SpaceTEC®

National Aerospace Technical Education Center

Vehicle Processing Readiness Course

Aerospace Systems

Instructed by: Bill Fletcher

Outline

- Basic Flight Principles
- Safety
- Orbits
- Propulsion
- Structure and Electromechanical Systems

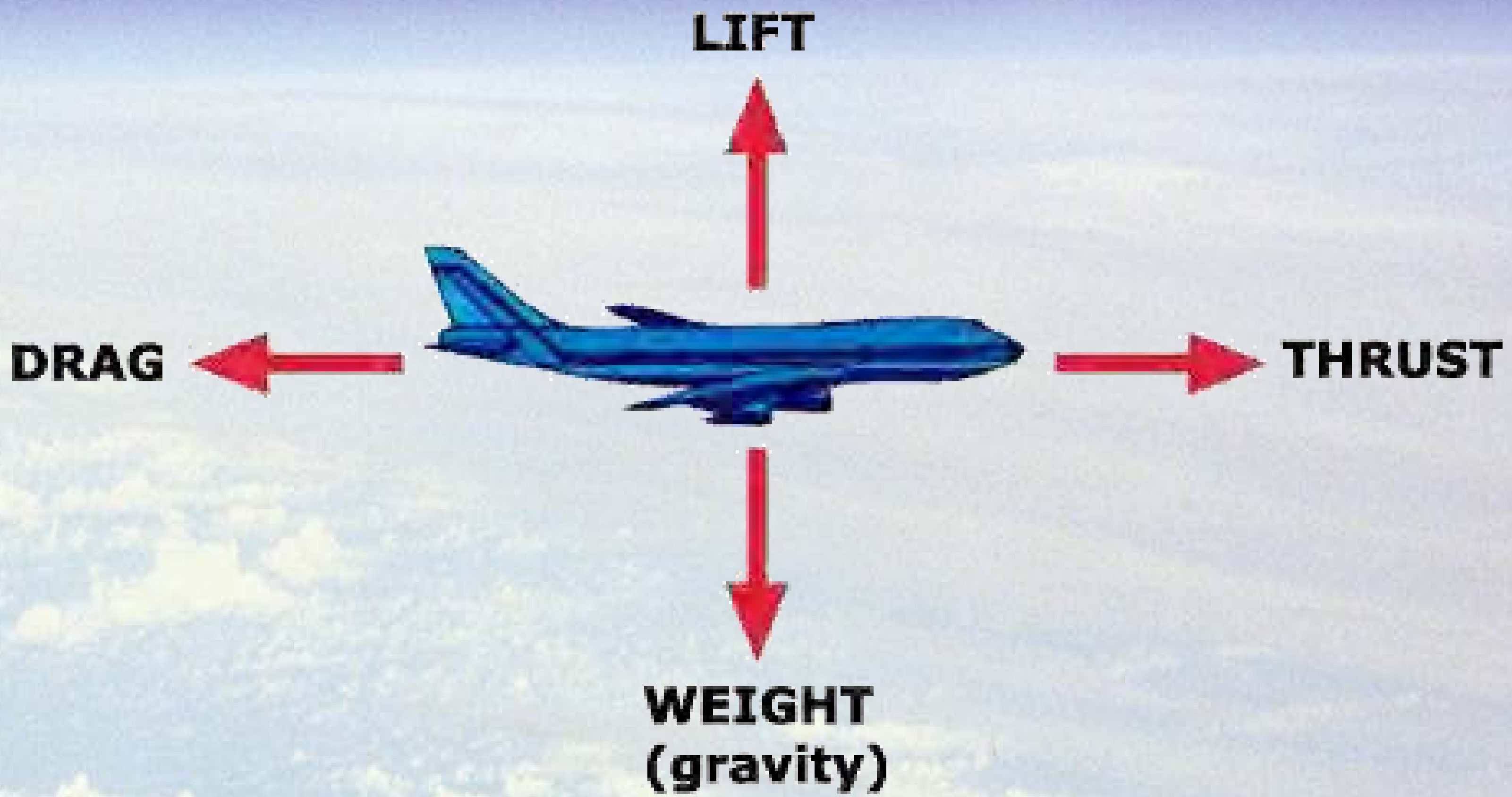
Basic Flight

- Systems
- Forces on a launch vehicle
- Flight control axis
- Center of pressure, center of mass
- Mass fraction
- Staging
  - Purpose
  - Parallel vs. serial staging
- Atmospheric pressure and Max Q

Systems

- A system is an assemblage of inter-related elements comprising a unified whole. A secondary or subordinate system, usually capable of operating independently of, or asynchronously with, a controlling system.
- Assembly: a group of machine parts that fit together to form a self-contained unit
- Part: something determined in relation to something that includes it;

In-Flight Forces



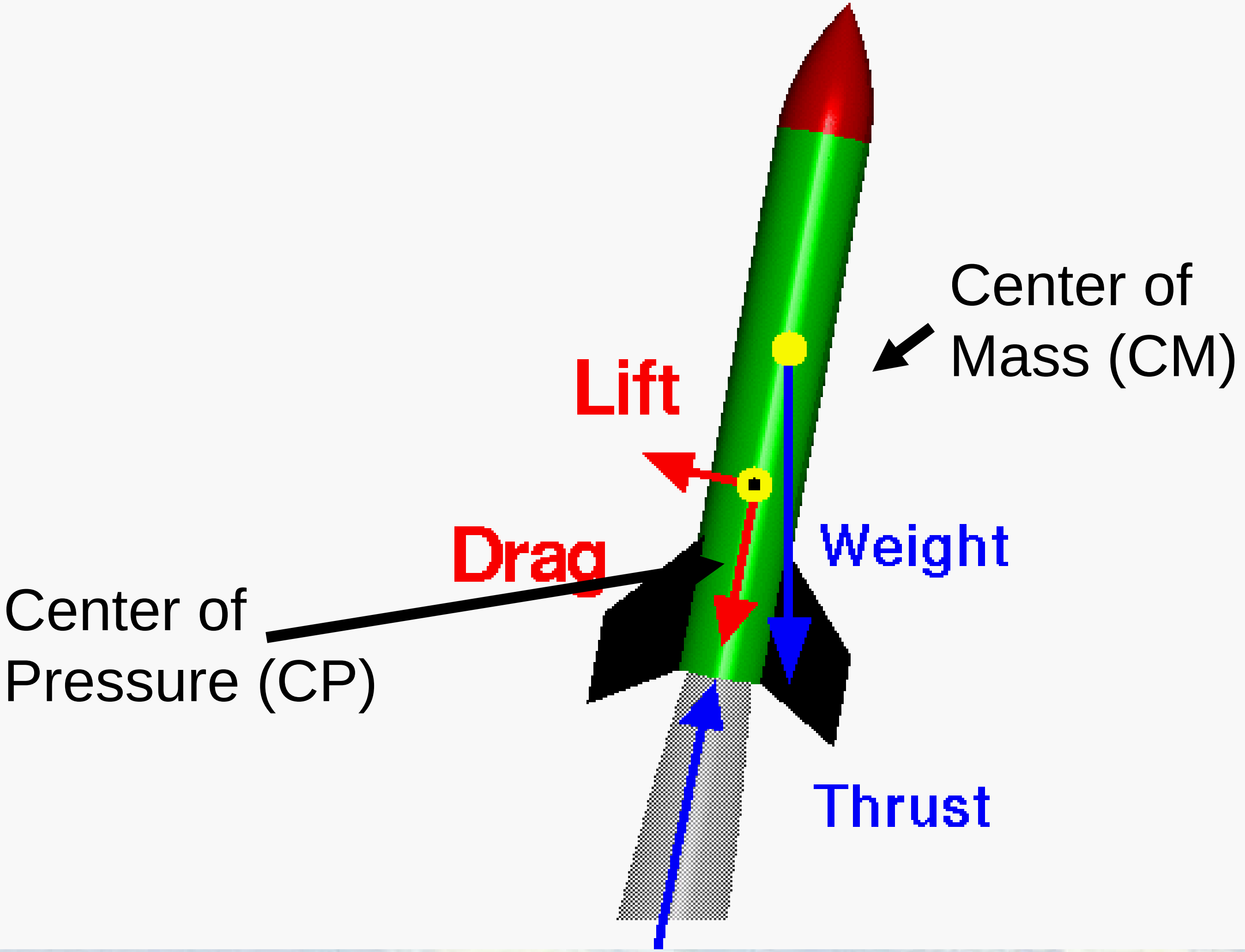
Control Axis

- Control Axis
  - Pitch
    - Up and down
  - Yaw
    - Side to side
  - Roll
    - Around “thrust” axis
- Co-ordinate Systems
  - X, Y and Z Axis

Vehicle Control

- Center of mass (CM) – that point where all the mass of that object is perfectly balanced
  - It is the point about which a unstable rocket will tumble
- Center of pressure (CP) – that point where the aerodynamic forces are balanced in flight
  - Uneven forces will cause vehicle to tumble
- Typically CP needs to be aft on vehicle and CM needs to be forward for best stability
- Difference in CP and CM provide moment arm to help establish vehicle control

Rocket Aerodynamics



Mass Fraction

$$\text{Mass Fraction} = \frac{\text{Mass of Propellants}}{\text{Total mass of vehicle}}$$

Typical mass fractions are in range of .82 (Shuttle) to .91 for some expendables

To overcome issues of mass fraction process of staging of vehicles is used

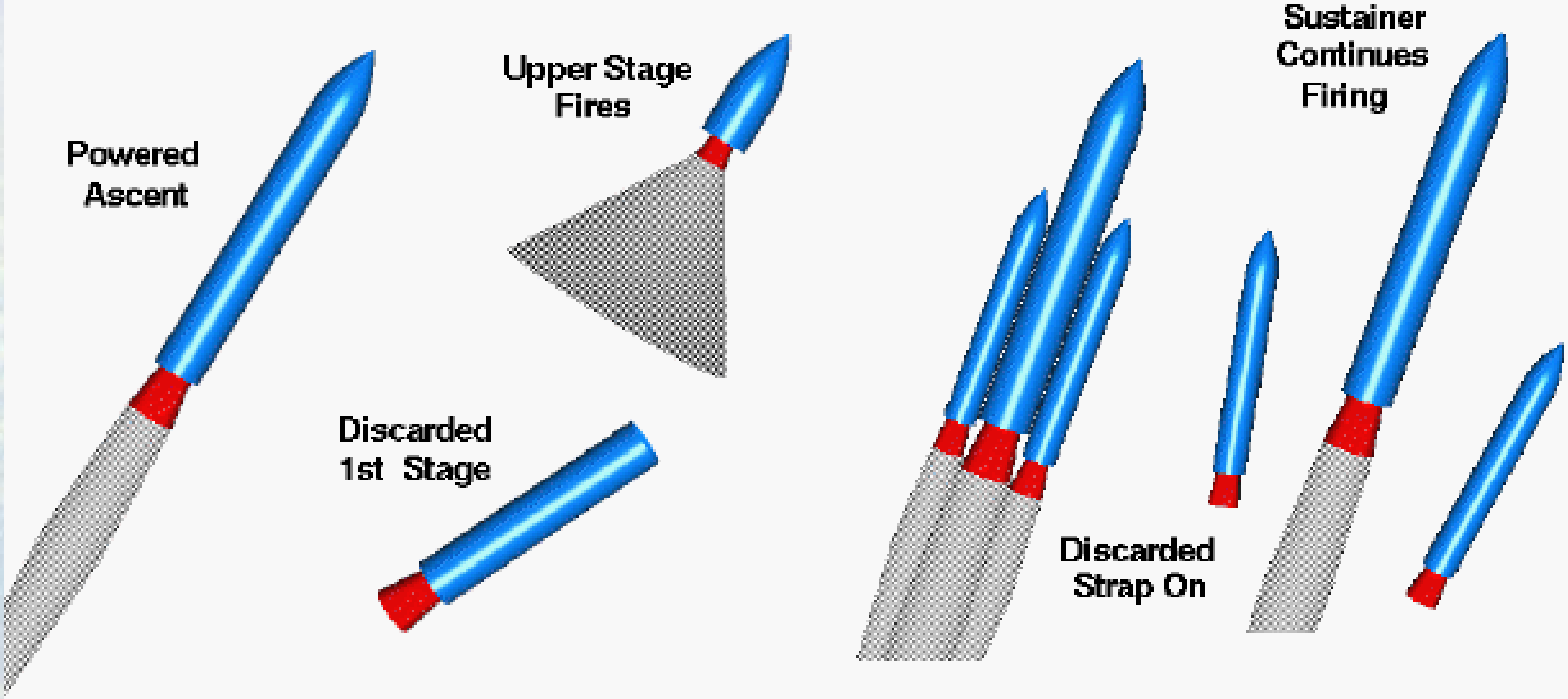
As tanks are emptied, excess structure is deleted

Staging

- Parallel Staging
  - All stages lit at once
  - Stages drop off as used
- Series Staging
  - Stages are lit one after the other

Booster Staging

Glenn
Research
Center



Serial Staging

Parallel Staging

Atmospheric Pressure and Max Q

- Max Q – place where vehicle goes through max dynamic pressure on vehicle
  - Created by speed of vehicle and density of air.
  - As vehicle speed increases forces on vehicle increase
  - As air density goes down dynamic forces on vehicle decrease
  - At first velocity builds up forces on vehicle, then as density goes down these forces drop off

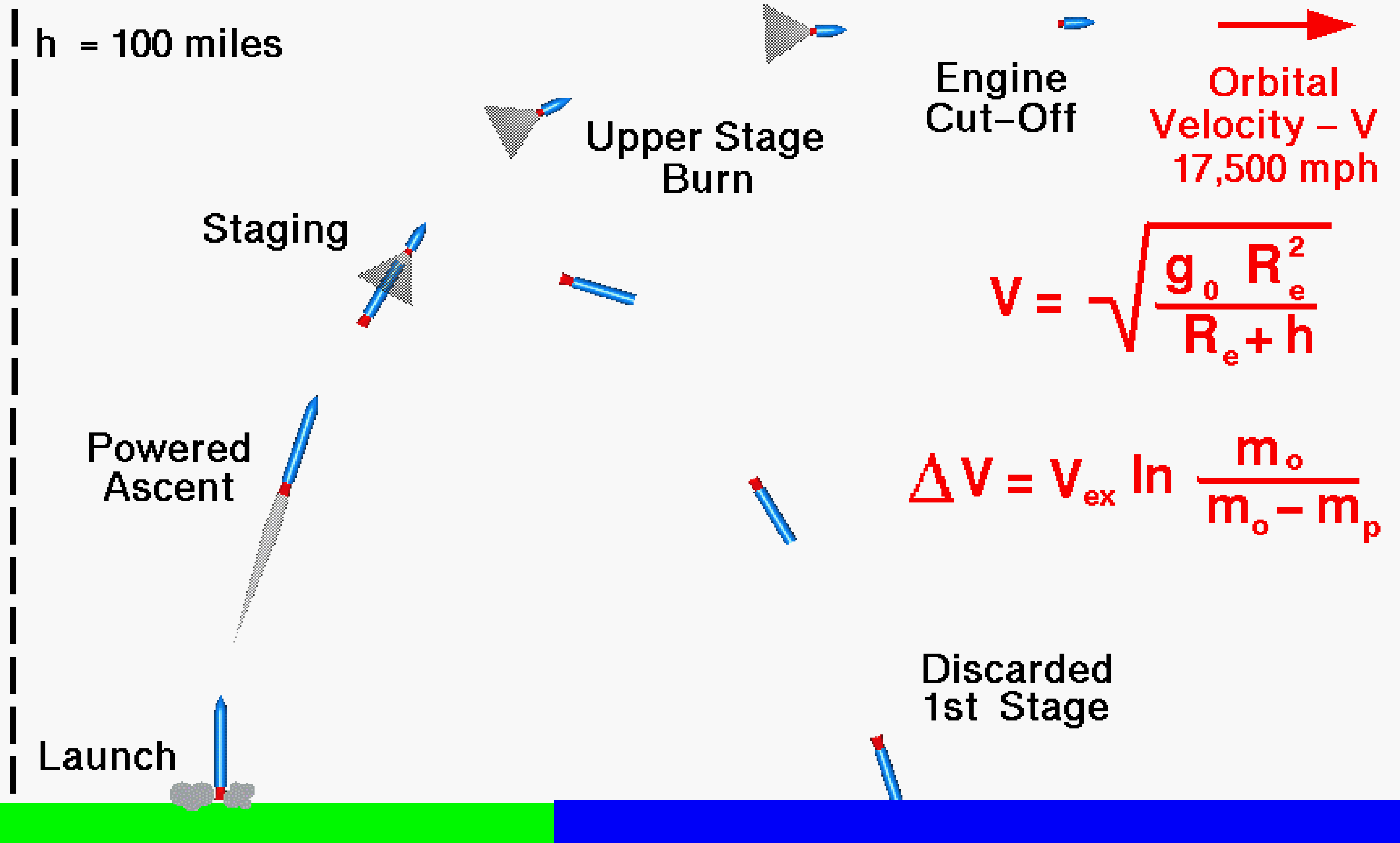
Safety

- Review of procedures
- Emergency Preparedness Documents
- Use of life support apparatus
- Personnel requirements
- Final launch authority
- Launch authority for commercial launches

