

Aerospace/Space Propulsion Fundamentals

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16 July 2009

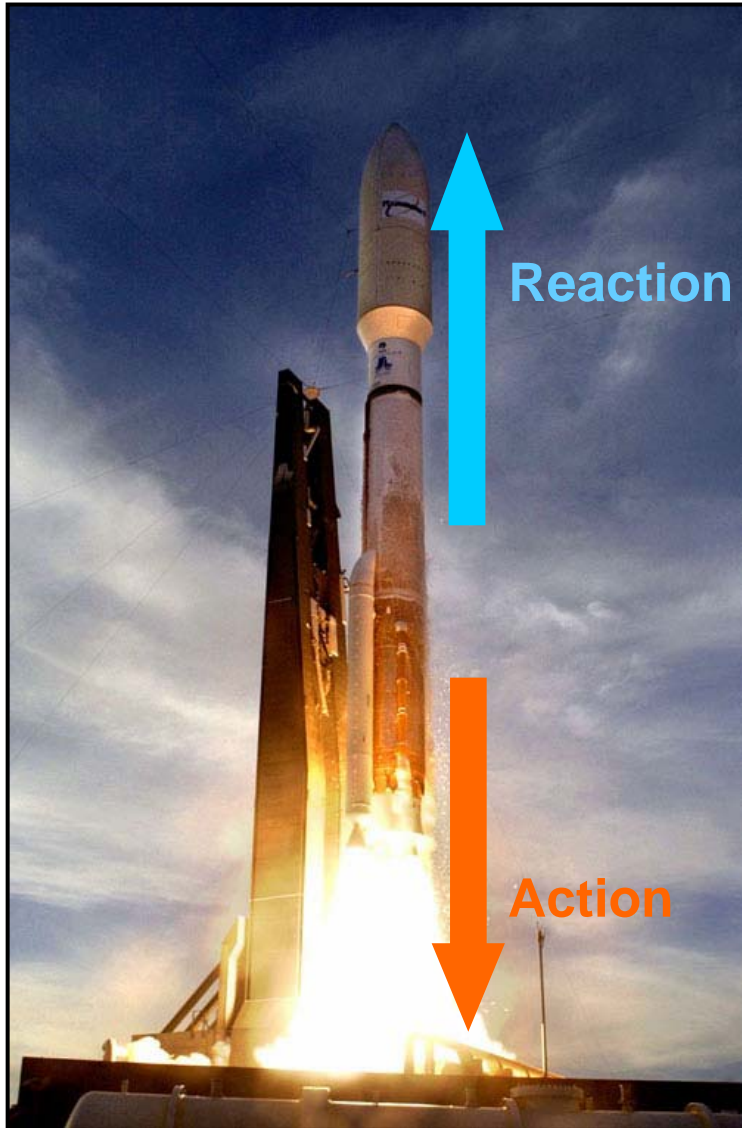
Agenda

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- Propulsion Fundamentals
- Propulsion Solutions for Mission Applications
- Propulsion Related Business Challenges

What is Rocket Propulsion?

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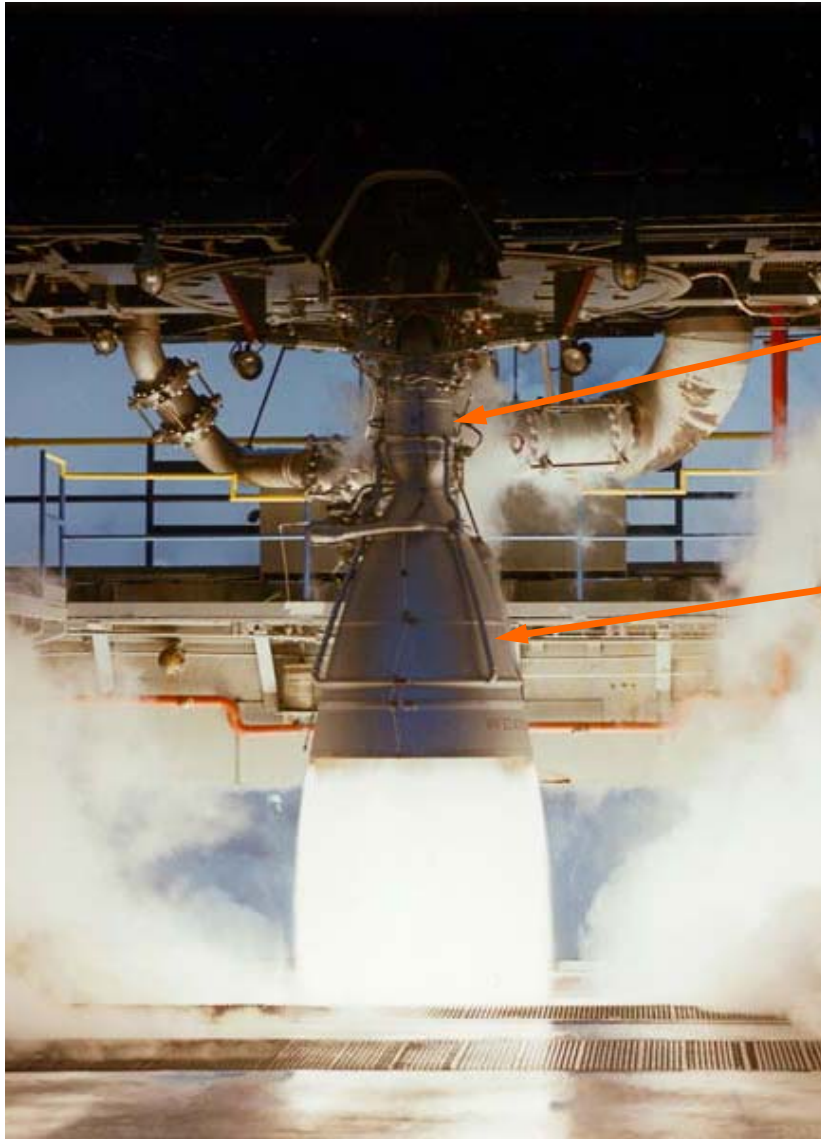


