

Introduction to Propulsion

AE 1350

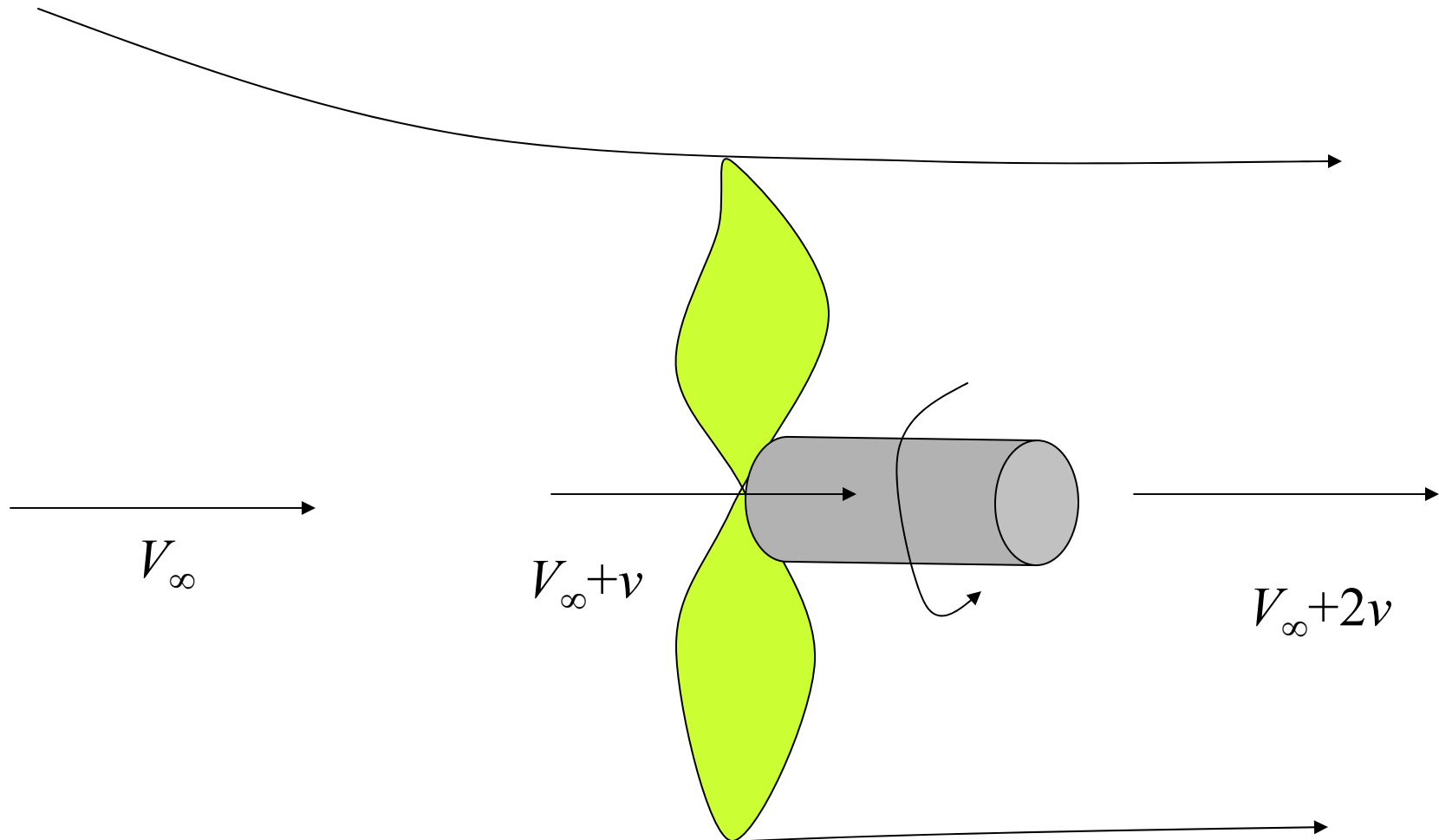


How does a propeller work?



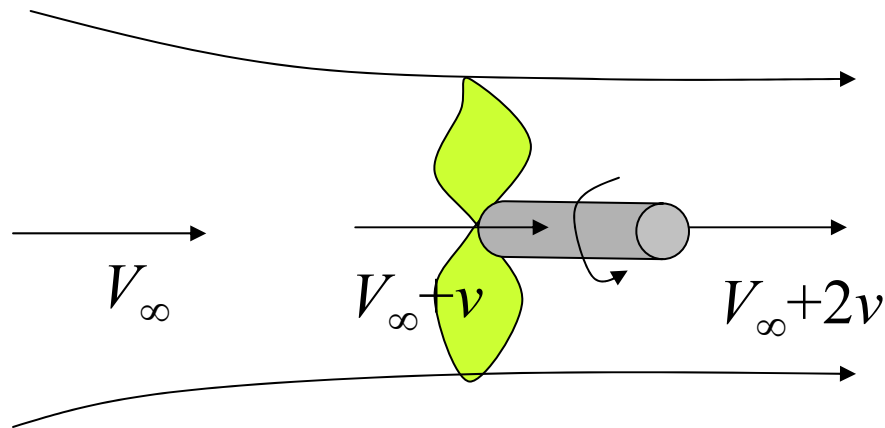
- Air approaches the propeller with low velocity, leaves with higher velocity, and energy
- This change in momentum of the particles is caused by the force exerted by the propeller on the particles
- There is an equal and opposite reaction - the particles exert a forward force on the propeller, called thrust

As the propeller turns...