Orbital Mechanics

- East Coast launches vs. west coast launches
- Types of orbits
- Orbit requirements for specific missions

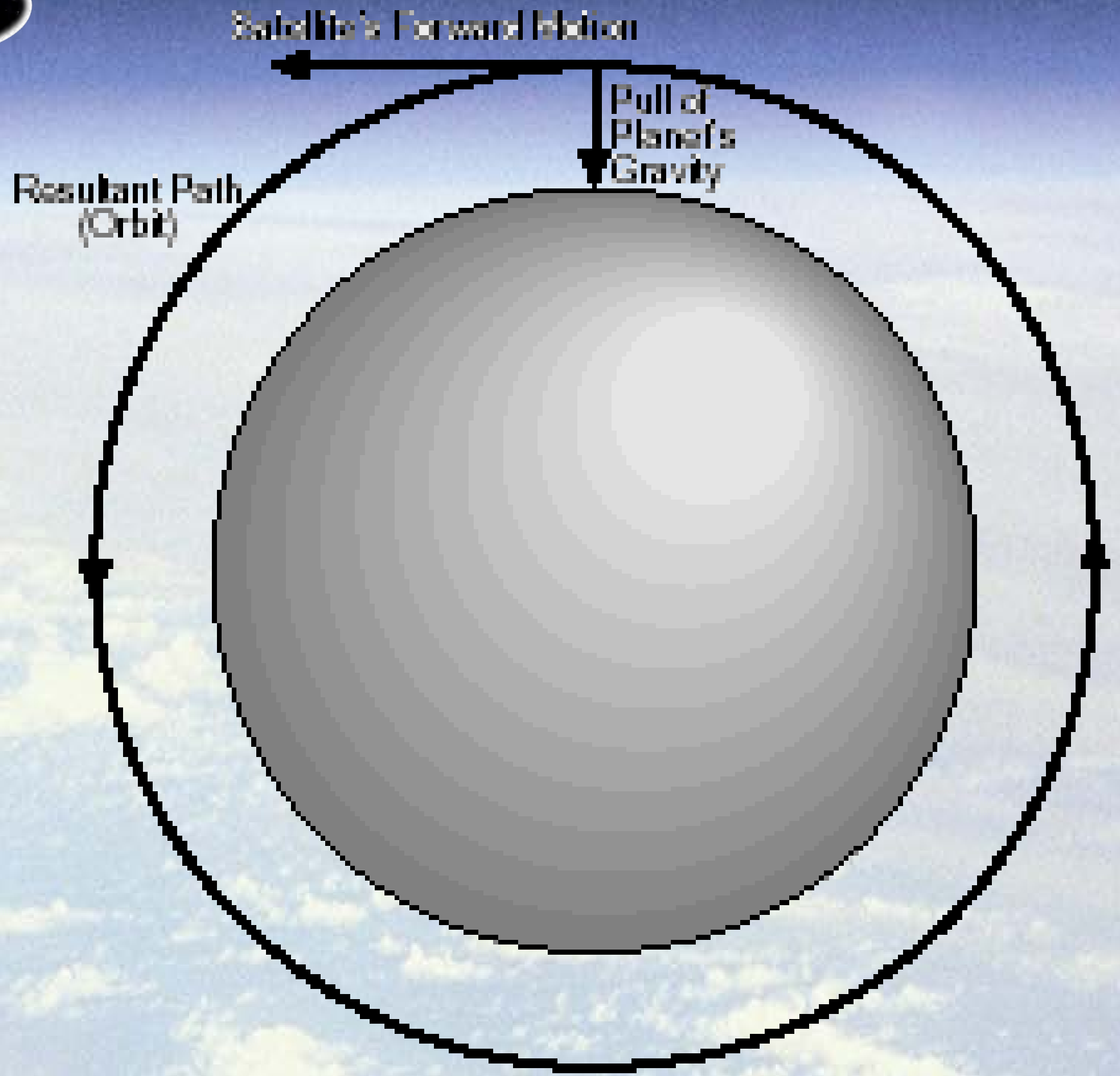
Flight to Orbit



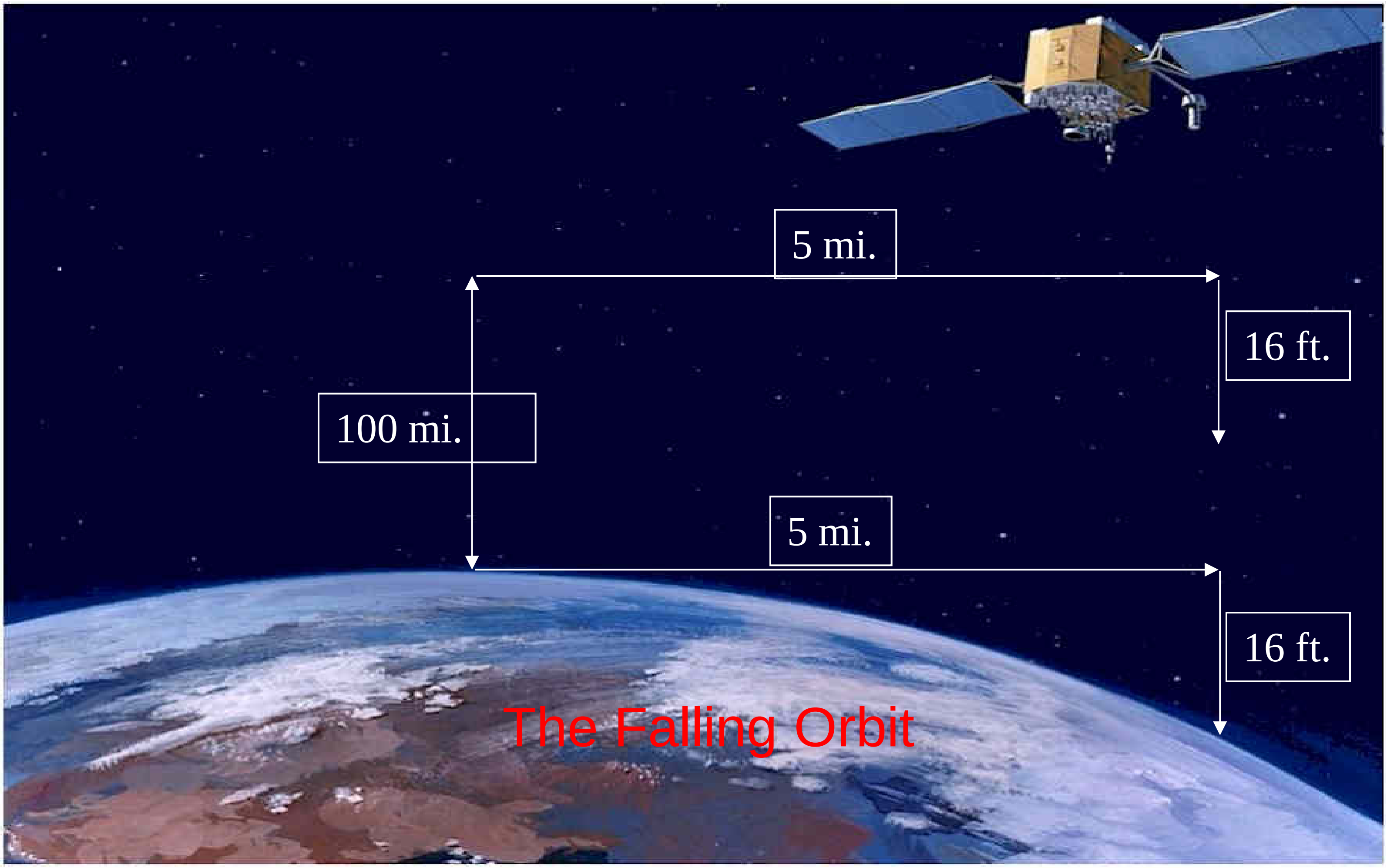
$$V = \sqrt{\frac{g_0 R_e^2}{R_e + h}}$$

$$\Delta V = V_{ex} \ln \frac{m_o}{m_o - m_p}$$

Orbits



Satellite's Forward Motion
Pull of
Planet's
Gravity
Resultant Path
(Orbit)


5 mi.
16 ft.
100 mi.
5 mi.
16 ft.
The Falling Orbit

Typical Orbits

- Low earth orbit (LEO)
  - Space Station, space science, earth observation, space observation
- Polar orbits (Sun synchronous)
  - Ability to pass over same spot on earth at same time of day
  - Weather forecasting and earth observation
- Intermediate orbits
  - Frequently may be oval
  - GPS, earth and space observation

Typical Orbits

- Geosynchronous transfer orbits
- Geosynchronous orbits
  - Weather and communications satellites
- Lunar Transfer Orbits
- Deep Space Orbits
  - Station Keeping for observations of sun, etc.
  - Deep space exploration
  - Deep Space and Return (Stardust)
  - Other Planets
  - Solar system escape

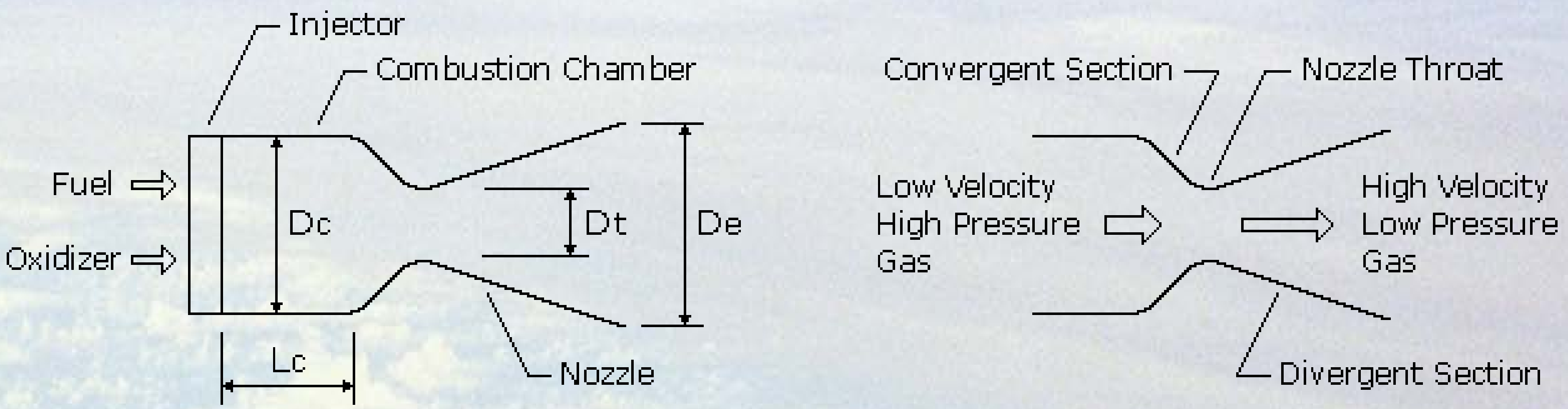
Propulsion Systems

- Thrust
- Major components of a rocket engine
  - Combustion chamber
    - Major parts and function/operation of each
    - Cooling
    - Nozzle design vs. external pressure
    - injectors
- Propellants
  - Types
  - ISP Ratings
  - Families (hypergol, cryo, petroleum)
  - Operating characteristics
    - Self igniting
    - Fuels used with which oxidizers
    - Mixture ratios
    - Relative tank sizes
- Purge gases
  - Which gases used and why
- Solid propellants
  - Typical fuels and oxidizers
  - Grain patterns
  - Safe and arm devices
- Bi-propellant vs. monopropellant engines
- Turbo pump use
- Joining flight plumbing
- Liquid engines starting mechanisms
- Reaction control system
- Bladder tanks

Thrust

- *Thrust* is the force that propels a rocket or spacecraft
  - Is measured in pounds, kilograms or Newtons.
- Physically speaking, it is the result of pressure which is exerted on the wall of the combustion chamber

Typical Rocket Engines

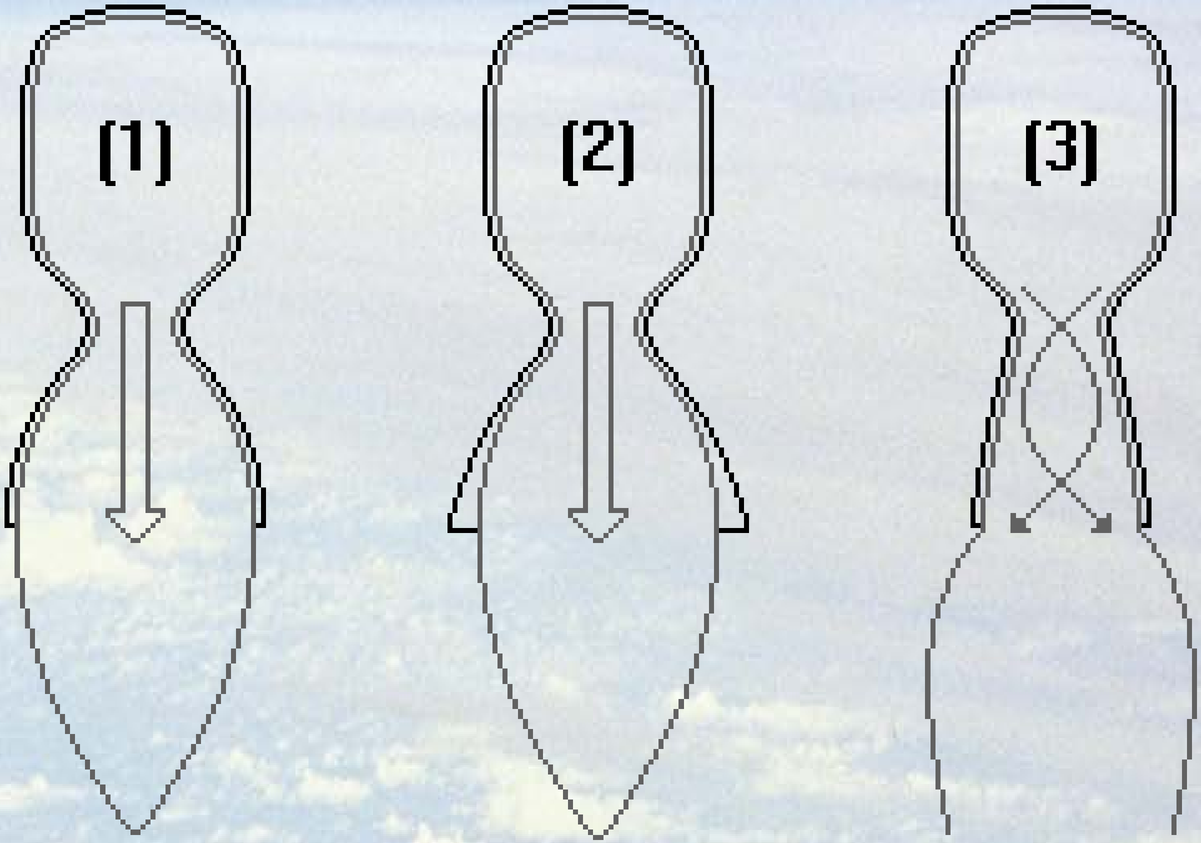


Engine / Nozzle

- Nozzle converts the chemical-thermal energy generated in the combustion chamber into kinetic energy.
  - Converts the slow moving, high pressure, high temperature gas in the combustion chamber into high velocity gas of lower pressure and temperature.

- Thrust is the product of mass and velocity, a very high gas velocity is desirable.

Nozzle Exhaust



Rocket Propellants

- Come in Two forms Liquids and Solids
- Liquids consist of:
  - Petroleum
  - Cryogenic
  - Hypergolic

Materials Selection - Propellants

- When choosing a propellant it is important to consider the following:
    - Isp
    - Density
    - Storage temperature
    - Corrosiveness
    - Reactivity
    - Availability
    - Engine operation
        - Smoothness of combustion
        - Coolant properties

Petroleum

- Fuels which are those refined from crude oil and are a mixture of complex hydrocarbons, i.e. organic compounds containing only carbon and hydrogen.
- The petroleum used as rocket fuel is kerosene, or a type of highly refined kerosene called RP-1 (refined petroleum). It is used in combination with liquid oxygen as the oxidizer.

