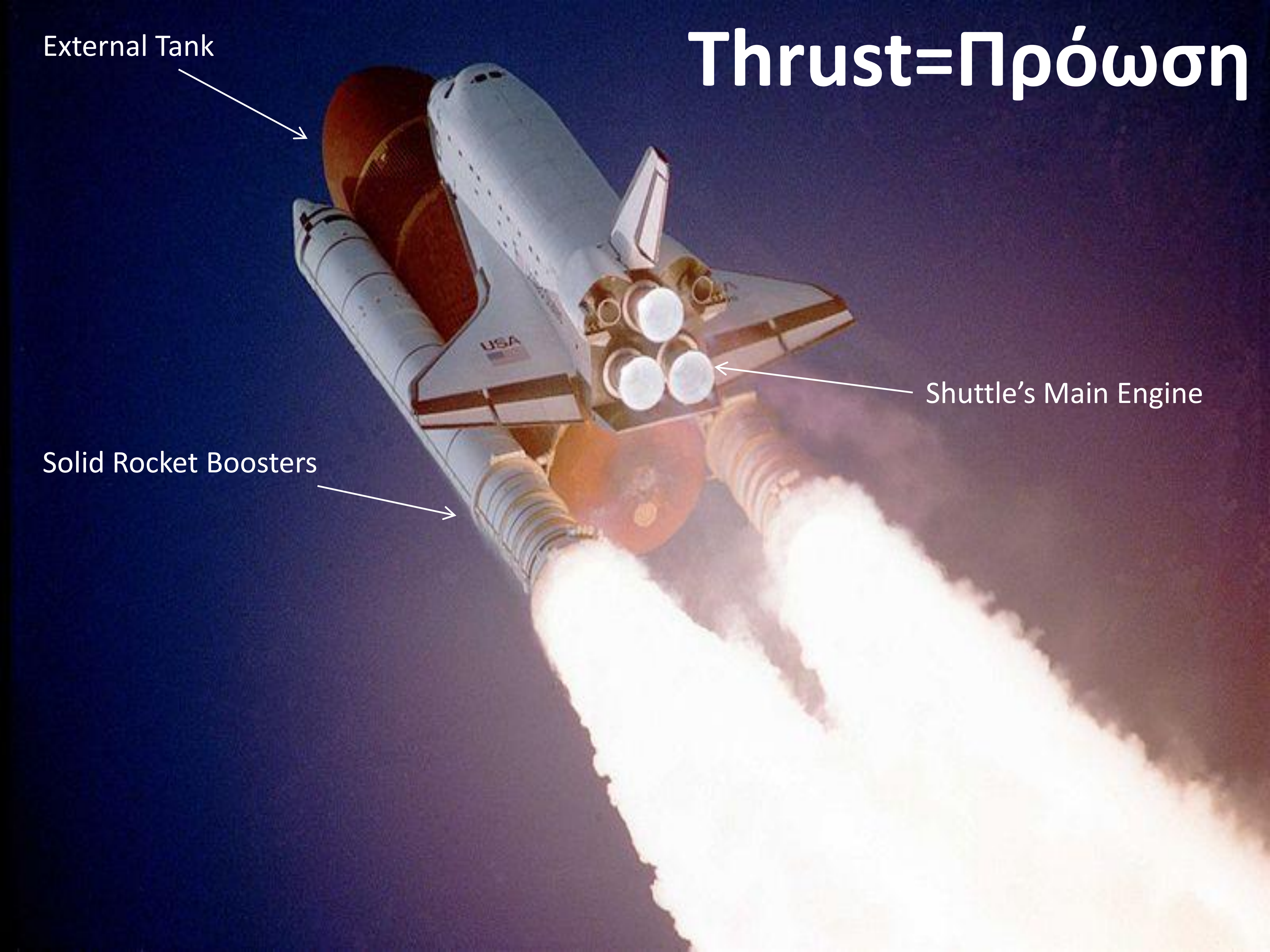
Thrust=Πρόωση



External Tank

The Space Shuttle External Tank (ET) on its way to the Vehicle Assembly Building at the Kennedy Space Center, Florida

Contains liquid oxygen (LOX) and liquid Hydrogen (LH2)