Streamlines contract as they approach the propeller,
Velocity of the particles increases

Thrust



Mass flow rate = $\rho A (V+v)$ where A is the propeller disk area

Momentum flow rate = mass flow rate times velocity

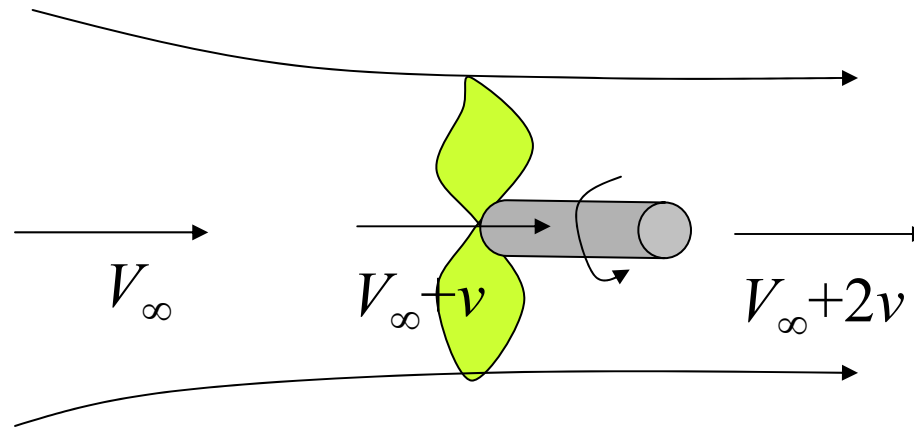
Thrust = Rate at which Momentum flows out-

Rate at which momentum flows in

$$T = \rho A (V_\infty + v) (V_\infty + 2v) - \rho A (V_\infty + v) V_\infty = 2\rho A (V_\infty + v)v$$

Thrust is increased if the disk area A is large, and/or if the excess velocity v is large

Power



Mass flow rate = $\rho A (V+v)$ where A is the propeller disk area
Energy flow rate = $1/2$ (mass flow rate) times (velocity squared)
Rate at which energy is added to the fluid (power) =
Energy rate out – energy rate in
 $= 1/2 \rho A (V_\infty + v) (V_\infty + 2v)^2 - 1/2 \rho A (V_\infty + v) V_\infty^2$
 $= 2 \rho A (V_\infty + v)^2 v = T(V_\infty + v)$

Notice that power consumed will be high for a given thrust T and forward velocity V_∞ , if v is high

Propeller Thrust vs. Power Consumed

$$T = 2\rho A (V_\infty + v)v$$

$$P = T(V_\infty + v) = TV_\infty + Tv$$

- The first term (TV_∞) is useful work done by the propeller to overcome drag
- The second term (Tv) called induced power, represents excess energy we dump into the wake, as the propeller accelerates the flow to a higher velocity
- To minimize this wasted power, this should be kept small
- Propulsive efficiency = Useful Power/Total Power
 $= TV_\infty / (TV_\infty + Tv) = V_\infty / (V_\infty + v)$
- Rule of Thumb for propellers: Keep disk area A as large as possible, this minimizes v at a given thrust
- Or, the bigger the prop, the lower the power required (within limits...)

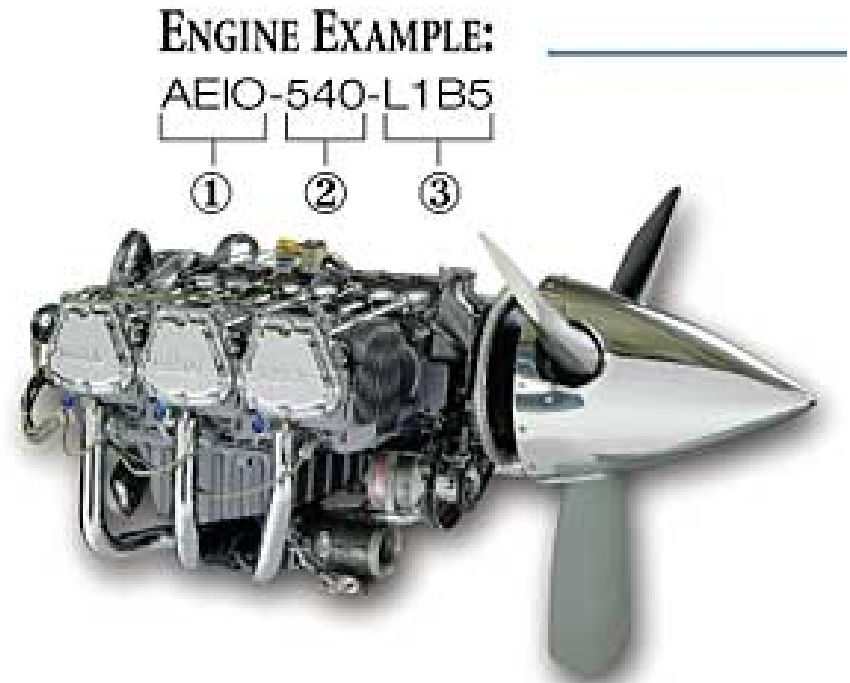
There is a limit to the Disk Area

- If we make the disk area too large, the blade radius and diameter will be high
- Tip of prop will be traveling at a high speed
- If cruise speed is also high, shocks will form on the blades (critical Mach number!)
- Additional power will be needed to overcome the wave drag on the blades caused by the shock waves
- Noise will also go up
- These factors have limited the use of propellers to aircraft that have relatively low subsonic cruise speeds (say, Mach 0.6 or less)