Cryogenic

- Propellants which are liquefied gases stored at very low temperatures
- Liquid hydrogen (LH2) as the fuel
  - LH2 remains liquid at temperatures of -423 degrees F (-253 degrees C)
- Liquid oxygen (LO2) as the oxidizer
  - LO2 remains in a liquid state at temperatures of -298 degrees F (-183 degrees C).
- Liquid hydrogen delivers a specific impulse about 40% higher than other rocket fuels.

Hypergolic

- Propellants which are fuels and oxidizers which ignite spontaneously on contact with each other and require no ignition source.
- The easy start and restart capability of hypergolics make them ideal for spacecraft maneuvering systems.
- Hypergolics remain liquid at normal temperatures
  - they do not pose the storage problems of cryogenic propellants.
- *Hypergolics are highly toxic and must be handled with extreme care*.

Hypergolic

- Hypergolic fuels commonly include:
  - hydrazine,
  - monomethyl hydrazine (MMH)
  - unsymmetrical dimethyl hydrazine (UDMH).
- The oxidizer is typically nitrogen tetroxide (N2O4) or nitric acid (HNO3).

PROPERTIES OF LIQUID ROCKET PROPELLANTS

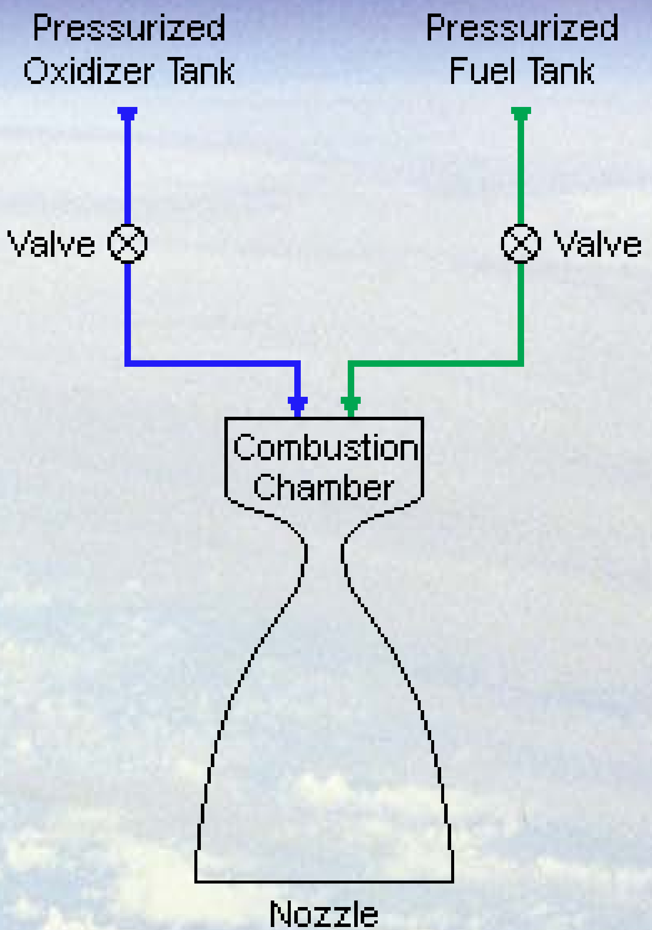
Compound	Chemical Formula	Molecular Weight	Density	Melting Point	Boiling Point
Liquid Oxygen	O_2	32.00	1.141 g/ml	-218.8^{o}C	-183.0^{o}C
Nitrogen Tetroxide	N_2O_4	92.01	1.45 g/ml	-9.3^{o}C	21.15^{o}C
Nitric Acid	HNO_3	63.01	1.55 g/ml	-41.6^{o}C	83^{o}C
Liquid Hydrogen	H_2	2.016	0.071 g/ml	-259.3^{o}C	-252.9^{o}C
Hydrazine	N_2H_4	32.05	1.004 g/ml	1.4^{o}C	113.5^{o}C
Methyl Hydrazine	CH_3NHNH_2	46.07	0.866 g/ml	-52.4^{o}C	87.5^{o}C
Dimethyl Hydrazine	$(CH_3)_2NNH_2$	60.10	0.791 g/ml	-58^{o}C	63.9^{o}C
Dodecane (Kerosene)	$C_{12}H_{26}$	170.34	0.749 g/ml	-9.6^{o}C	216.3^{o}C

NOTES:
(1) Chemically, kerosene is a mixture of hydrocarbons; the chemical composition depends on its source, but it usually consists of about ten different hydrocarbons, each containing from 10 to 16 carbon atoms per molecule; the constituents include ***n*-dodecane**, alkyl benzenes, and naphthalene and its derivatives.
(2) Nitrogen tetroxide and nitric acid are hypergolic with hydrazine, MMH and UDMH. Oxygen is not hypergolic with any commonly used fuel.

Power Cycles

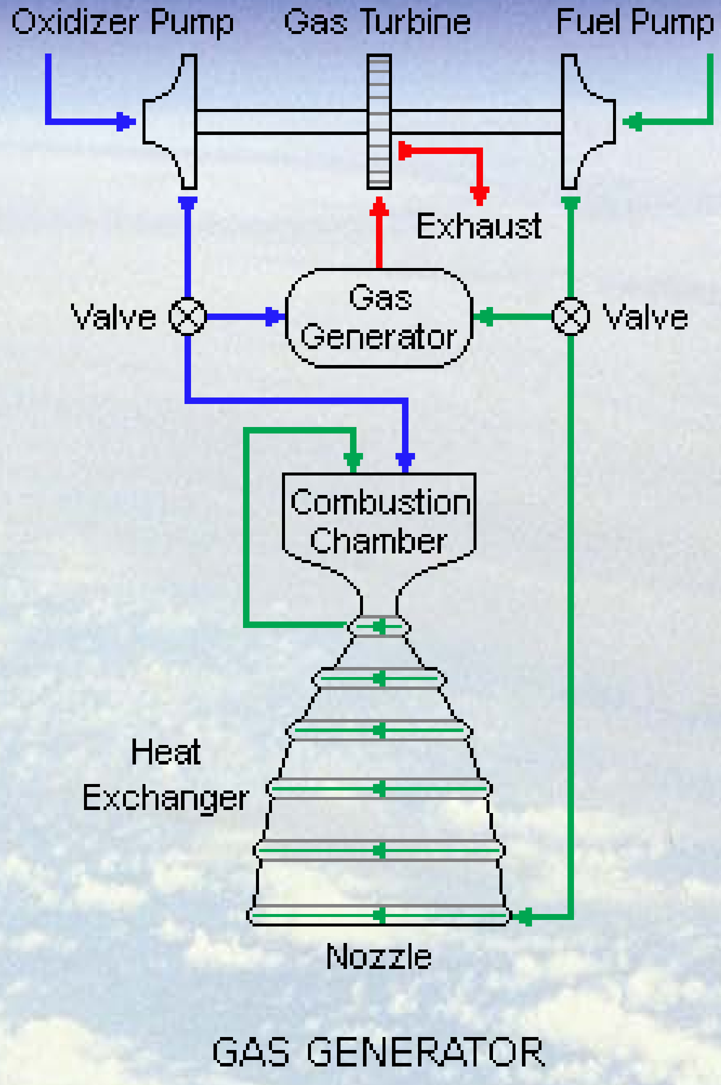
- Liquid bipropellant rocket engines can be categorized according to their power cycles, that is, how power is derived to feed propellants to the main combustion chamber.

Pressure-fed cycle:

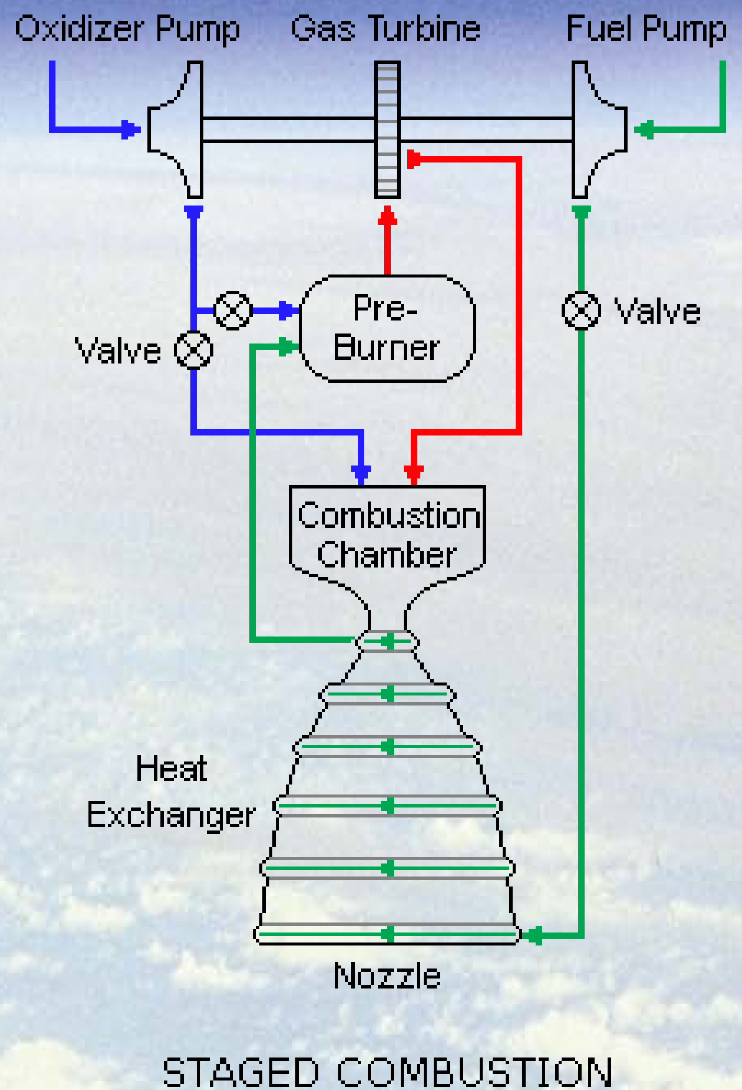


PRESSURE-FED

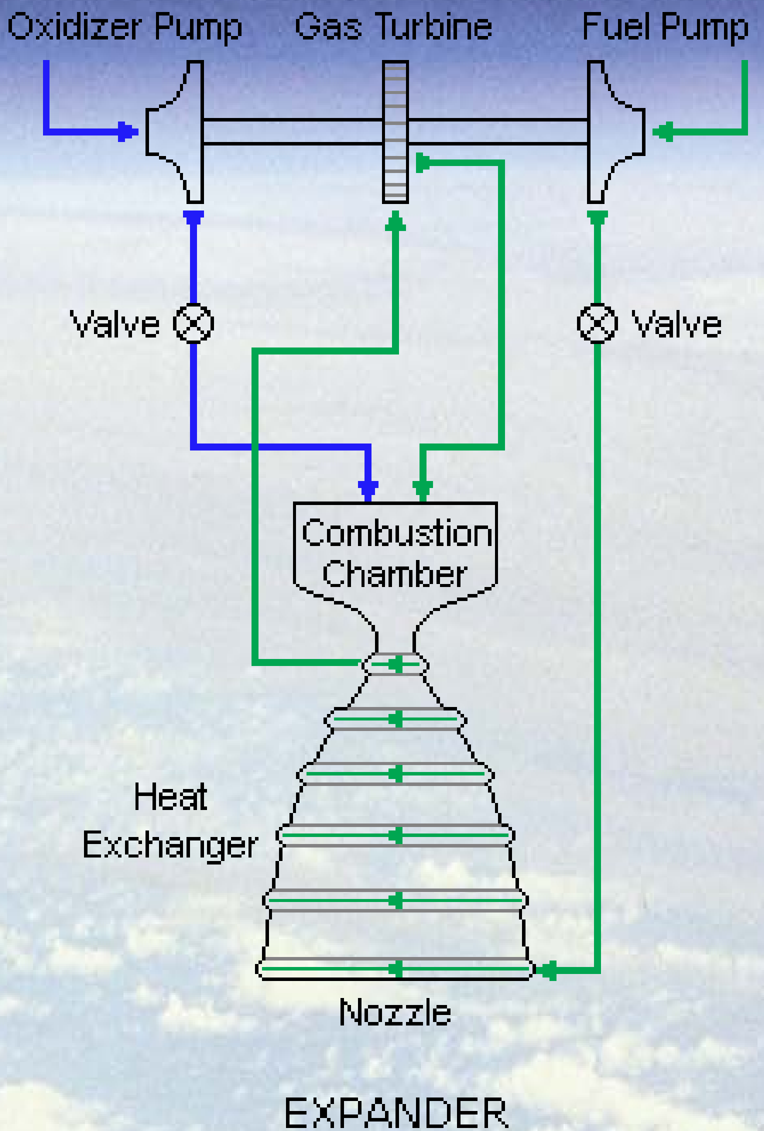
Gas Generator Cycle



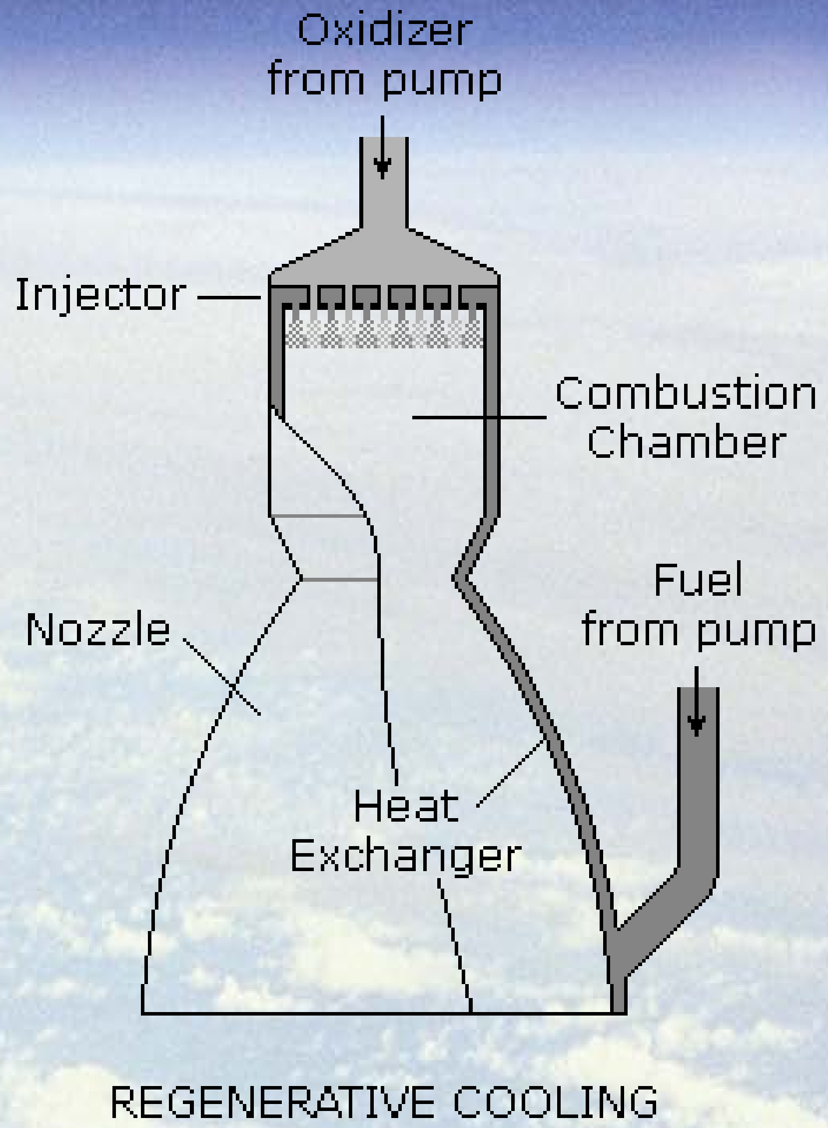
Staged combustion cycle



Expander cycle:

