capturing the physics more central to the device or system operation:

Data:

- For the F16 F100-PW-229, we found the air mass flow $\dot{m}$ to be 125kg/s[1] ,and it generates $1.2*10^5$N of thrust[2]
- We found an inlet temperature (T_{in}) of 1,620 K[3] and an outlet temperature (T_{out}) of 1100K[4]
- Using a reasonable subsonic v_{in} of 200 m/s for turbine exit - nozzle inlet (assumption)
- Average Temp of 1360K gives Cp value of 1013 J/KgK[5]

Mass Balance:

We know that all of the fuel and air used in the jet engine (entering the greater system through the engine's intake manifold and being expelled to the nozzle's entrance) goes through the nozzle, so all mass that enters must leave. Therefore,

$$\dot{m}_{in} = \dot{m}_{out} = \dot{m}$$

Entropy Balance:

As with all real-world devices/systems, there exists some entropy generation and exchange as the nozzle performs its function. Therefore,

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[1](“Pratt & Whitney F100”)
[2] (“F-16 Fighting Falcon > Air Force > Fact Sheet Display”)
[3] (Clancy and Gresham 64)
[4] (Usarek)
[5] (“Specific Heat Capacity of Air: Isobaric and Isochoric Heat Capacities at Various Temperatures and Pressures”)

$$\Delta\dot{S}_{cv} = \Sigma\frac{\dot{Q}_{cv}}{T} + \Sigma\dot{m}_i s_i - \Sigma\dot{m}_o s_o + \dot{\sigma}$$

Since the jet is cruising at a constant velocity, we can assume it to be operating at steady state, and thus $\Delta\dot{S}_{cv} = 0$. Furthermore, since the nozzle is cooled in real life to minimize heat transfer, we can assume adiabatic, and thus $\Sigma\frac{\dot{Q}_{cv}}{T} = 0$.

Since the mass flow is constant, and we are assuming only one mass flow, the equation becomes:

$$\dot{m}(s_i - s_o) = \dot{\sigma}$$

Energy Balance:
Since we are analyzing a control volume (CV) device, we can write out the following energy balance equation:

$$\dot{E} = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}(h_{in} - h_{out}) + \frac{\dot{m}}{2}(v_{in}^2 - v_{out}^2) + \dot{m}(gz_{in} - gz_{out})$$

Since we are assuming adiabatic, steady state, nozzle analysis with negligible potential energy difference, the energy balance simplifies to:

$$0 = \dot{m}(h_{in} - h_{out}) + \frac{\dot{m}}{2}(v_{in}^2 - v_{out}^2)$$

$$(v_{in}^2 - v_{out}^2) = 2(h_{out} - h_{in})$$

$$v_{out} = \sqrt{v_{in}^2 - 2(h_{out} - h_{in})}$$

Specifically for the F16, we can calculate v_{out} using our data for mass flow rate, inlet velocity, and temperatures:

$$v_{out} = \sqrt{v_{in}^2 - 2Cp(T_{out} - T_{in})} = \sqrt{(200 m/s)^2 - 2(1013\, J/kgK)((1100K) - (1620K))}$$

$$v_{out} = 1045.71\, m/s$$

This value is significantly higher than the inlet velocity, suggesting a substantial amount of thrust has been generated - to be expected from an F16!

Describe a change to device or system design or operating conditions, and then how that change influences device performance

If the insulation system for the jet engine failed, and the system were not adiabatic, the efficiency of the system would be reduced. This is because heat that could be converted to thrust is lost to the surroundings. Thus, less heat energy is converted into kinetic energy.

Resources:

Works Cited

Clancy, Tom, and John Gresham. *Fighter Wing: A Guided Tour of an Air Force Combat Wing*. Penguin Publishing Group, 2007. Accessed 8 December 2025.

“F-16 Fighting Falcon > Air Force > Fact Sheet Display.” *AF.mil*, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104505/f-16-fighting-falcon/. Accessed 19 November 2025.

“Pratt & Whitney F100.” *Pratt & Whitney F100 - Wikipedia*, 2025, https://en.wikipedia.org/wiki/Pratt_%26_Whitney_F100? Accessed 8 December 2025.

“Specific Heat Capacity of Air: Isobaric and Isochoric Heat Capacities at Various Temperatures and Pressures.” *The Engineering ToolBox*, https://www.engineeringtoolbox.com/air-specific-heat-capacity-d_705.html. Accessed 8 December 2025.

Usarek, Włodzimierz. “Module engine operating on example of Pratt&Whitney F100-PW-229.” *combustion-engines.eu*, https://www.combustion-engines.eu/pdf-117058-46258?filename=46258.pdf.