How is the propeller or fan turned?

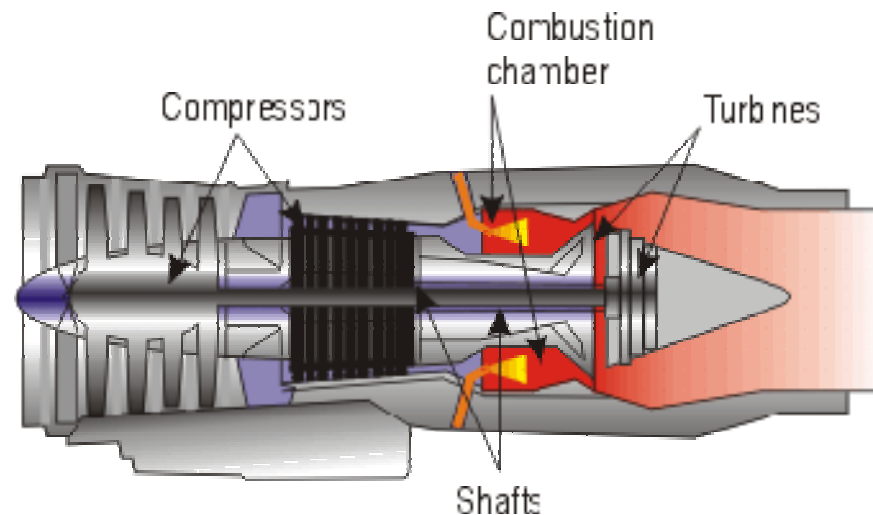
- With a
 - piston engine (as in a typical car)
 - or a
 - gas turbine engine