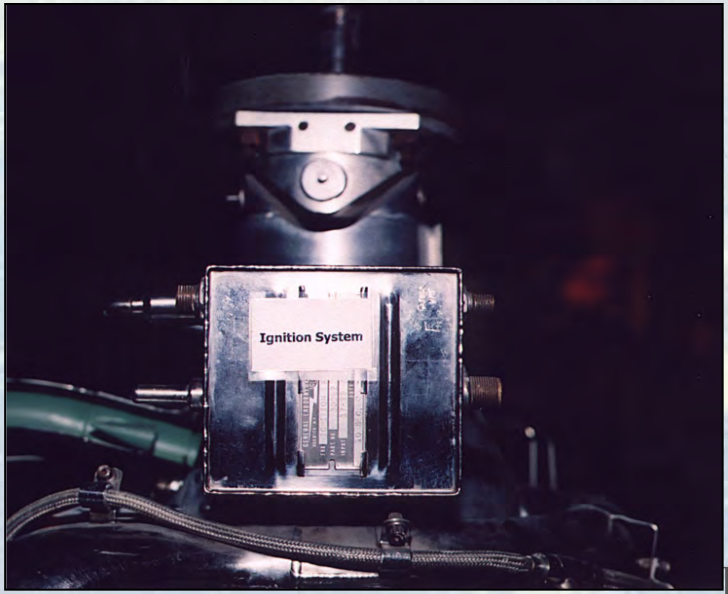


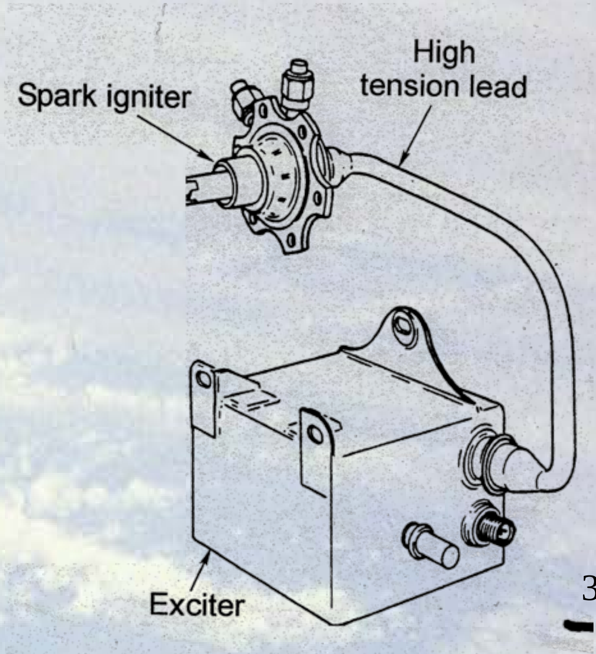
Regenerative Cooling



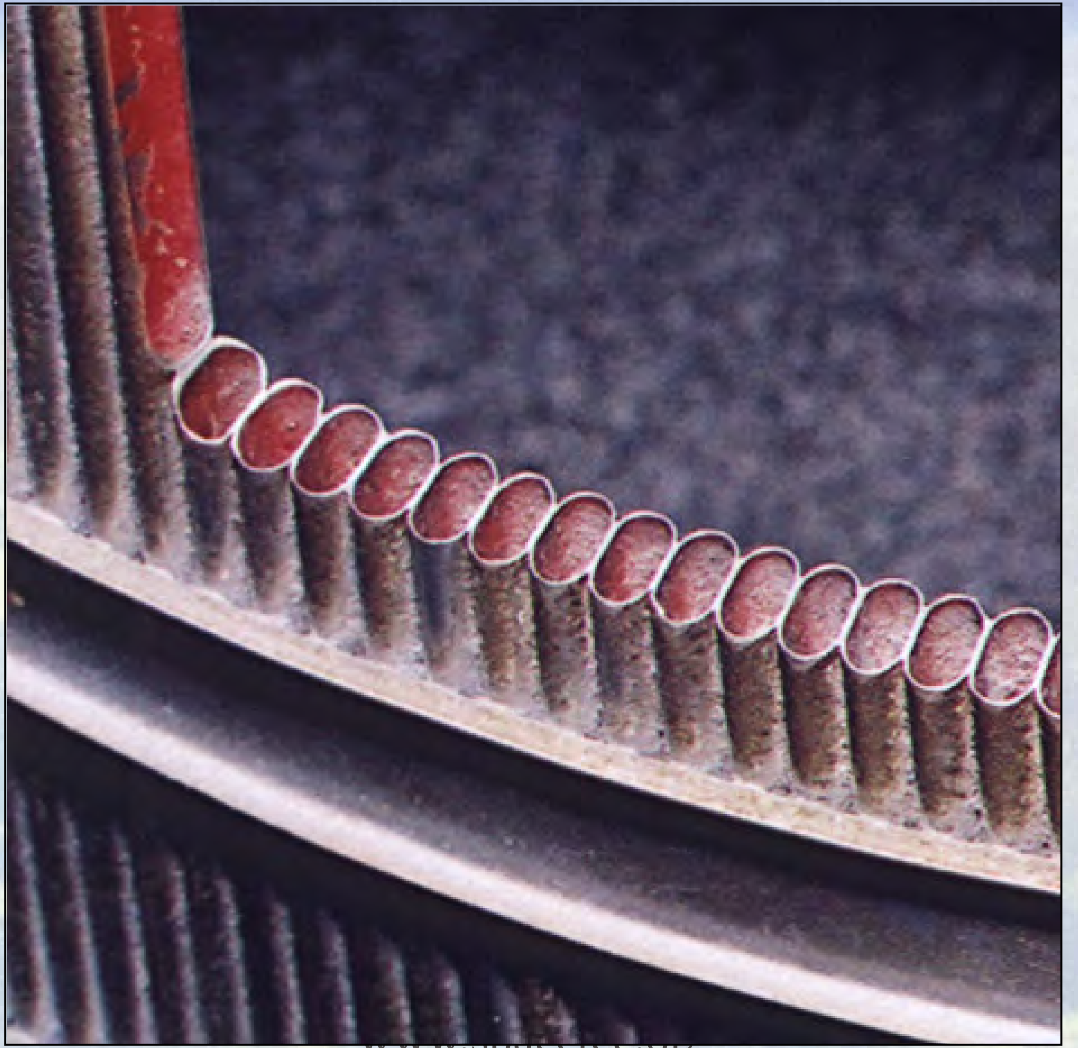
RL-10 Engine Ignition sub-system

A spark igniter protruding through the injector face achieves ignition. A high energy electrical spark is produced by an exciter through a high-tension lead to the igniter.

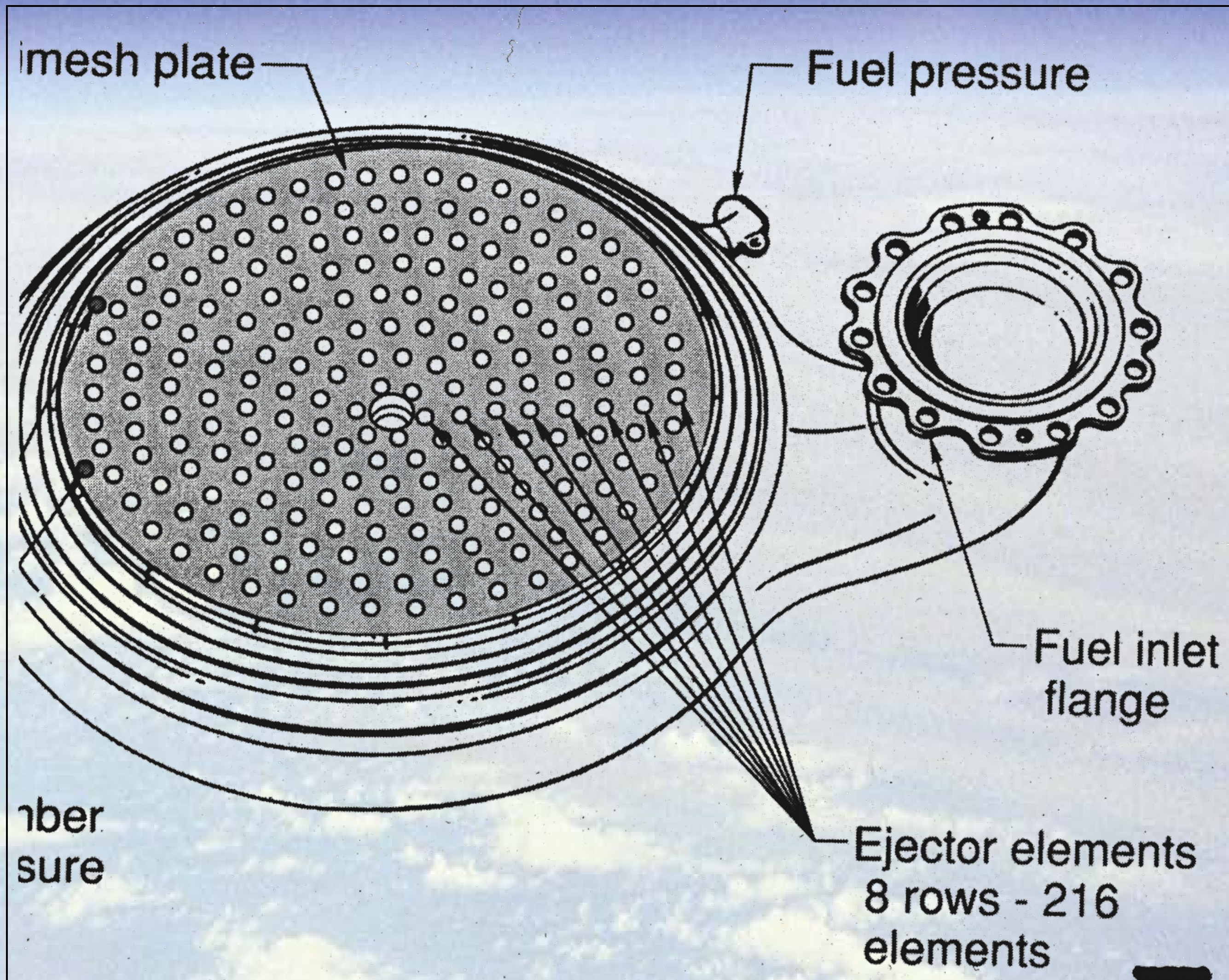




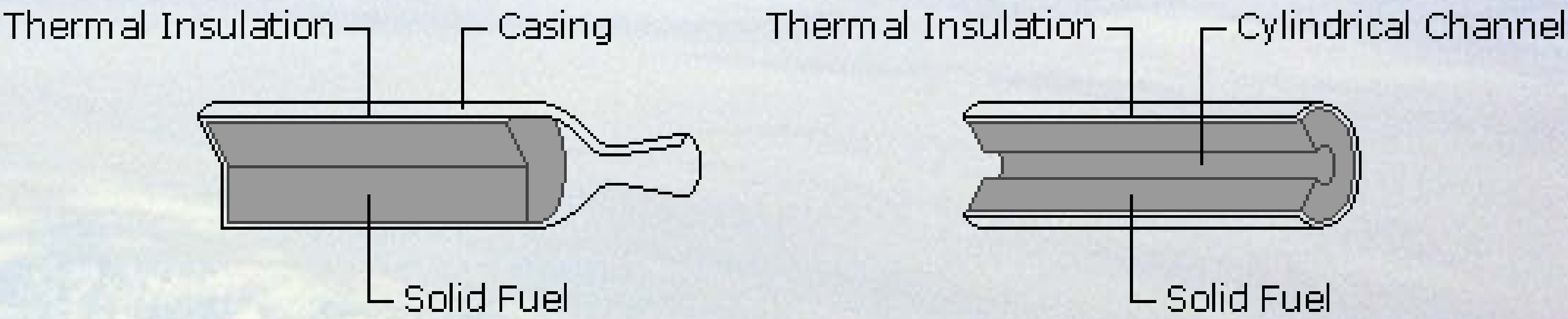
RL-10 Engine Nozzle Coolant Tubes



RL-10 Engine Injector



Typical Solid Motor Configuration



Solid Propellants

- There are two families of solids propellants: homogeneous and composite. Both types are dense, stable at ordinary temperatures, and easily storable.
- Homogeneous propellants are either simple base or double base. A simple base propellant consists of a single compound, usually nitrocellulose, which has both an oxidation capacity and a reduction capacity. Double base propellants usually consist of nitrocellulose and nitroglycerine, to which a plasticiser is added. Homogeneous propellants do not usually have specific impulses greater than about 210 seconds under normal conditions. Their main asset is that they do not produce traceable fumes and are, therefore, commonly used in tactical weapons. They are also often used to perform subsidiary functions such as jettisoning spent parts or separating one stage from another.

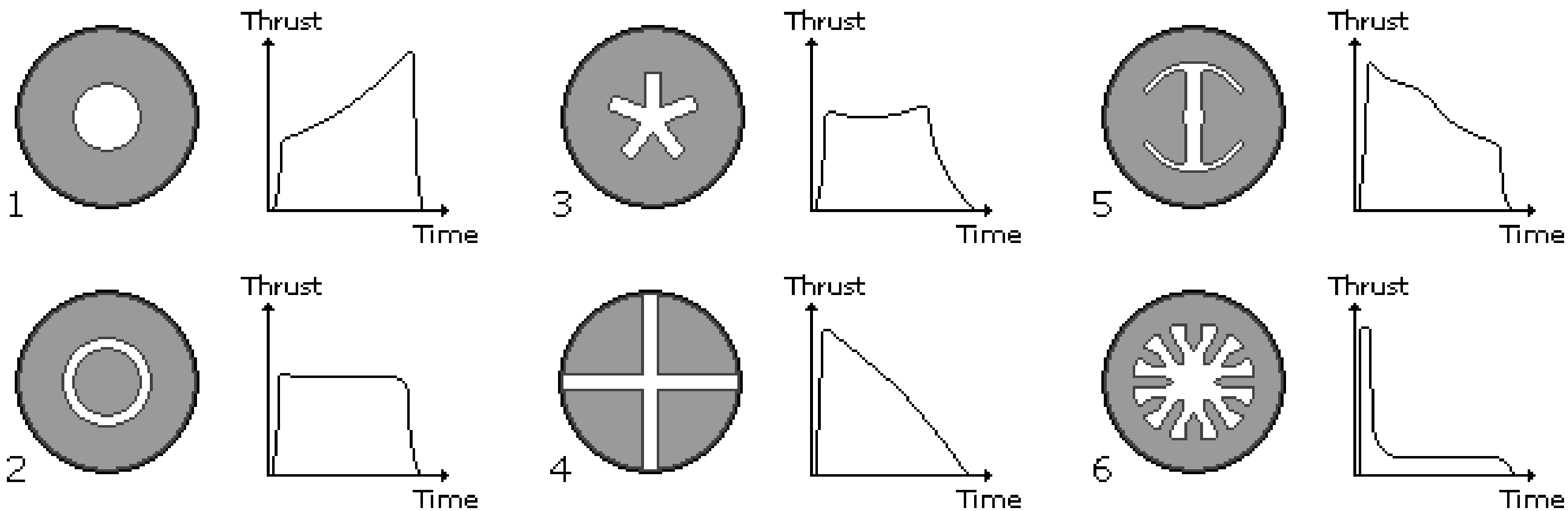
Solid Propellants

- Modern composite propellants are heterogeneous powders (mixtures) which use a crystallized or finely ground mineral salt as an oxidizer, often ammonium perchlorate, which constitutes between 60% and 90% of the mass of the propellant. The fuel itself is aluminum. The propellant is held together by a polymeric binder, usually polyurethane or polybutadienes. Additional compounds are sometimes included, such as a catalyst to help increase the burning rate, or other agents to make the powder easier to manufacture. The final product is rubberlike substance with the consistency of a hard rubber eraser.

Propellant	**Type**	**Composition**
Balistite (USA)	Double Base Homogeneous	Nitrocellulose (51.5%), Nitroglycerine (43.0%), Plasticiser (1.0%), Other (4.5%)
Cordite (Soviet)	Double Base Homogeneous	Nitrocellulose (56.5%), Nitroglycerine (28.0%), Plasticiser (4.5%), Other (11.0%)
SRB Propellant	Composite	Aluminum Powder (16%) as fuel, Ammonium Perchlorate (69.93%) as oxidizer, Iron Oxidizer Powder (0.07%) as catalyst, Polybutadiene Acrylic Acid Acrylonitrile (12.04%) as rubber-based binder, Epoxy Curing Agent (1.96%)

NOTE:
The density of solid rocket propellants range from 1.5 to 1.85 g/ml (95-115 lb/cf). SRB propellant has a density of 1.715 g/ml (107 lb/cf).

The shape of the fuel block for a rocket is chosen for the particular type of mission it will perform. Since the combustion of the block progresses from its free surface, as this surface grows, geometrical considerations determine whether the thrust increases, decreases or stays constant.



- Structures
  - Purpose of structure
  - Isogrids
- Electromechanical devices
  - Purposes
  - characteristics
    - torques
    - drive direction
    - limit switches
    - brakes

- Two major categories
  - The ***Primary*** structure or main structure
    - Purpose is to transmit loads to the base of the satellite through specifically design components (central tube, honeycomb platform, bar truss, etc.).
    - Provides the attachment points for the payload and the associated equipments.
    - Failure of the primary structure leads to a complete collapse of the satellite

- Two major categories
  - ***Secondary*** structures
    - Such as baffles, thermal blanket support and solar panels must only support themselves and are attached to the primary structure which guaranties the overall structural integrity.
    - A secondary structure failure is not a problem for the structural integrity, but it could have some important impacts on the mission if it alters the thermal control, the electrical continuity, the mechanisms or if it crosses an optical path.