Newton's Third Law of Motion

- Every Action has an Equal and Opposite Reaction
- The Action is the Rocket Engine Exhaust Jet Momentum
- The Reaction is the Rocket Vehicle Mass and Vehicle Acceleration

How is the Action Achieved?

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- A Rocket Engine is basically an Internal Combustion Heat Engine
- The high velocity exhaust gas is created by combusting a solid, liquid, or gaseous fuel with an oxidizer in a combustion chamber
- The extremely hot gas passes through a Bell Shaped Nozzle which accelerates the gas, thus converting most of the Thermal Energy into Kinetic Energy

There Are Two Key Requirements of a Rocket Engine

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1. Thrust (F)

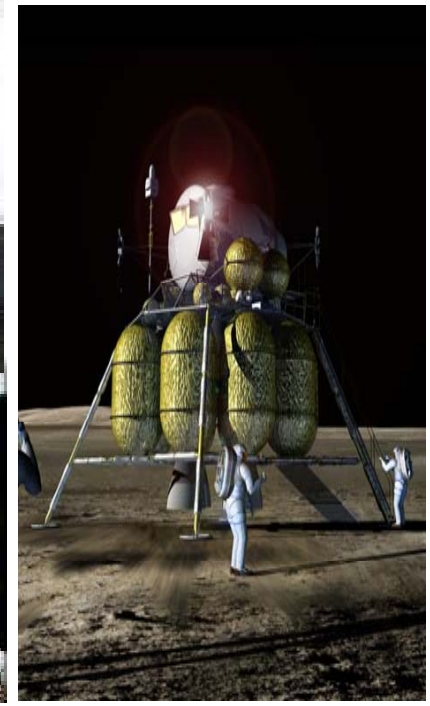
- The amount of force required of the rocket engine (thrust) to accelerate a vehicle or payload

2. Specific Impulse (Isp)

- The efficiency of the rocket engine. Isp represents the change in momentum (Impulse) per unit of propellant.
- The higher the Isp, the less propellant needed to gain momentum
- Isp is similar to the gas mileage of a car

Propulsion Solutions Highly Dependant of Type and Phase of Mission

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Boost

- These are the BIG rocket engines required to lift the Fully Loaded Rocket in the Highest Gravity
- Typically Solid Propulsion, Liquid Propulsion, or a Combination of Liquid and Solid
- Thrust is key design driver

Second Stage

- On a Two Stage Rocket, these are smaller than Boosters and are either Solid Propulsion or Liquid Propulsion
- Isp is key design driver

In-Space

- There are many types of In-Space Propulsion
 - Reaction or Attitude Control Propulsion – adjust the pitch / yaw of spacecraft
 - Roll Control – create or null spacecraft roll
 - Orbital Maneuvering Propulsion – provides axial velocity

Landers

- Propulsion for Descent, Ascent, and Reaction Control for Landing on Moon, Mars, or other planetary bodies