Piston Engines

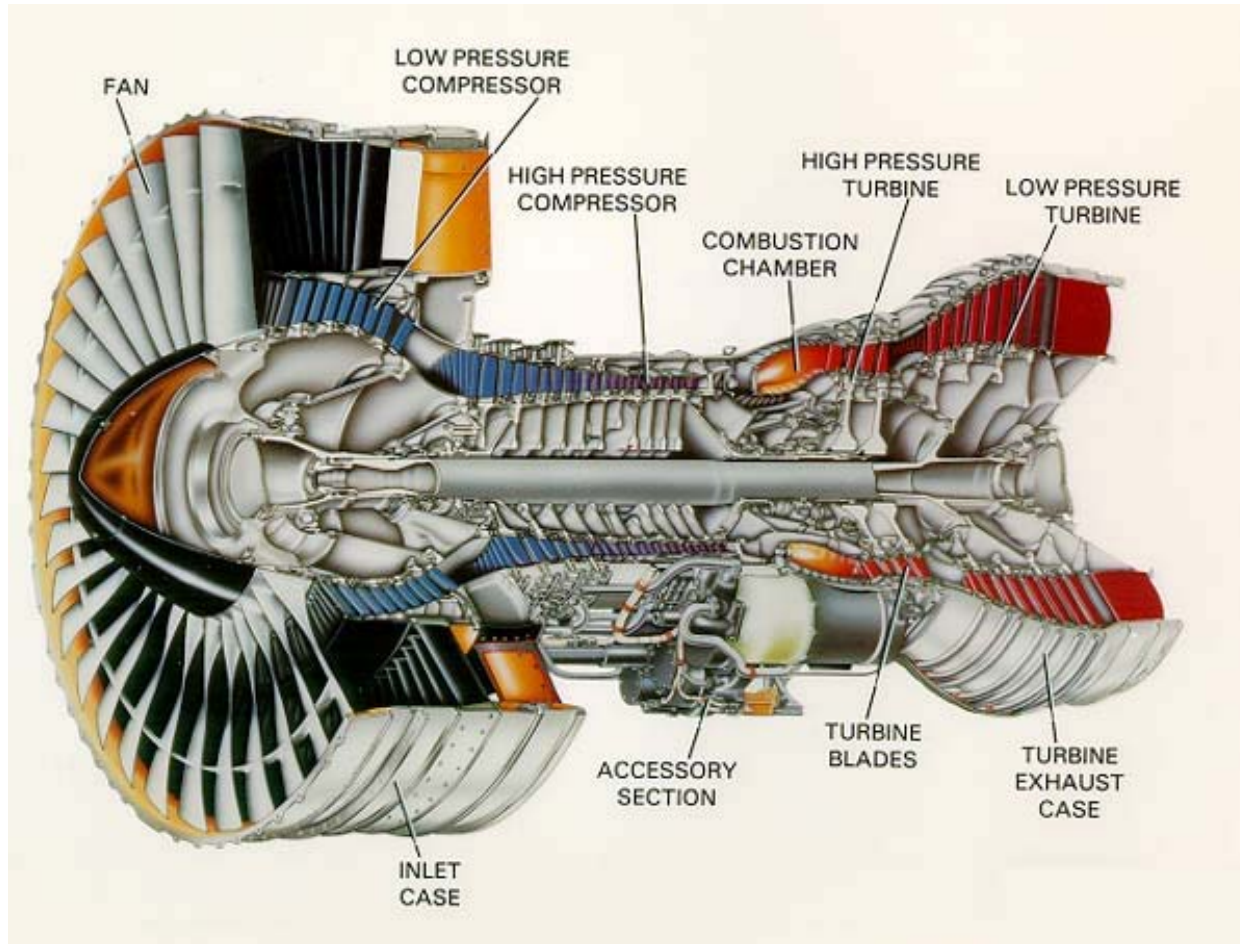


Gas Turbine Engines

- Compressor — draws in outside air and increases the pressure of the air
- Combustor — mixes fuel with the air, ignites mixture
- Turbine — extracts energy from the heated air to turn the compressor and possibly other components



Turbofan



Turbine turns a fan, where the majority of the air does not go through the combustor/turbine (it is bypass flow) - The fan acts like a propeller, provides the majority of thrust

Low Bypass Ratio Turbofan



Fan tip diameter: *54.0 inches*

Length, flange to flange: *168.6 inches*

Takeoff thrust: *21,000 pounds of thrust*

Bypass ratio: *1.74-to-1*

Overall pressure ratio: *18.2 to 19.4*

Fan pressure ratio: *1.91*

Engine Models

JT8D-standard

JT8D-217/219

Planes Powered by JT8D

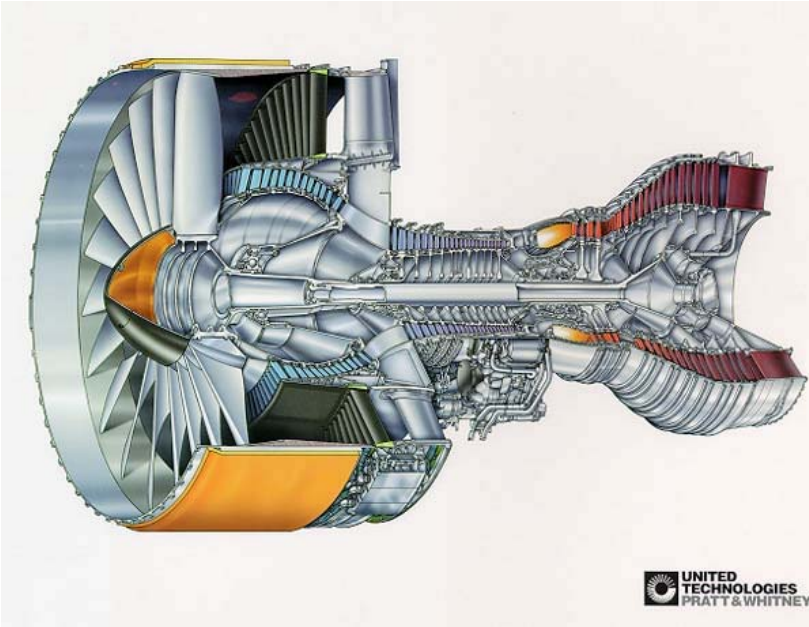
Boeing 727

Boeing 737-100/-200

McDonnell Douglas DC-9

Boeing MD-80

High Bypass Ratio Turbofan



Fan tip diameter: *112 inches*

Length, flange to flange: *191.7 inches*

Takeoff thrust: *86,760 - 98,000 pounds*

Bypass ratio: *5.8-to-1 to 6.4-to-1*

Overall pressure ratio: *34.2 - 42.8*

Fan pressure ratio: *1.70 - 1.80*

Engine Models

PW4084

PW4090

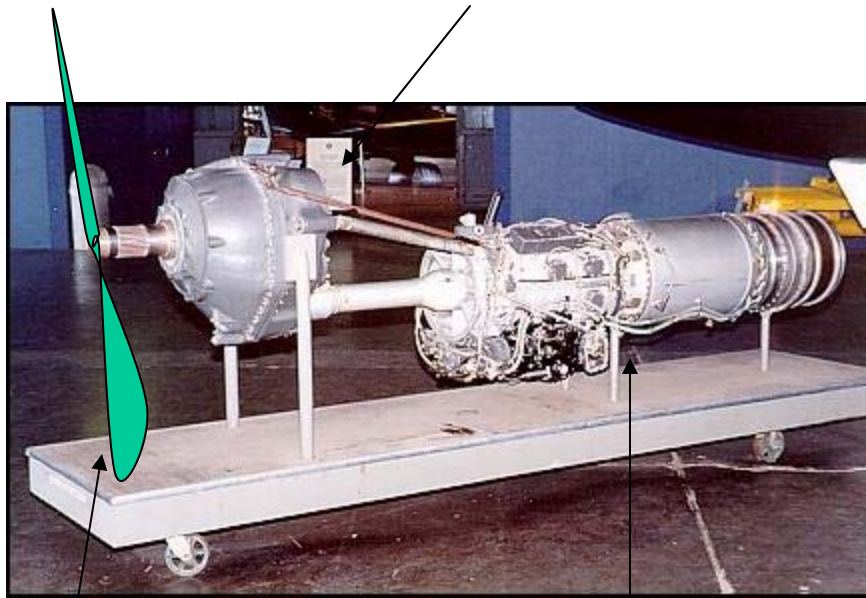
PW4098

Planes Powered by PW4000

Boeing 777-200/-300

Turboshaft Engines (Turboprop)