- For the new generation of large satellites, we must consider a third type of structure: ***Flexible appendages*** such as antenna reflectors and solar arrays. These structures have generally low resonant frequencies which interact directly on the dynamic behavior of the satellite and require a special care for design
- Finally, some spacecraft structures are more complex than the ones described above, and cannot be described with general rules due to their uniqueness and particular requirements . Among these are the manned spacecraft structures (orbiter and space station) and the future lunar outposts.

- Resist the loads induced by the launch environment (acceleration, acoustics thermal), met all
- Functional performances required on orbit
  - such as dimensional stability for
  - interface with some other subsystems
    - Thermal control
    - optical components
    - electronic equipment
    - Mechanism
    - etc.

- The typical factors of safety for space structures (unmanned flights) are given in the following list:
  - a) Test qualified structures
    - Qualification level : Flight x 1.45
    - Yield : Qualif. x 1.1
    - Ultimate : Qualif. x 1.25
  - b) Computed structures only
    - Yield : Flight x 2
    - Ultimate : Flight x 3
  - c) Pressure tanks (fracture analysis)
    - Yield : nominal x 1.5
    - Ultimate : nominal x 2.0

- Aluminum
- Steel
- Titanium
- Magnesium
- Beryllium
- Composites
- Ceramics

- Thermal Gradients
- Debris Protection
- Deployable Appendage Constraints
- Aerobrake or Aerothermodynamic Heating

Spacecraft Design Criteria

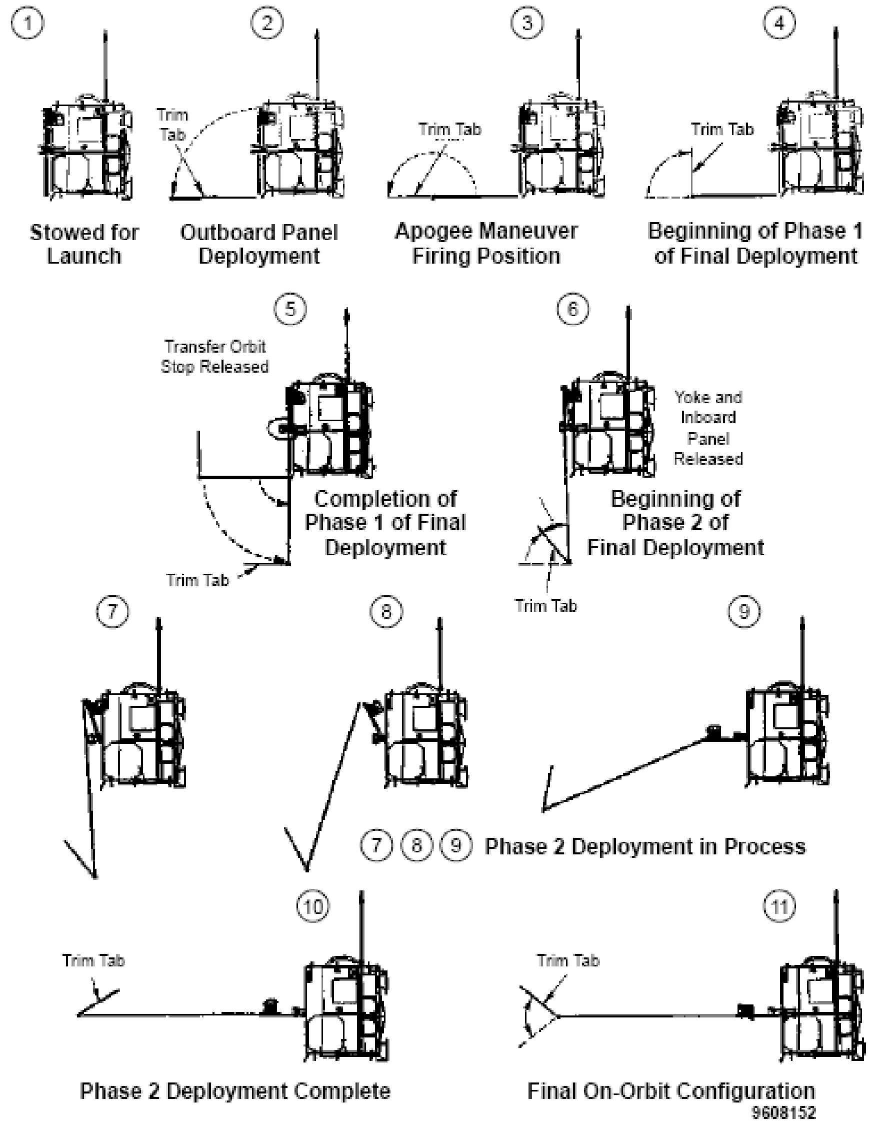
- Mass Distribution
- Mass
- Electrical Grounding
- Design Verification

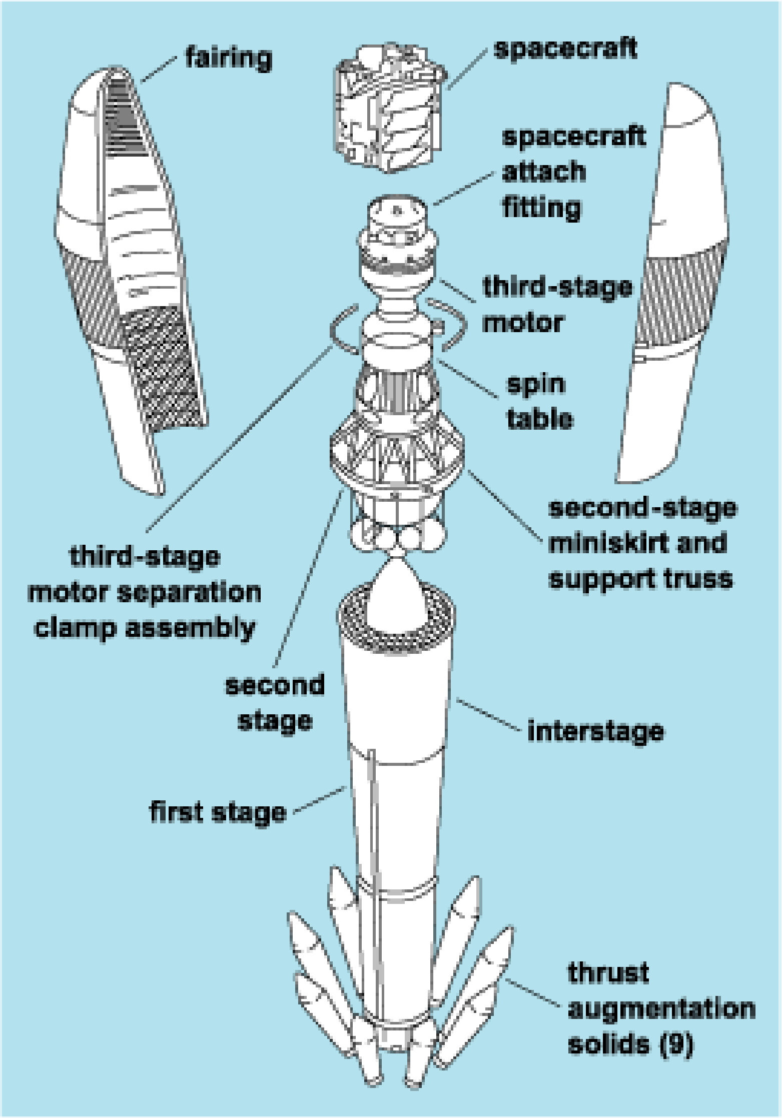
- The deployable appendages are:
  - Solar array
  - Magnetometer boom
  - Solar sail and boom
  - Imager and Sounder radiant cooler covers

- These deployments are initiated by ground commands and occur at three different time periods:
- First, early in the transfer orbit, about 90 minutes after launch, the outer solar panel is partially deployed to about 90° from its launch position, exposing its solar cells to the sun and providing power for the spacecraft during the transfer orbit phase.

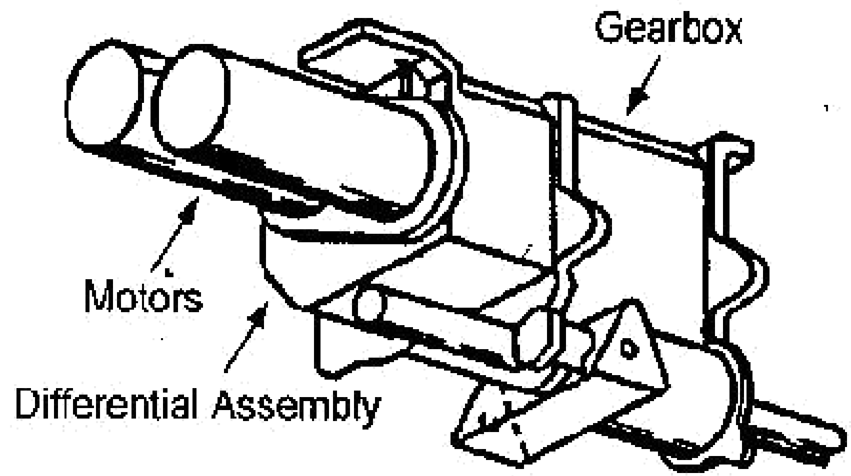
- All of the deployable appendages are released by pyrotechnically driven cutters (electroexplosive devices, EEDs) that cut a tensioned cable or rod holding the appendage in its stowed, launch position.
- The cutters are fired by ground command.
- All cutters are fully redundant with independent knives, firing circuits and commands.
  - If the first cutter does not release the appendage, the redundant cutter may be used later.

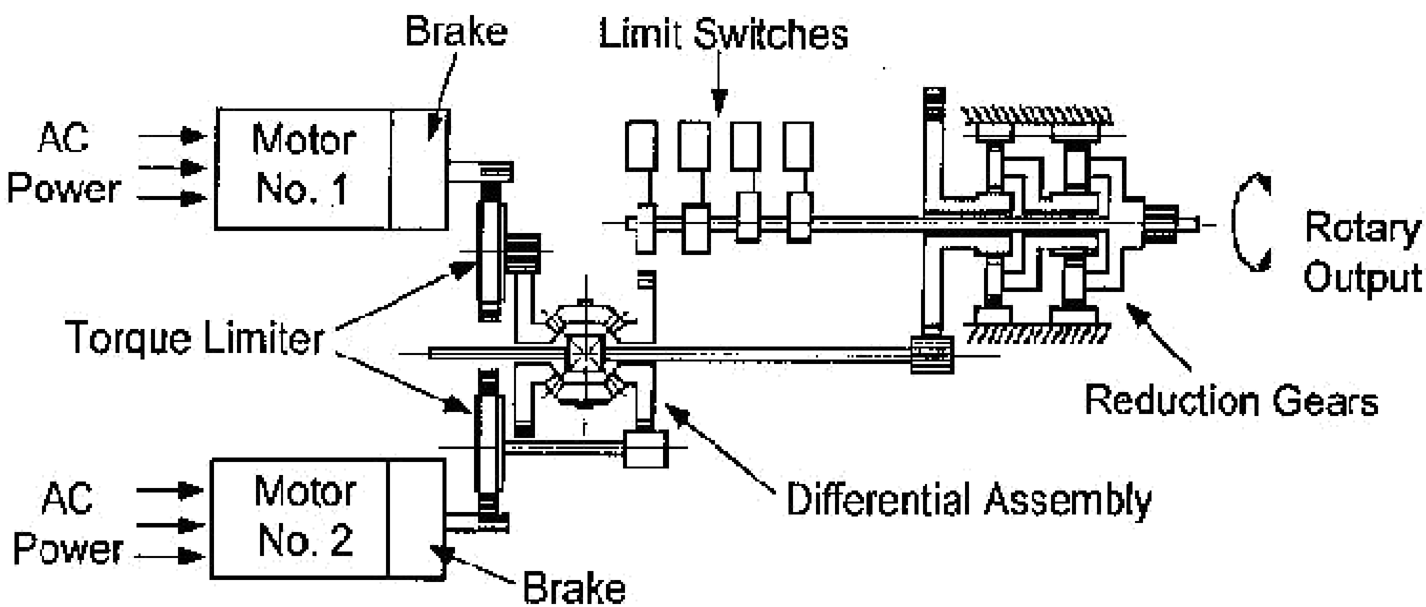
Solar Array Deployment Sequence




fairing
spacecraft
spacecraft attach fitting
third-stage motor
spin table
second-stage miniskirt and support truss
third-stage motor separation clamp assembly
second stage
interstage
first stage
thrust augmentation solids (9)

- Mechanical systems refer to components that must be deployed, stowed, opened, or closed.
- Electromechanical systems use electric motors to provide torque to mechanical linkages.


Gearbox
Motors
Differential Assembly


Brake
Limit Switches
AC
Power
Motor
No. 1
Rotary
Output
Torque Limiter
Reduction Gears
Differential Assembly
AC
Power
Motor
No. 2
Brake

- Brakes prevent the motors from turning when they are unpowered. When power is applied to the motor, the brake will disengage and allow the motor to move.
- The differential uses gearing to combine the output of each AC motor into one output shaft. If two motors are operating, it is referred to as dual-motor drive. If one motor is operating, it is referred to as single-motor drive.

- Torque limiters protect against mechanical or structural damage in case a mechanism binds or jams. The torque limiters will disengage the motor output from the differential output at approximately 1.5 times the normal load.
- The gearbox is the link between the differential and the mechanism to be driven. It contains a series of reduction gears that transfer the low torque/high speed output from the differential to a high torque/low speed output

- Limit switches indicate the state of a mechanism (open, closed, latched, released, deployed, or stowed). There are two limit switches for each state. These limit switches will turn the motors off when the mechanism is driven to the desired position.

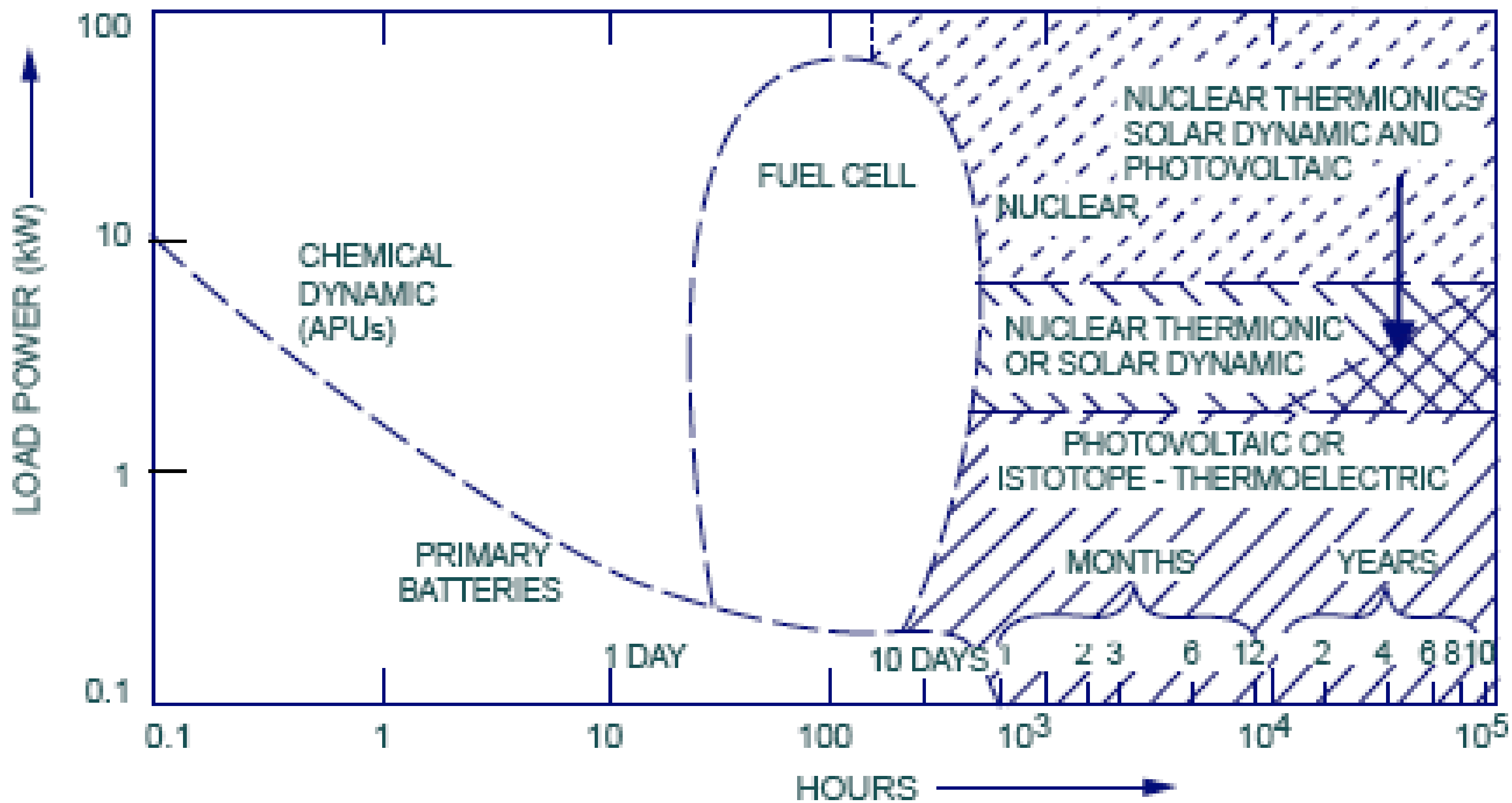
Four major components of a power system
Fuel cell operation
    Operating processes
    Hydrogen/oxygen consumption
    Power supplied
    By-products
Batteries
    Types
    Where used
    Charge Rates
    Measure of capacity
    Connections Parallel vs. series
    Battery servicing operations
    Testing batteries – load tests
    Launch Preparations
	Solar cells
	    operation
	RTG's
	    Method of electrical generation
	Needs for excess power generation
	    Methods of disposing of excess power
	Electrical Distribution
	    Shunt loads - purpose