Liquid Boost / Second Stage Propulsion Characteristics

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Titan A50/NTO Booster



SSME LOX/Hydrogen Booster



AJ-26 LOX/Kerosene Booster

- **Earth Storable Propellants (Aerozine 50 Fuel / Nitrogen Tetroxide Oxidizer) -- Titan**
 - **Benefits:** Long term storage, hypergolic combustion (no separate ignition source required), relatively high Isp performance (pump fed), High Maturity
 - **Challenge:** High Toxicity of propellants – special handling required with extensive infrastructure, high cost of propellants
- **Cryogenic Propellants (Liquid Oxygen Oxidizer / Liquid Hydrogen Fuel) – Space Shuttle**
 - **Benefits:** Very high Isp Performance, Fuel is Excellent Coolant, High Maturity
 - **Challenge:** Pumping cryogenic propellants, oxygen compatible materials, low density fuel requires large tanks on vehicle, complex engine cycles (pump fed), reliability
- **Liquid Oxygen/Kerosene (RP-1) – Atlas V, Delta II, Titan I**
 - **Benefits:** High Isp Performance, High density fuel requires smaller fuel tanks on vehicle, fuel is good coolant, simple engine cycles (pump fed)
 - **Challenge:** Oxygen compatible materials, reliability, Low Maturity in United States

Solid Boost Propulsion Characteristics

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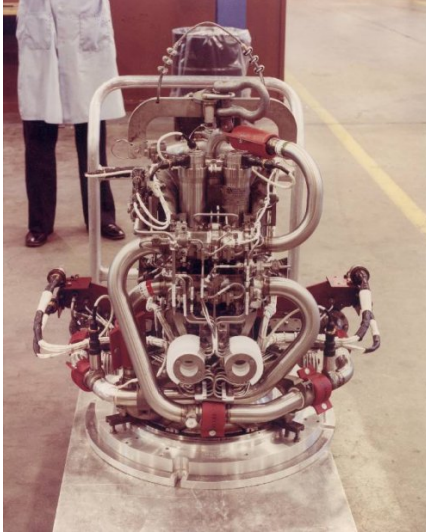


Atlas V Solid Rocket Booster

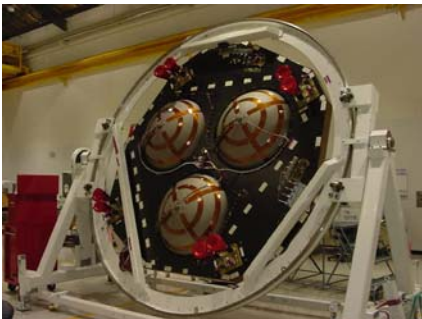
- **Solid Oxidizer / Solid Fuel – Atlas V, Space Shuttle SRB, Delta II, etc.**
 - **Benefits: High Density Propellants, Simplicity, Very long term storage, Lower Cost than Liquids, High Maturity**
 - **Challenge: Relatively Low Isp Performance, High Weight, Reliability**

In-Space and Lander Propulsion Characteristics

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Shuttle OME



X-38 Deorbit Module Monopropellant

- **Earth Storable Liquid Propellants (MMH/NTO)**
 - **Benefits:** Relatively High Isp Performance, High Reliability (pressure fed), Highly Mature Design
 - **Challenge:** Propellant toxicity (handling), Expensive propellants, Deep Throttle Capability (Landers)
- **Cryogenic Liquid Propellants (LOX/Hydrogen or Methane)**
 - **Benefits:** Very High Isp Performance (pressure fed), Non-toxic
 - **Challenge:** Long Term Space Storage of Cryogenic Propellants, Low Maturity
- **Hydrazine Monopropellant**
 - **Benefits:** Very simple operation, high reliability
 - **Challenge:** Low Isp Performance

Rocket Propulsion Industry Outlook Positive

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- **NASA ARES and Orion Program Providing “Boost” to Propulsion Industry**
 - Major Propulsion Related Design and Development Activities
 - Major Updates of Existing Rocket Engines
 - Some New Rocket Engine Development, i.e., LOX/Methane propellants
 - Interest in Nuclear Rocket Engine Development for Manned Mars Missions
- **Non-Traditional Commercial Space Propulsion Becoming a Reality**
 - Emphasis on low cost payload to orbit
- **Continued Support of Existing Launch Vehicles**
 - Space Shuttle
 - EELV
 - ...

However, There Are Still Challenges

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- **Programs Have Limited Funding**
 - **High Development Costs Drive to Reuse of Existing/Heritage Systems**
 - **New Propulsion Technology Developments are Lightly Funded with Long Timelines**
 - **Difficult to Build or Recruit Technical Expertise**
 - **Drive to Low Cost / High Reliability**
 - **Extensive Modeling and Simulation Required**
 - **Improved Manufacturing and Test Methods Required**
 - **Balance of Low Cost with Mission Assurance Requirements**
 - **Propulsion Industry Standard is 100% Mission Success**
 - **Shrinking Supplier Base**
 - **New Suppliers Require Extensive Training to Support Aerospace Quality Standards**