Gear Box



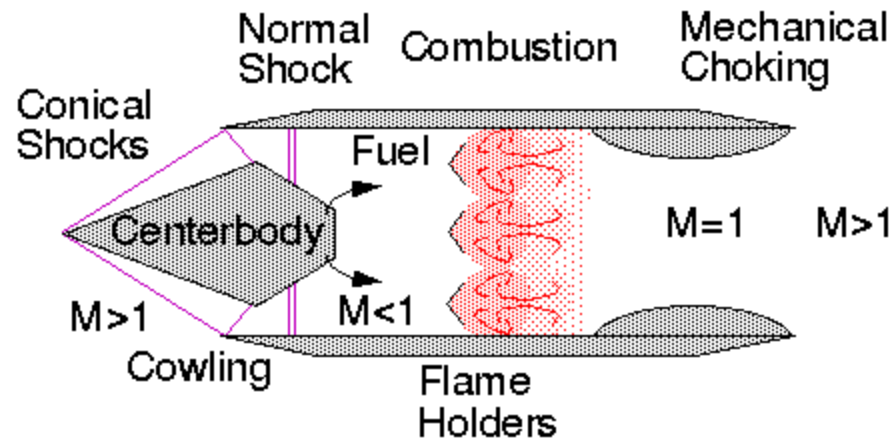
Propeller
or
Rotor

Core

Through a gear box, the power from the engine shaft may be used to spin:
a propeller (turboprop),
or helicopter rotor (turboshaft)

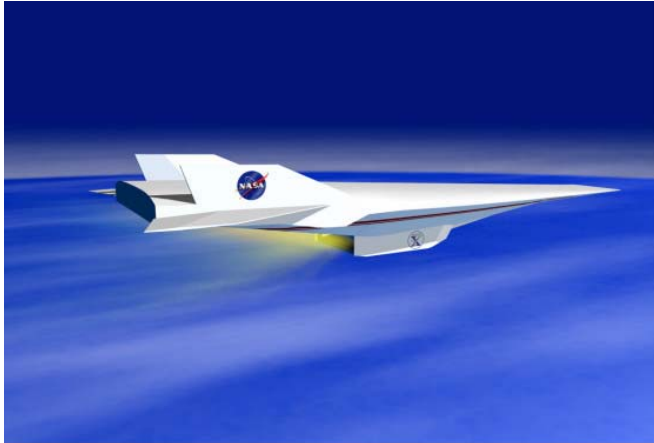
Ram Jet Engines

Conventional Ramjet



- Only work above about Mach 3
- Dramatic pressure rise from slowing flow from supersonic to subsonic (through shock waves) increases pressure for computer

Supersonic Combustion Ram Jet SCRAMJET Engines



Dryden Flight Research Center ED97 43968-03
FIRED UP: This is an artist's depiction of a Hyper-X
research vehicle under scramjet power in free-flight
following separation from its booster rocket.

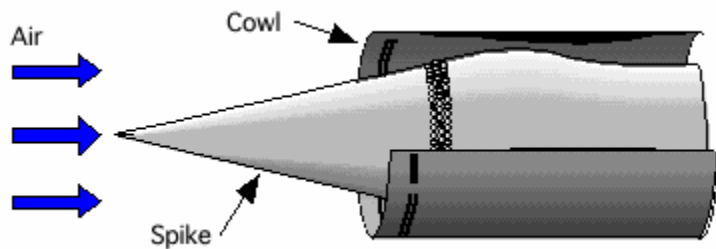


In this engine, compressors are not used

Shock waves in front of the aircraft and inside the inlet slow down the flow and increase the pressure

The flow inside the entire engine, including the compressor, is supersonic ($Mach > 1$)

When you want to go very fast...

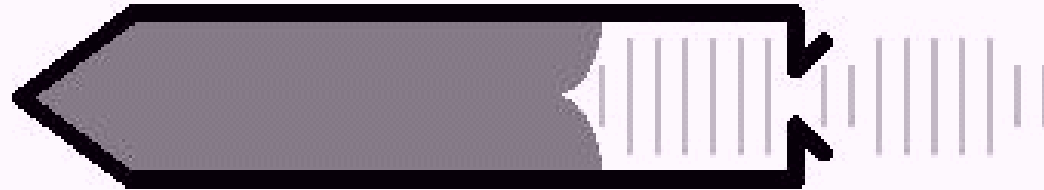


Jet Engines and Piston Engines Need Air...