- Power Source
- Energy Storage
- Power Distribution
- Power Regulation and Control

- Supply power
- Control and distribute
- Support for average and peak loads
- Convert to AC or regulated DC
- Provide health and status to control system
- Protect against failures
- Suppress transients
- Fire ordnance

Primary Batteries	***Radioisotope***
Secondary Battery	Thermionic converter
Fuel cell	Thermoelectric converter
Regenerative fuel cell	***Photovoltaic***
Chemical dynamic	Solar dynamic
Nuclear	Flywheel Storage
Electrodynamics Tethers	Propulsion-charged tether

- Solar Panels
  - Primarily used by payloads
  - Use battery systems as storage
- Radioisotope Thermal Generators
  - Used by payloads for deep space missions where solar panels are not effective
  - Batteries used as storage
- Batteries
  - Prime power supply on ELV’s
- Fuel Cells
  - Prime power supply on Space Shuttle



Approximate ranges of application of different power sources.

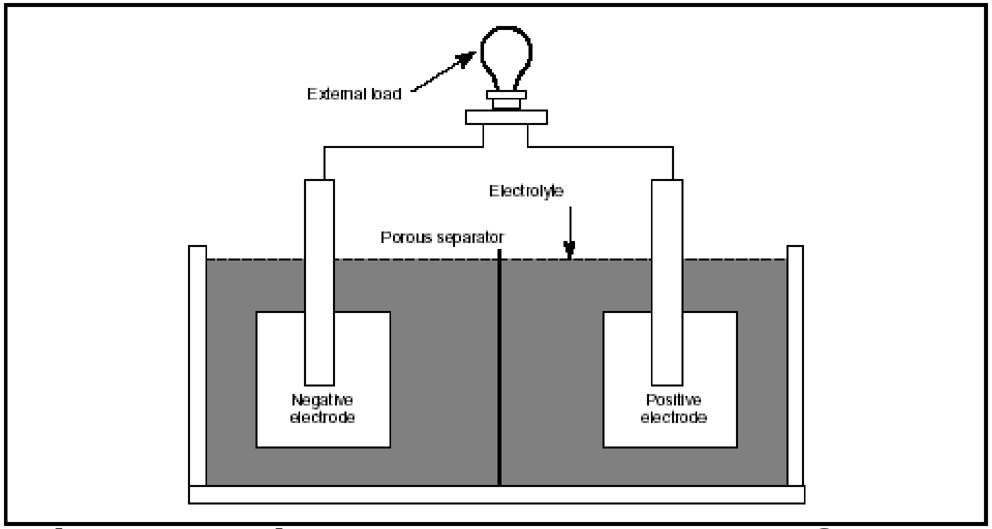
Battery Type	Primary	Secondary
General usage	Flashlight	Auto
Distinguishing Feature	Non-rechargeable	Rechargeable

- Nickel Cadmium
  - Very Rechargeable
  - Mature technology
- Nickel Hydrogen
  - New
  - Very Rechargeable
  - Good Discharge Recovery

- Lead Acid
  - Very Rechargeable
  - Mature technology
  - Heavy
- Lithium
  - High energy
  - Light
- Zinc Silver
  - Very High Current

Table 6.6. Characteristics of secondary batteries for spacecraft use

	Silver zinc	Nickel cadmium	Nickel hydrogen
Energy density (W h/kg)	90	35	75
Energy density (W h/dm^3)	245	90	60
Operating temperature range (°C)	0–20	0–20	0–40
Storage temperature (°C)[a]	0–30	0–30	0–30
Dry storage life	5 yr	5 yr	5 yr[b]
Wet storage life	30–90 days	2 yr	2 yr
Maximum cycle life (approx.)	200	20,000	20,000[b]
Open circuit (V/cell)	1.9	1.35	1.55
Discharge (V/cell)	1.8–1.5	1.25	1.25
Charge (V/cell)	2.0	1.45	1.50
Manufacturers	Eagle-Picher, Yardney Technical Products	Eagle-Picher, Gates Aerospace Batteries	Eagle-Picher, Yardney Technical Products, Gates Aerospace



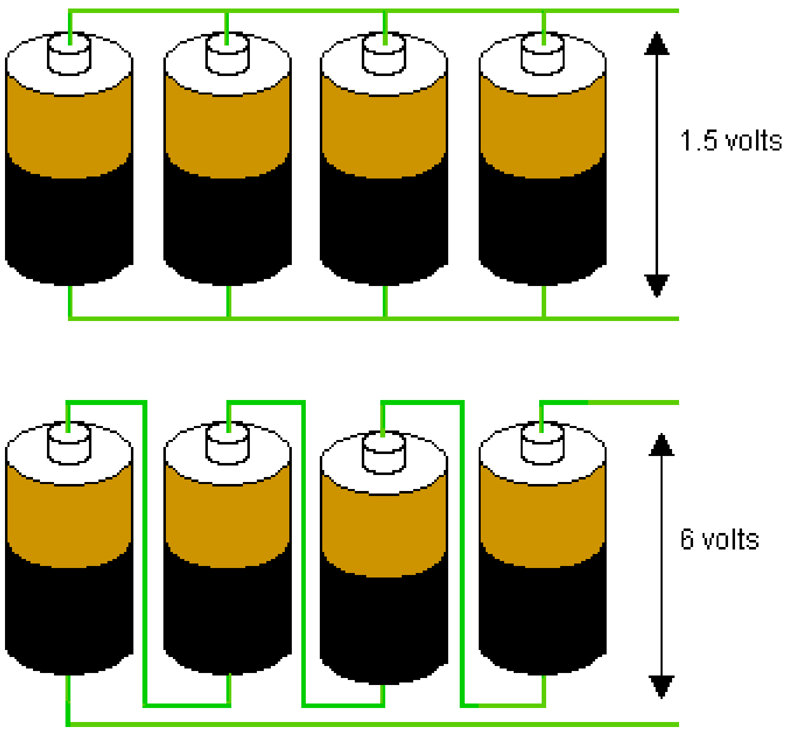
Five major component of a cell

1. Container
2. Negative electrode
3. Positive electrode
4. Electrolyte
5. Separator

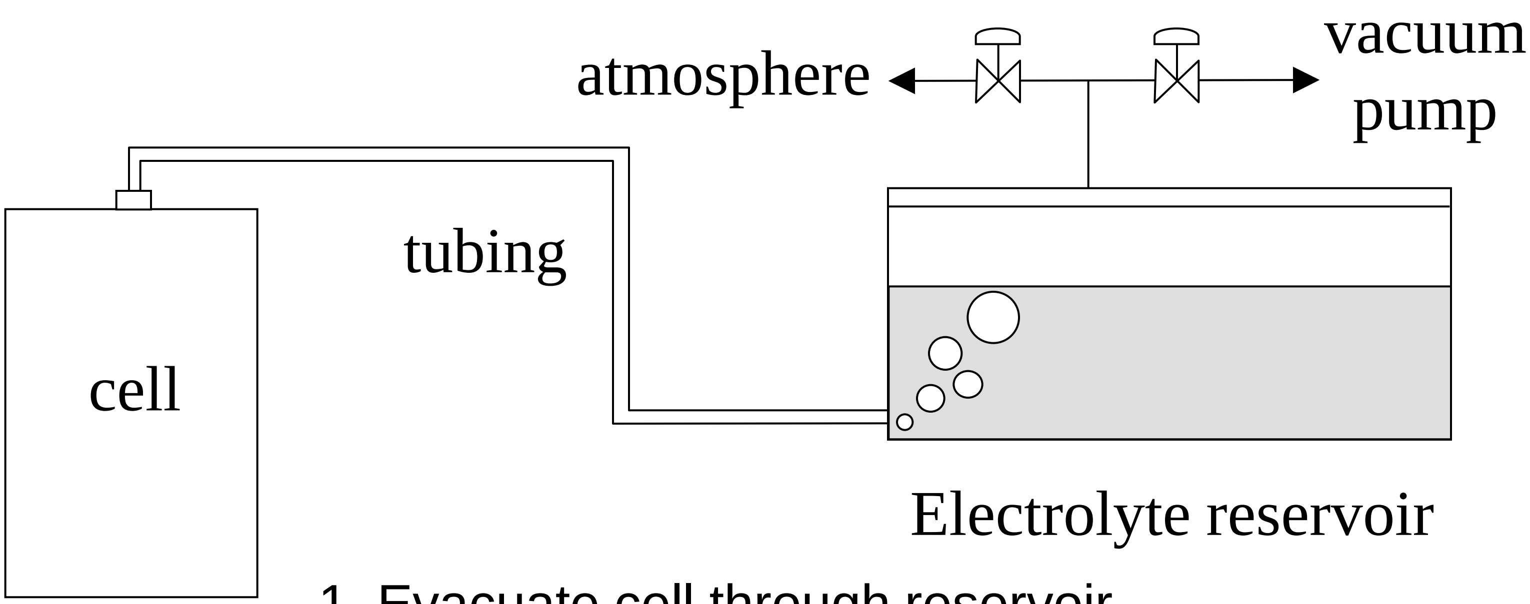
The negative electrode provide electrons to the load and the positive electrode accepts electrons from the load during discharge. The electrolyte provides the positive ions

- Battery Voltage
  - The potential difference between the positive and negative electrodes. Measured in volts
  - For different cells usually runs between 1.25 and 2 volts depending on the type cell and charge state of battery
- Battery capacity
  - The amount of charge available expressed in amp-hours
  - E.G., 200 Ahr battery will deliver 20 amps for 10 hours
  - Capacity may be expressed in “C”-rate as a ratio of capacity
    - **E.G., C/10 rate for 200 Ahr battery == 20 amp**
    - **“C” rate can be used as a charge or discharge rate**.

- Battery arrangement
  - In parallel:
    - currents add
    - Capacity add
  - In series:
    - voltages add



- Vacuum Activation
- Electrolyte Redistribution



1. Evacuate cell through reservoir
2. Force electrolyte into cell
   with atmospheric pressure

- Open Circuit Voltage (OCV)
  - monitor OCV for state of charge
- Conditioning (optional)
  - removes surface charge
  - draws out capacity
- Load Testing
  - reproduces expected flight loads
  - ensures state of health & capacity
- Top Charging
  - restores capacity

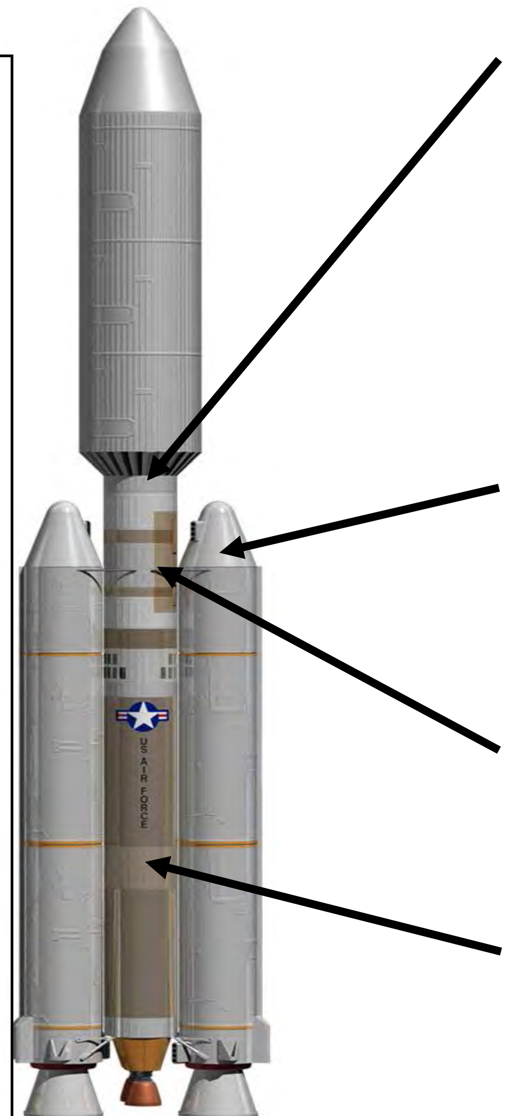
Flight Termination System
- CDS - Command Destruct System
- ADS - Automatic Destruct System

Electrical Actuators
- VPS - Vehicle Power Supply

Telemetry
- IPS - Instrumentation Power System
- WIS - Wideband Instrumentation System

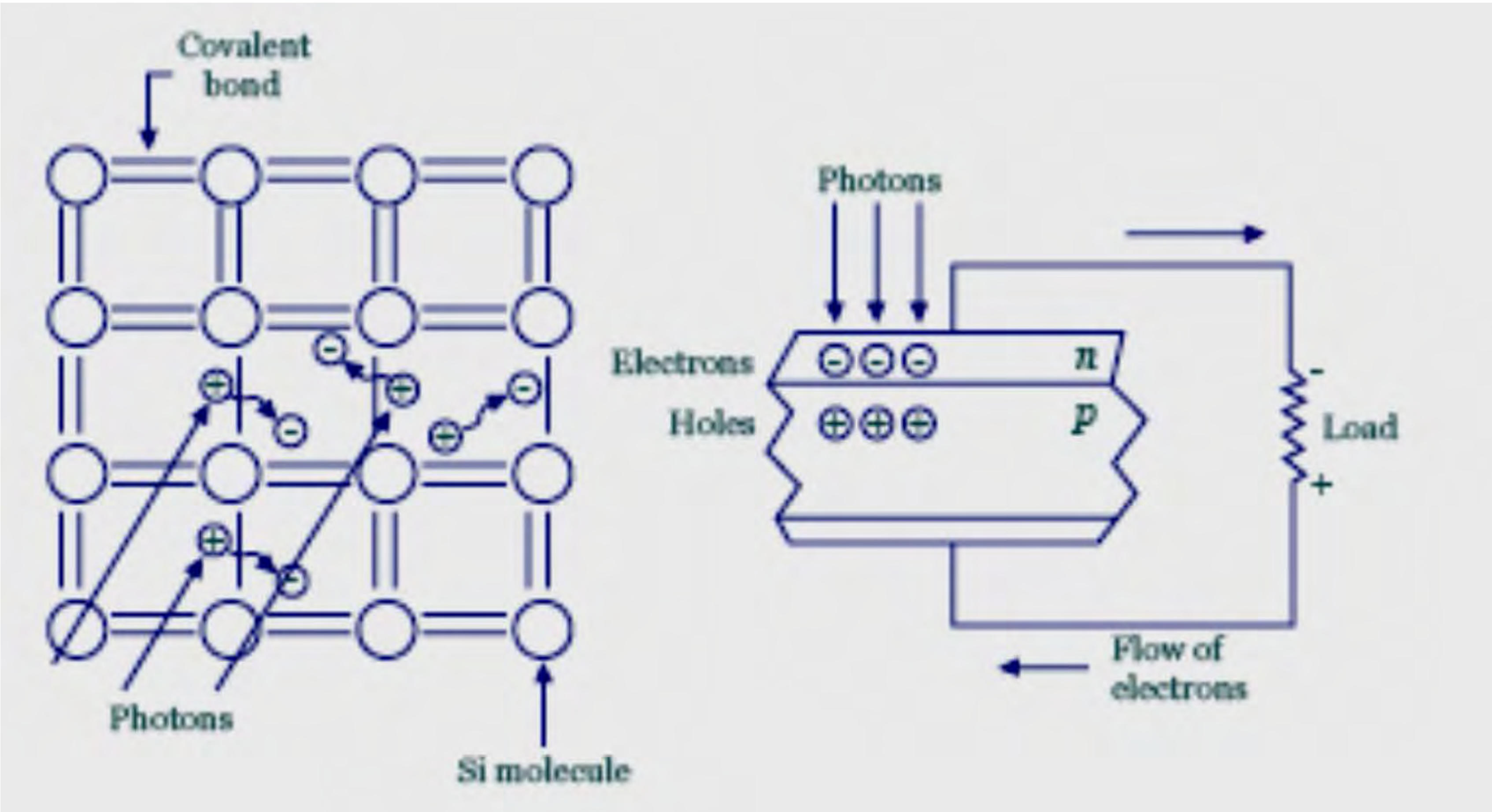
Operational Ordnance
- TPS - Transient Power Supply