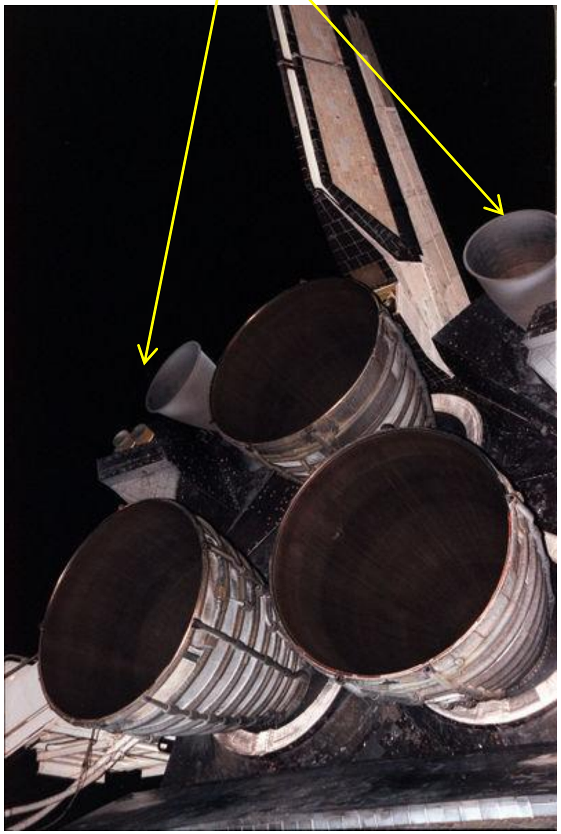
LOX+LH2 $\longrightarrow$ Water + energy

ET
Length: 46.9 m
Diameter: 8.4 m
Empty Mass: 26,560 kg
Liftoff Mass: 762,100 kg

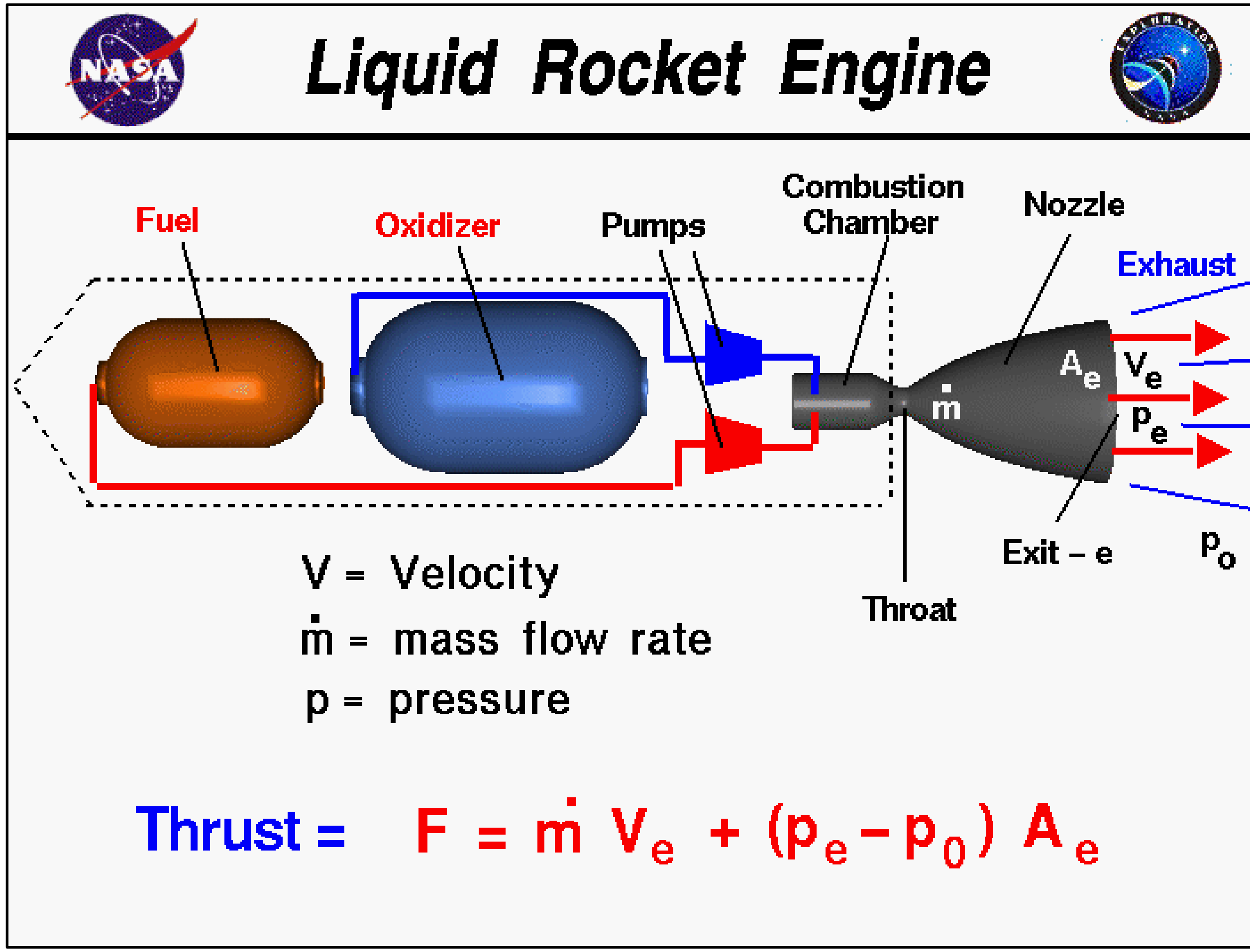
LOX
Length: 16.6 m
Diameter: 8.4 m
Volume: 553,358.2 liters
LOX mass: 629,340 kg
Temp: 90 K=-183 ^{o}C