- They need air (or oxidizer) for combustion of the fuel and generation of energy
- For this reason, these are called “air-breathing” engines
- Jet and piston engine aircraft carry only the fuel
- Advantage: They don’t have to carry the oxidizer around with them
- Disadvantage: These devices stop working outside the atmosphere...

Solid vs. Liquid Fuel Rocket Motors

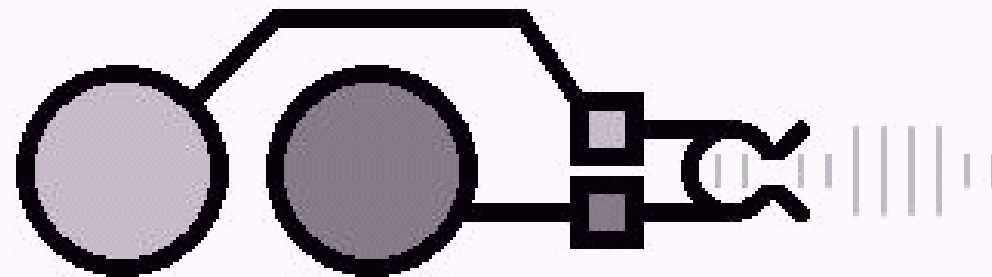
Solid Fuel Rocket



Solid Propellant: Fuel & Oxidizer

Nozzle

Liquid Fuel Rocket



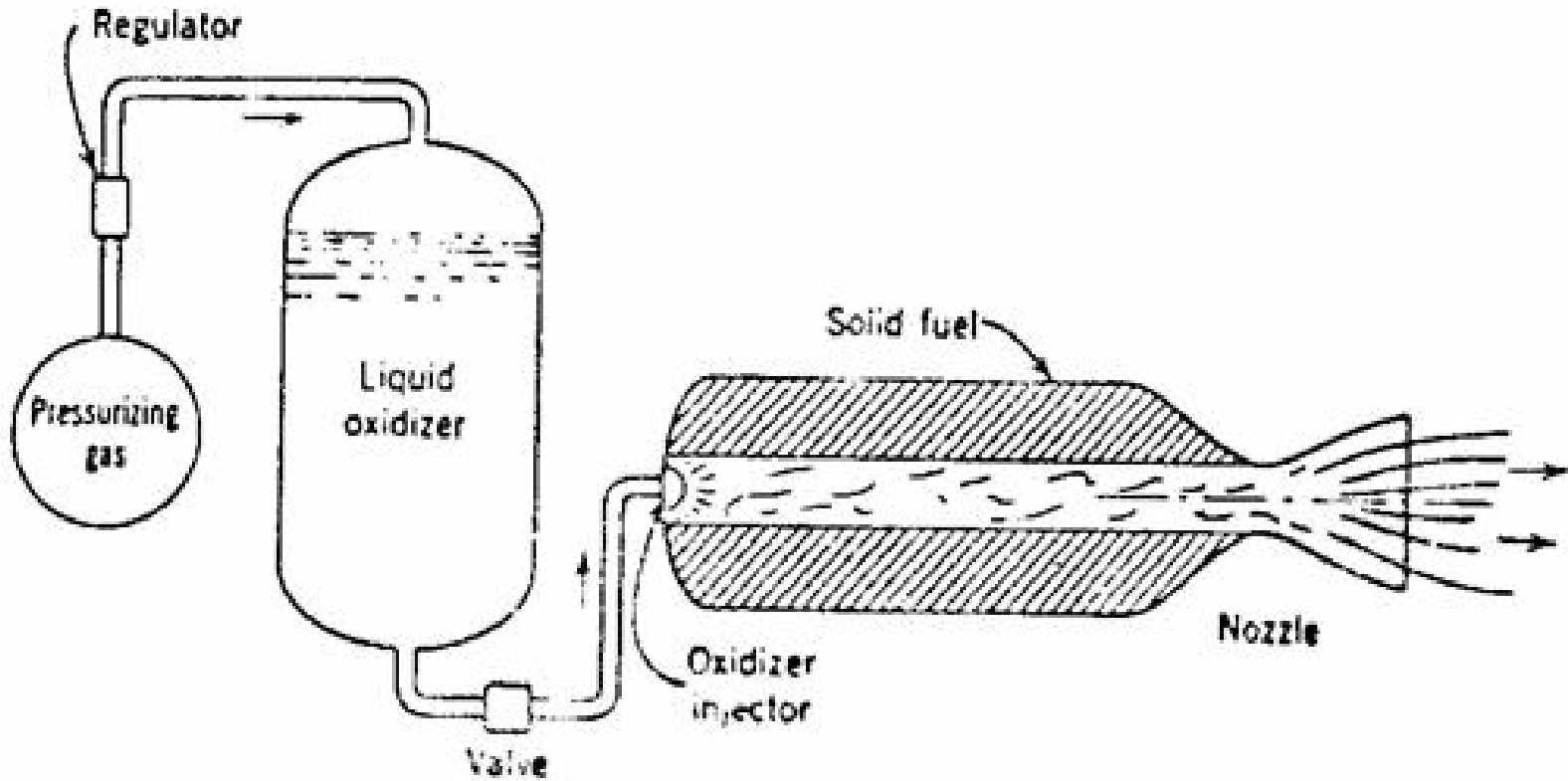
Fuel

Oxidizer

Pumps

Nozzle

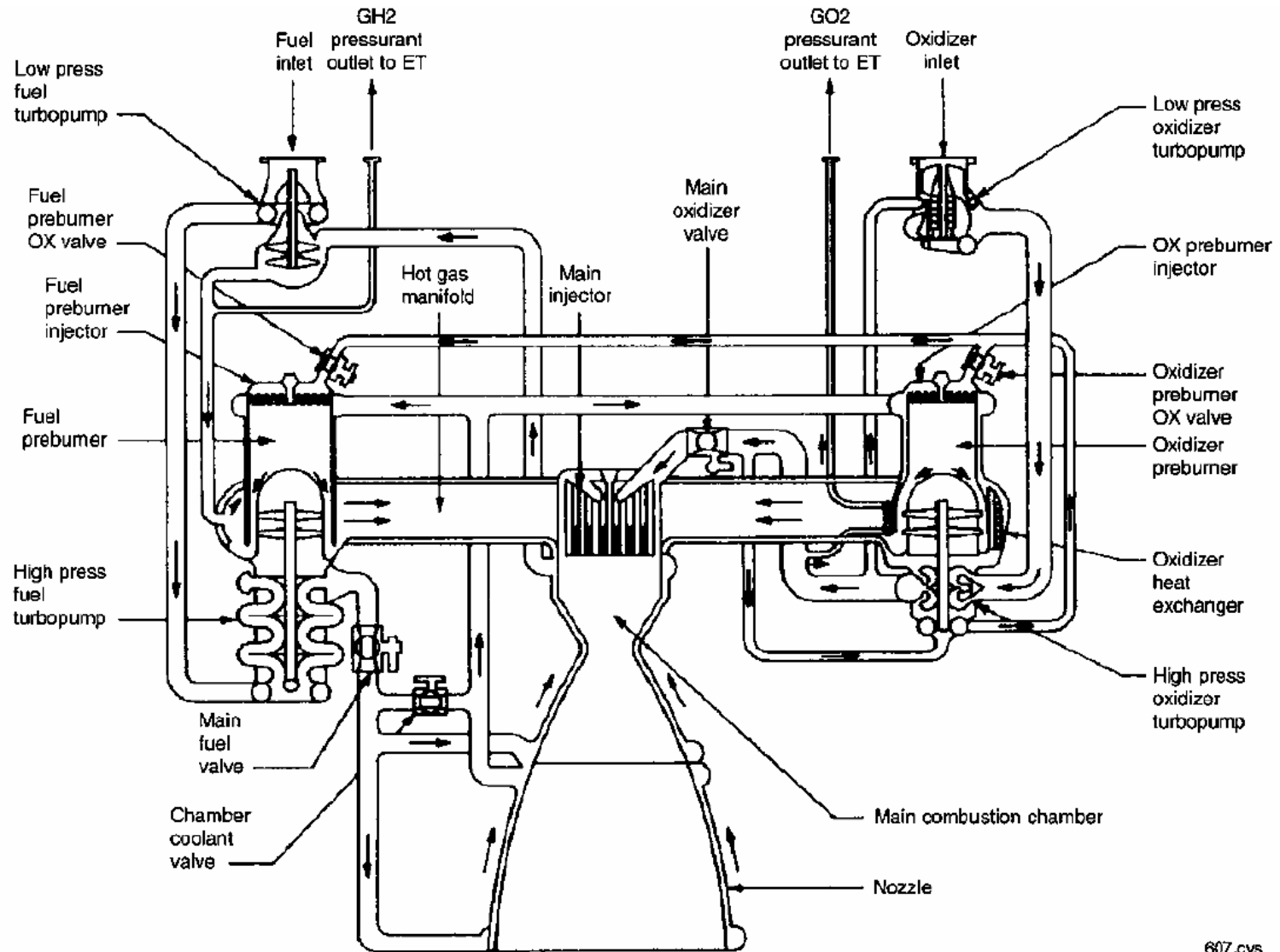
Hybrid Rocket Motor (Combo!)