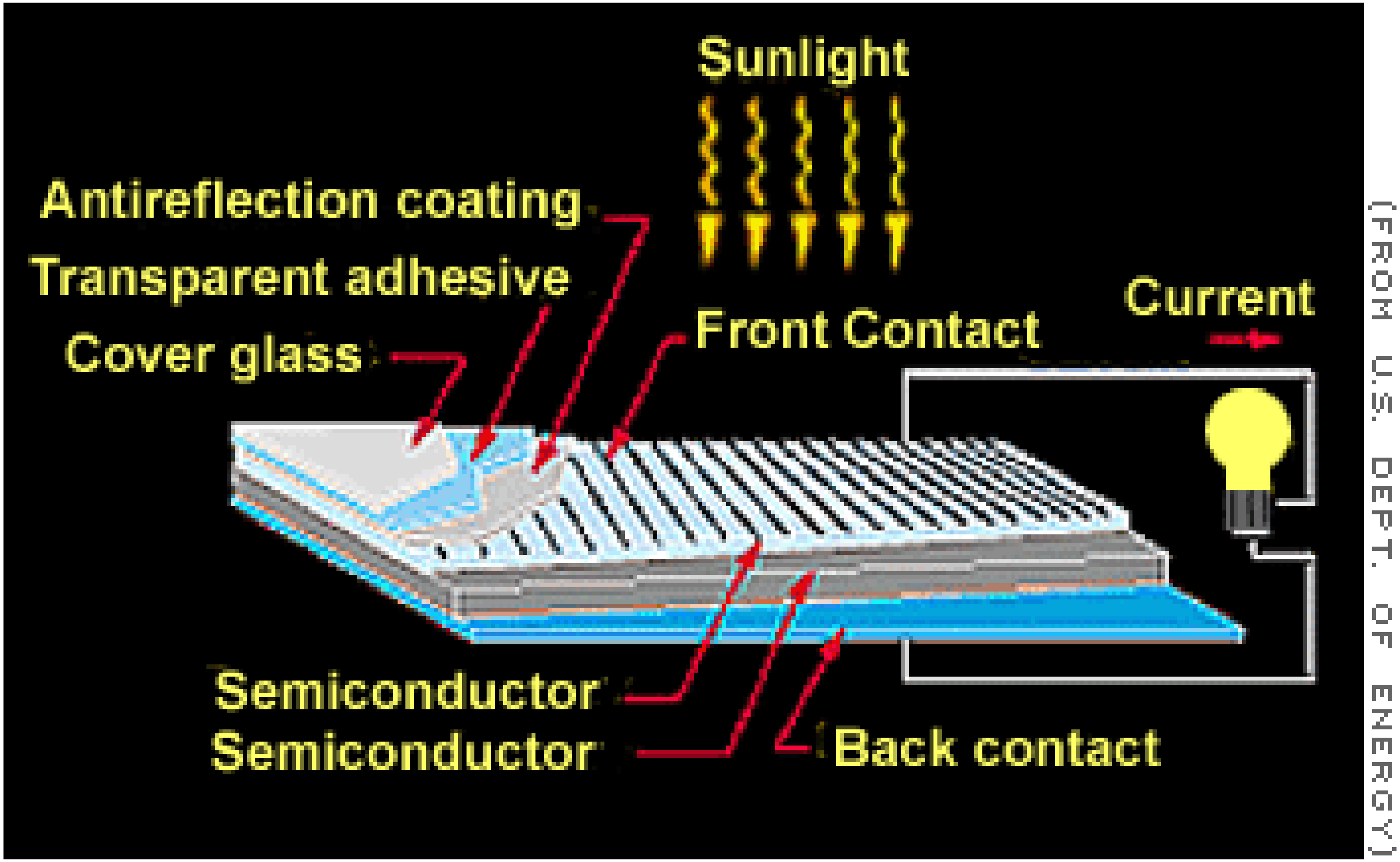
SRM Avionics
- LCU - Loop Closure Unit
- SCU - Signal Conditioning Unit



- Oldest Source of Continual Power in Space
- ~100W/ meter^2
- Silicon
  - Low Efficiency~10%
  - Radiation Sensitive
  - Low cost
- Gallium Arsenide GaAs
  - Efficient~20%
  - Radiation Insensitive
  - Costly

- Long heritage, high reliability power source
- High specific power, low specific cost
- Elevated temperature reduce cell performance
- Radiation reduces performance and lifetime
- Most orbits will require energy storage systems to accommodate eclipses

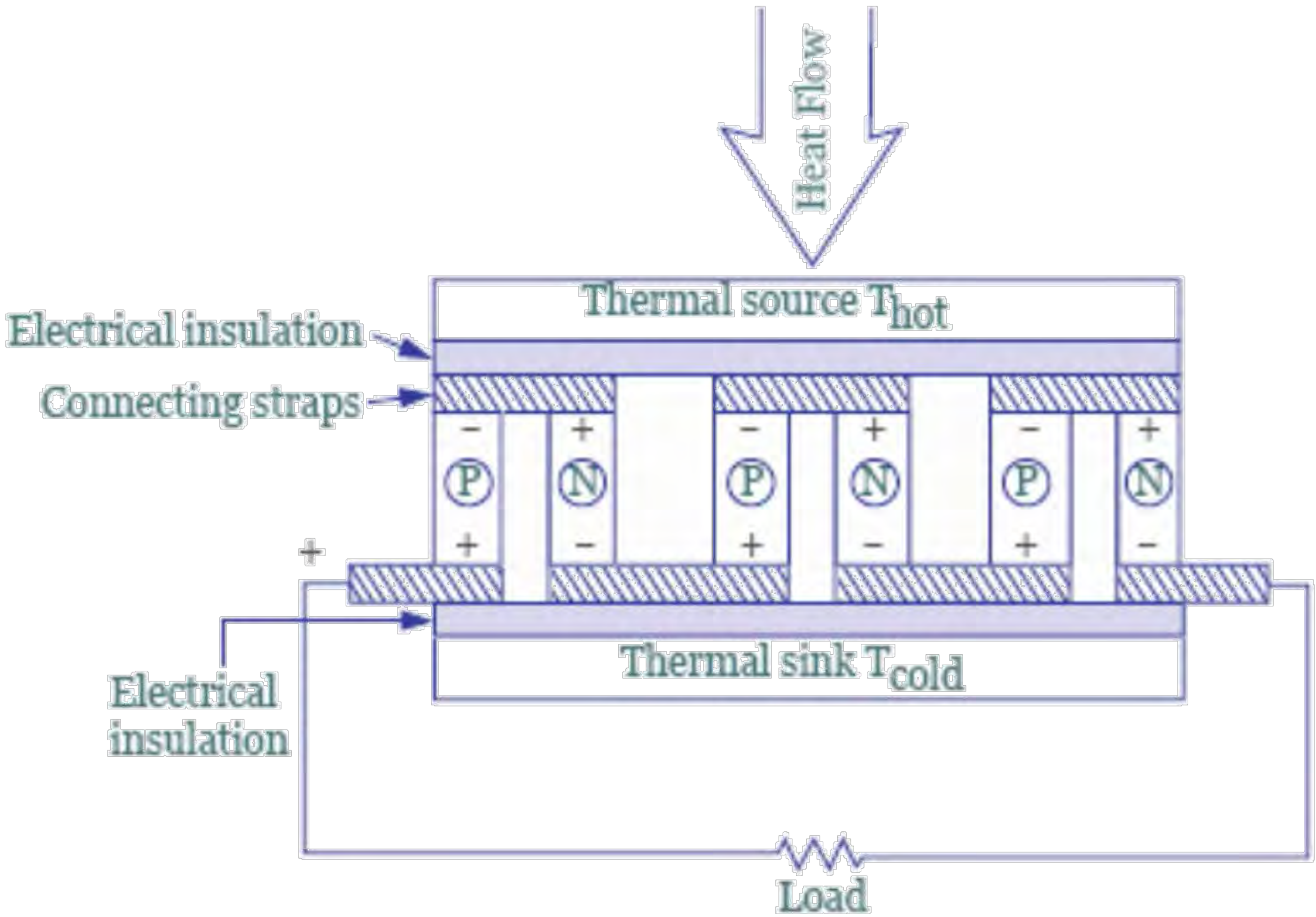

Covalent bond
Photons
Si molecule
Photons
Electrons
Holes
n
p
Load
-
+
Flow of electrons



Cells in series provide the required voltage; parallel strings provide required current

- A radioisotope thermoelectric generator, or RTG, uses the fact that radioactive materials (such as plutonium) generate heat as they decay into non-radioactive materials. The heat used is converted into electricity by an array of *thermocouples* which then power the spacecraft.

- A thermocouple is a device which converts thermal energy directly into electrical energy. Basically, it is made of two kinds of metal that can both conduct electricity. They are connected to each other in a closed loop. If the two metals are at different temperatures, an electric potential will exist between them. When an electric potential occurs, electrons will start to flow, making electric current.


Heat Flow
Thermal source T_{hot}
Electrical insulation
Connecting straps
−
P
+
+
N
−
−
P
+
+
N
−
−
P
+
+
N
−
+
Electrical insulation
Thermal sink T_{cold}
Load

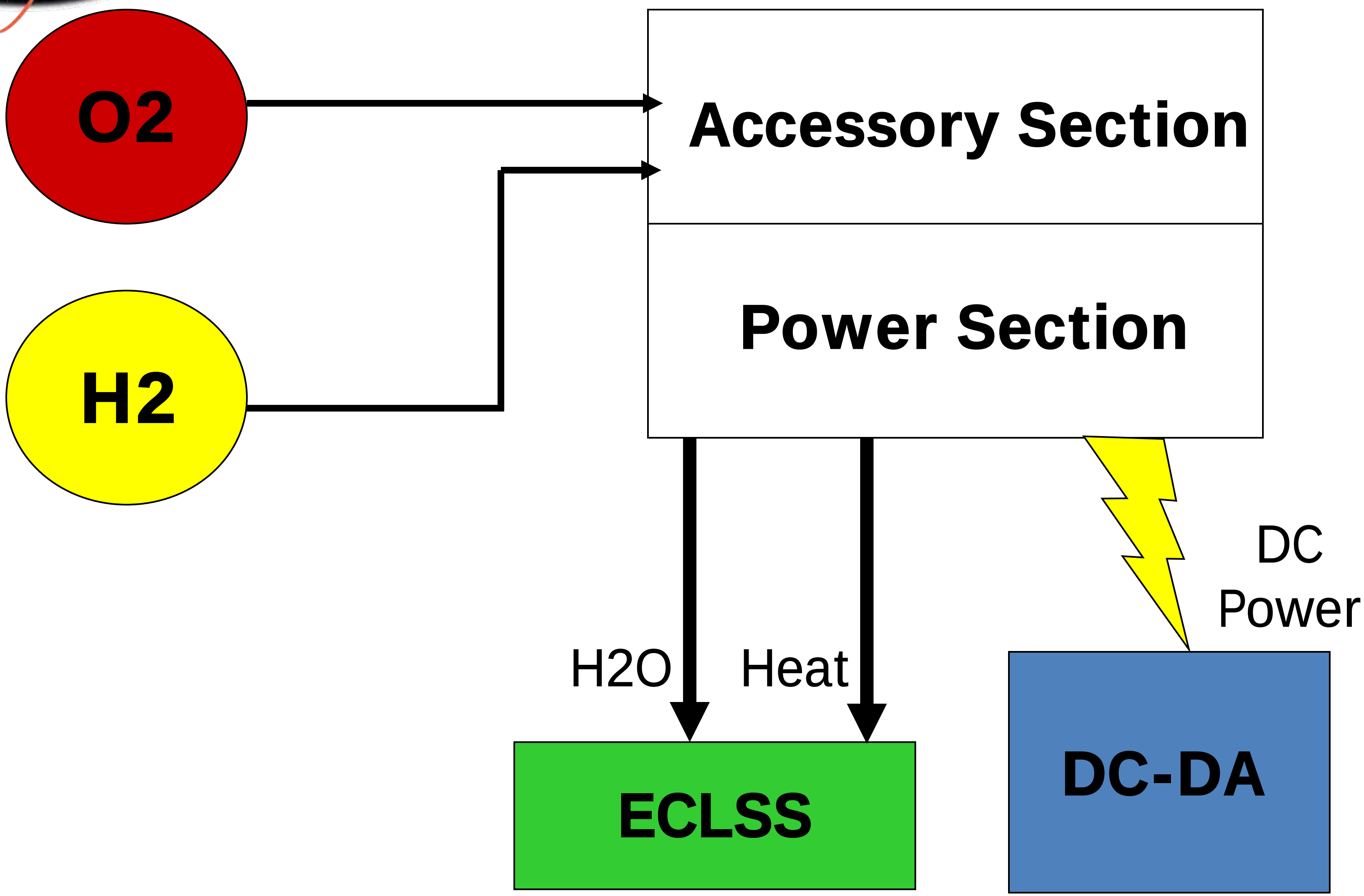
- **Advantages**
- Do not require sunlight to operate
- Long lasting and relatively insensitive to the chilling cold of space and virtually invulnerable to high radiation fields.
- RTGs provide longer mission lifetimes than solar power systems.
  - Supplied with RTGs, the Viking landers operated on Mars for four and six years, respectively.
  - By comparison, the 1997 Mars Pathfinder spacecraft, which used only solar and battery power, operated only three months.
- They are lightweight and compact. In the kilowatt range, RTGs provide more power for less mass (when compared to solar arrays and batteries).
- No moving parts or fluids, conventional RTGs highly reliable.
- RTGs are safe and flight-proven. They are designed to withstand any launch and re-entry accidents.
- RTGs are maintenance free..