LH2
Length: 29.5 m
Diameter: 8.4 m
Volume : 1,497,440 liters
LH2 mass: 106,261 kg
Temp: 20K=-253 ^{o}C

Thrusters for orbital maneuvering and orbit injection



Shuttle's Main Engine Nozzles



Mass=2000 t

Weight at lift-off
mass*g=20 MN

Thrust
Shuttle's Main Engines: 1.8 MN
Solid Rocket boosters: 14.7 MN each
Total Thrust=39.4 MN

Solid Rocket Boosters

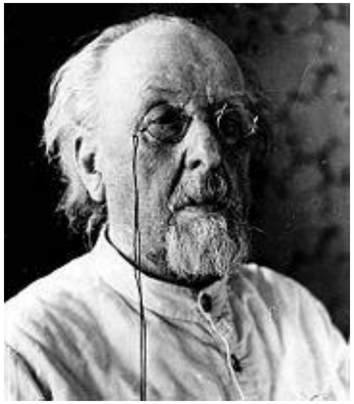
SRB's separate at 45.7 km and parachute to the sea.

Oxidizer
Ammonium perchlorate: NH_4ClO_4

Fuel
Aluminum: Al

Length: 45 m
Diameter: 3.7 m
Mass at Launch: 590,000 kg
Empty mass: 91,000 kg

Tsiolkovsky rocket equation (1903)



Konstantin Tsiolkovsky (1857-1935)

$$\Delta v = v_e \ln \frac{m_0}{m_1}$$

Δv is the rocket's change of velocity
m_0 is the initial total mass, including propellant, in kg
m_1 is the final total mass in kg
v_e is the effective exhaust velocity in m/s

Example: Solid Rocket Boosters

$$\left.\begin{aligned} m_0 &= 2\times10^6 \text{ kg} \\ m_1 &= 2\times10^6\text{-}2\times0.5\times10^6 \text{ kg} \\ &= 1.0\times10^6 \text{ kg} \\ v_e &= 3000 \text{ m/s} \end{aligned}\right\} \Rightarrow \Delta v = 3000\ln\frac{2}{1.0} = 3000\times0.69 = 2079 \text{ m/s} = 7485 \text{ km/h}$$

With gravity $$v(t) - v(0) = v_e \ln\frac{m(0)}{m(t)} - gt$$

Continued Example: Solid Rocket Boosters

$$\left.\begin{array}{l}\text{Thrust } F_{th} = 15 \text{ MN} \\ F_{th} = v_e \dfrac{dm}{dt} \\ v_e = 3000 \text{ m/s}\end{array}\right\} \Rightarrow \left.\begin{array}{l}\dfrac{dm}{dt} = 5000 \text{ kg/s} \\ M = 500{,}000 \text{ kg}\end{array}\right\} \Rightarrow \tau = \frac{M}{dm/dt} = 100 \text{ s}$$

Final velocity including gravity

$$g\tau = 1000 \text{ m/s} \Rightarrow v = 2079 - 1000 \text{ m/s} = 1079 \text{ m/s} = 3900 \text{ km/h}$$

Final Altitude

$$\left.\begin{array}{l}v_i = 0 \\ v_f = 3900 \text{ km/h}\end{array}\right\} \Rightarrow \bar{v} \approx 2000 \text{ km/h} \Rightarrow L = \bar{v}\tau = 2000 \ \frac{\text{km}}{\text{h}} \frac{100}{3600} \text{h} = 55 \text{ km}$$