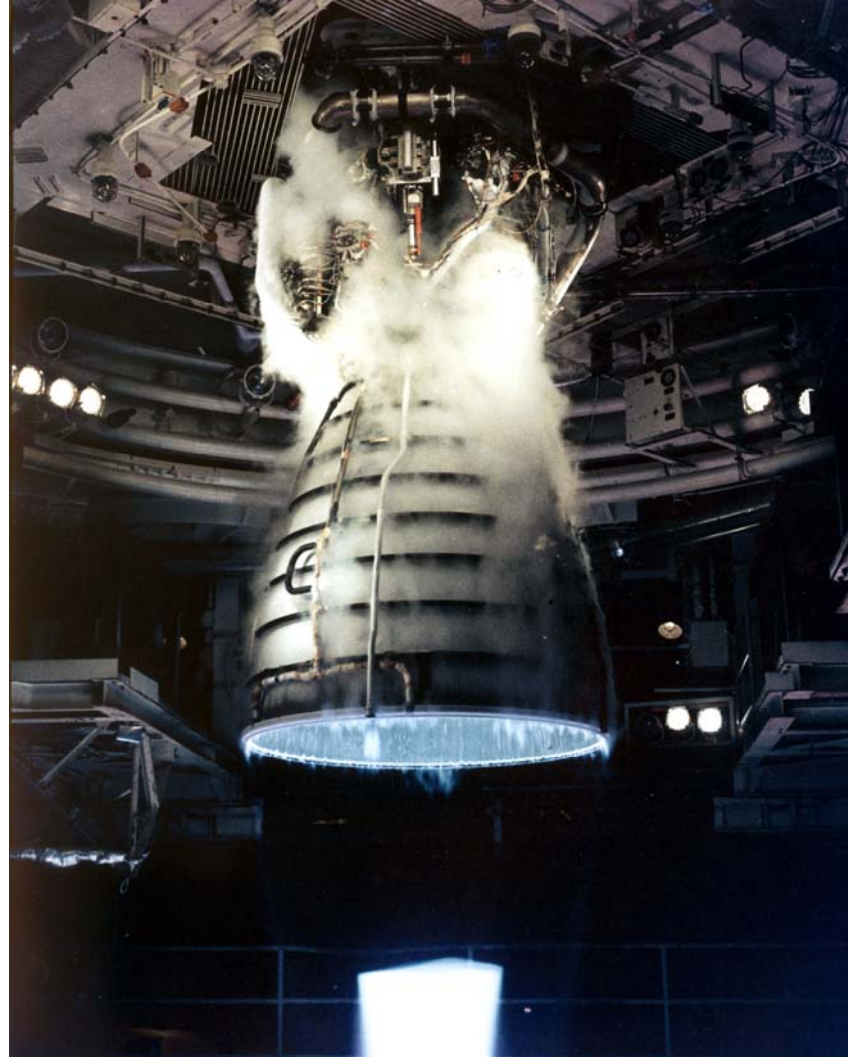
Liquid Fuel Rocket Motor

- Uses separate liquid fuel and oxidizer, which are combined only at the moment of combustion
- Pumps are required to get the fuel & oxidizer to the motor quickly enough to develop desired thrust, and at enough pressure for desired efficiency (turbopumps)
- This makes liquid fuel rockets more complicated
- Liquid fuel rockets can be turned off and then turned on again
- Some can be throttled for more or less thrust

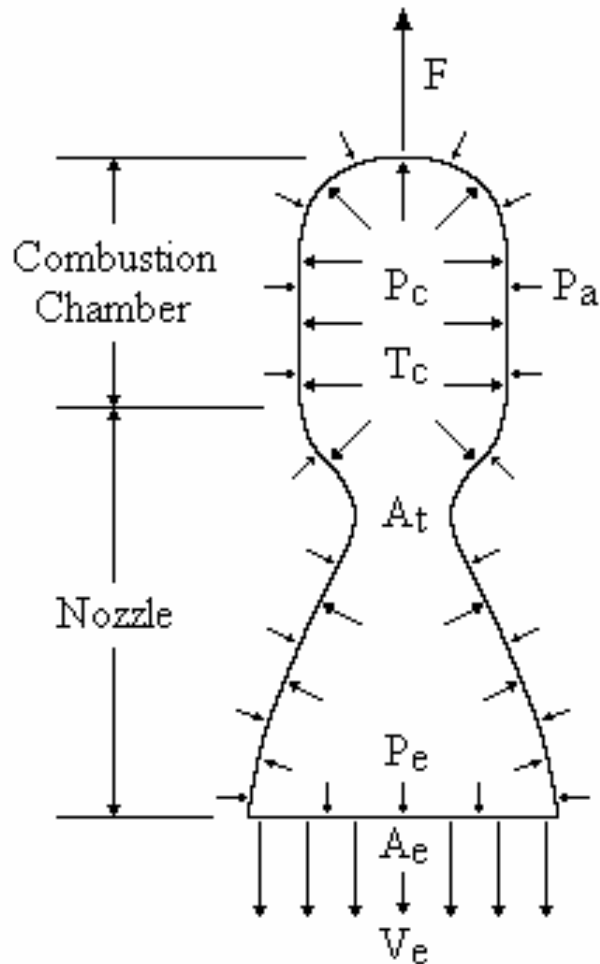
Space Shuttle Main Engine (SSME)



Space Shuttle Main Engine (SSME)



Rocket Motor Thrust



$$\text{Thrust} = (\text{Mass Flow Rate}) * V_{\text{jet}} \\ + (p_{\text{exit}} - p_{\infty}) A_{\text{exit}}$$

Specific Impulse

- Specific Impulse is how long a pound of fuel can develop a pound of thrust

$$F_{\text{thrust}} = I_{\text{sp}} \cdot \frac{\Delta m}{\Delta t} \cdot g_0$$

- Thrust is Specific Impulse, multiplied by the mass flow rate of propellants and the acceleration of gravity
- A very good chemical rocket in terms of Specific Impulse is the Space Shuttle main engine, at about 453 seconds
- Air breathing engines can do better if there is air (and we're going slow enough), due to the fact they do not have to count the oxidizer

Specific Impulse