- **Disadvantages**
- The nuclear decay process cannot be turned on and off. An RTG is active from the moment when the radioisotopes are inserted into the assembly, and the power output decreases exponentially with time.
- An RTG must be cooled and shielded constantly.
- The conversion efficiency is normally only 5 %.
- Radioisotopes, and hence the RTGs themselves, are expensive

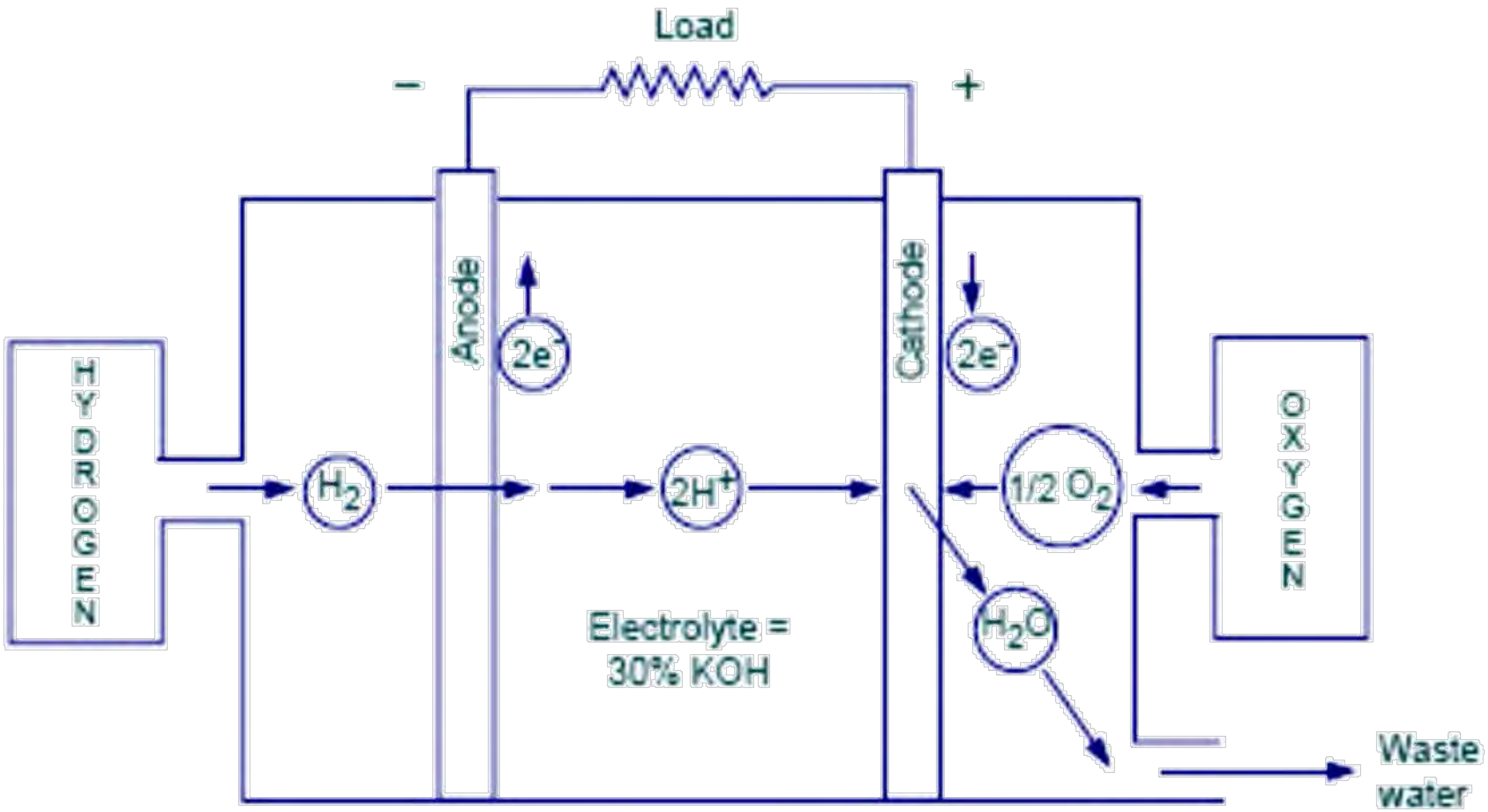
- Space Shuttle has 3 fuel cells
- Each operates as an independent electrical power source, supplying 28 volts dc
- Each power plants is reusable and restartable

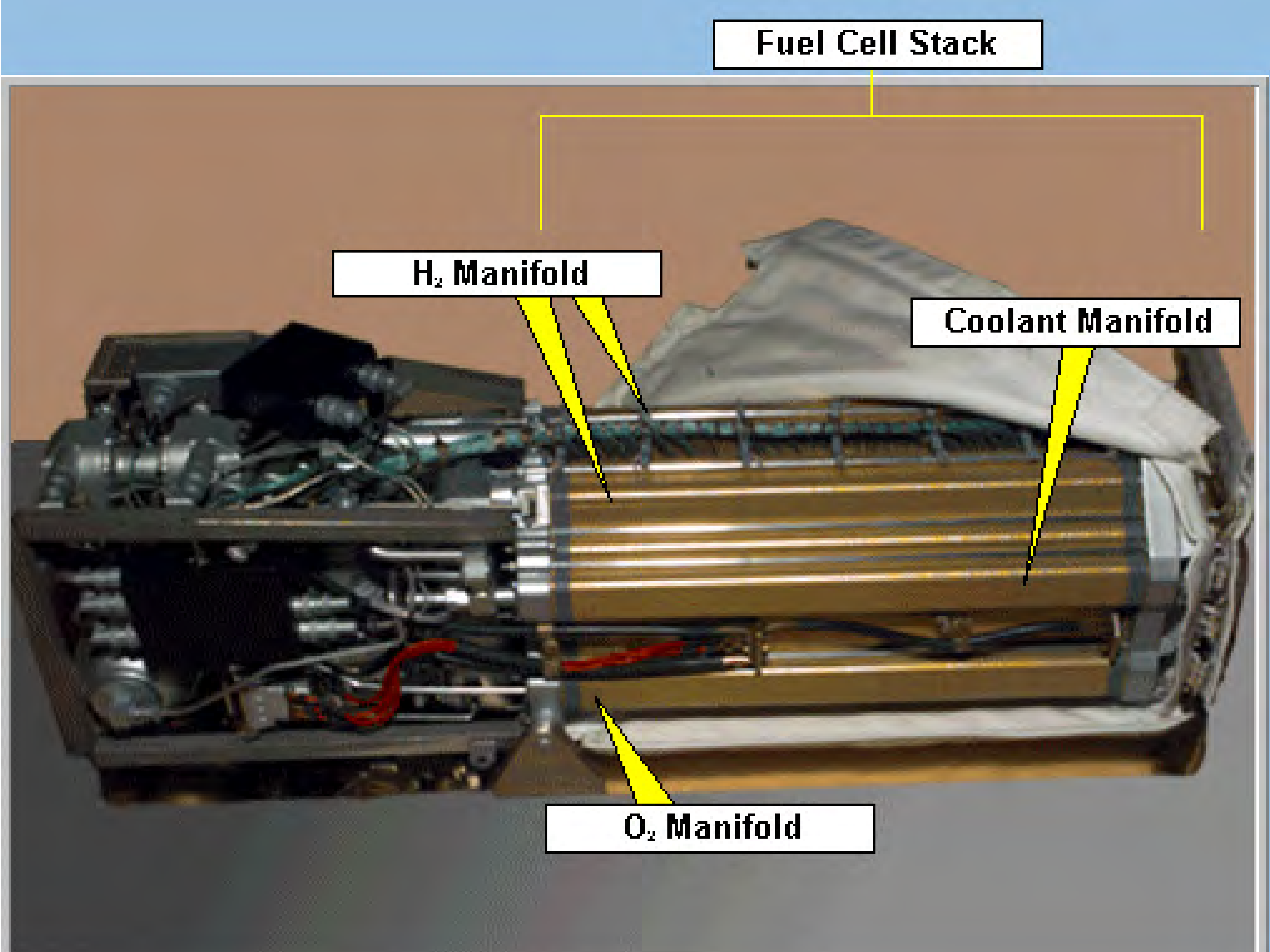
Shuttle Fuel cell consists of 2 primary components:

1. Power section - chemical reaction occurs
   - Hydrogen and oxygen are transformed into electrical power, water and heat
   - 96 cells in 3 substacks
2. Accessory section - controls & monitors power section's performance


O2
H2
Accessory Section
Power Section
H2O
Heat
DC
Power
ECLSS
DC-DA

- Output voltage per cell 0.8 volts in practice
- Consumes hydrogen and oxygen
  - Produces water as by-product (1 Pint/kW h)
  - Heat also by-product
- High specific power (275 W/kg)
- Shuttle fuel cells produce 16 kW peak
- Reaction is reversible so regenerative fuel cells are possible

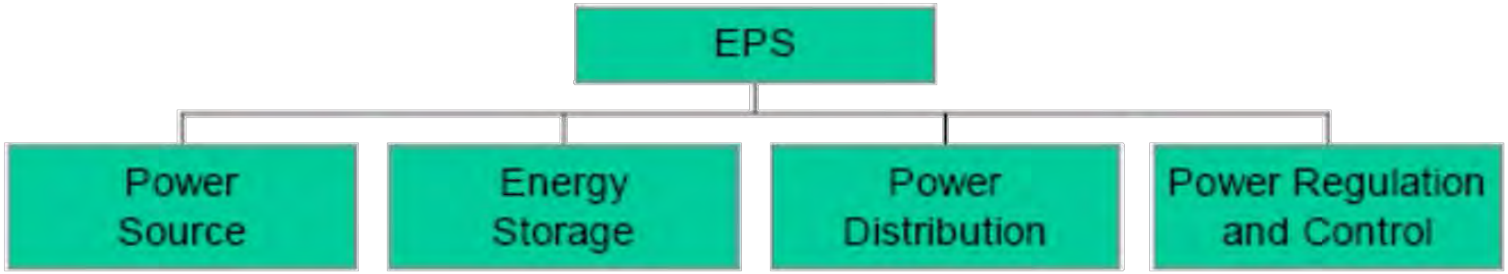

Load
−
+
HYDROGEN
Anode
Cathode
2e-
2e-
H2
2H+
1/2 O2
H2O
OXYGEN
Electrolyte =
30% KOH
Waste
water

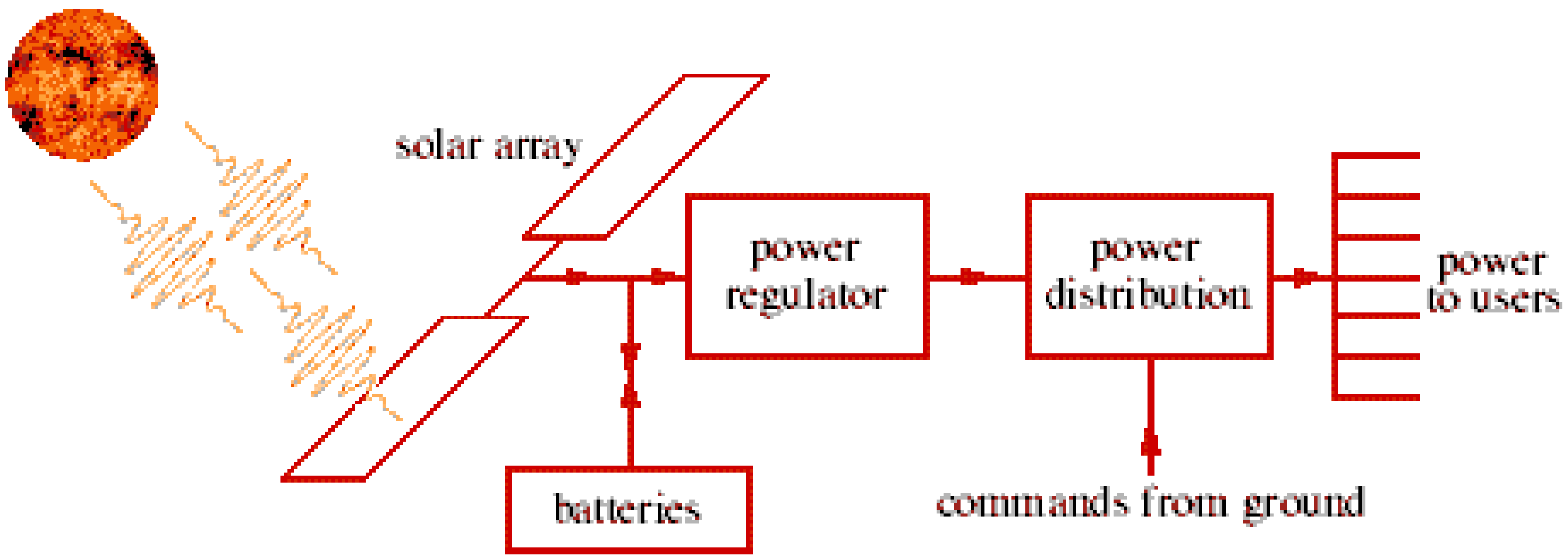


Fuel Cell Stack
H_2 Manifold
Coolant Manifold
O_2 Manifold

Power Distribution

Electrical Power System




solar array
power regulator
power distribution
power to users
batteries
commands from ground

What is an electrical bus?

It is a wire that transports electricity.

- Standard Bus usually 28v dc
- May need low voltage dc
  - 5 to 270? Volts
- May need AC voltage
  - Single phase 120v 60Hz
  - Three phase 120v 400 Hz

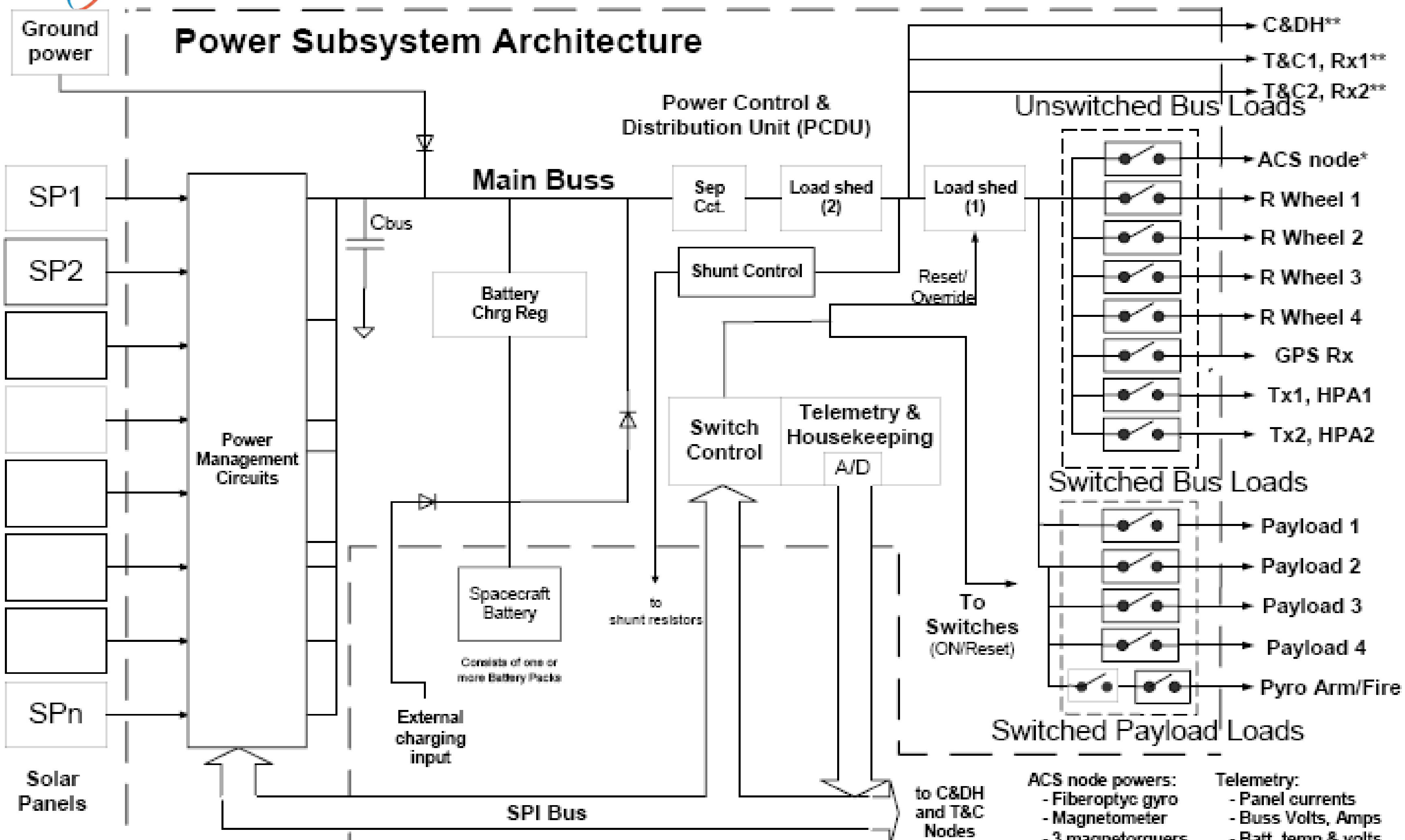
These converted from 28v dc

- Voltage conversion
- Transient behavior damping
  – Isolate bus “noise” from end user
- Must control power generated to prevent overcharge of the battery and overheating of spacecraft
- For solar array systems, have two concepts
  – Peak Power Tracker
  – Direct Energy Transfer

- Must control power generated to prevent overcharge of the battery and overheating of spacecraft
- For solar array systems, have two concepts
  - Peak Power Tracker
  - Direct Energy Transfer

- Detection, Isolation, and Correction
- Detection
  - Failed load implies short circuit
    - Draws excessive power
    - Stress cabling, etc
    - Drains energy storage
- Isolate with fuses (or circuit breakers)
  - May need to reset
- Correction
  - Reroute
  - Redundant loops

Power Subsystem Architecture



Notes: ** Unswitched connections have redundant in-line fuses
Pyro to be fired using Battery or (Battery + Pyro Cap)

ACS node powers:
- Fiberoptyc gyro
- Magnetometer
- 3 magnetorquers
- Sun sensor
- Earth sensor

Telemetry:
- Panel currents
- Buss Volts, Amps
- Batt. temp & volts
- Switch status
- Load currents

- Kapton is Dupont’s trade name for a Polyimide film
- Used by many wire manufacturers as insulation
- Kapton has been used in the Aerospace community for more than 25 years
- Used thru out Aerospace, Civilian, and Military

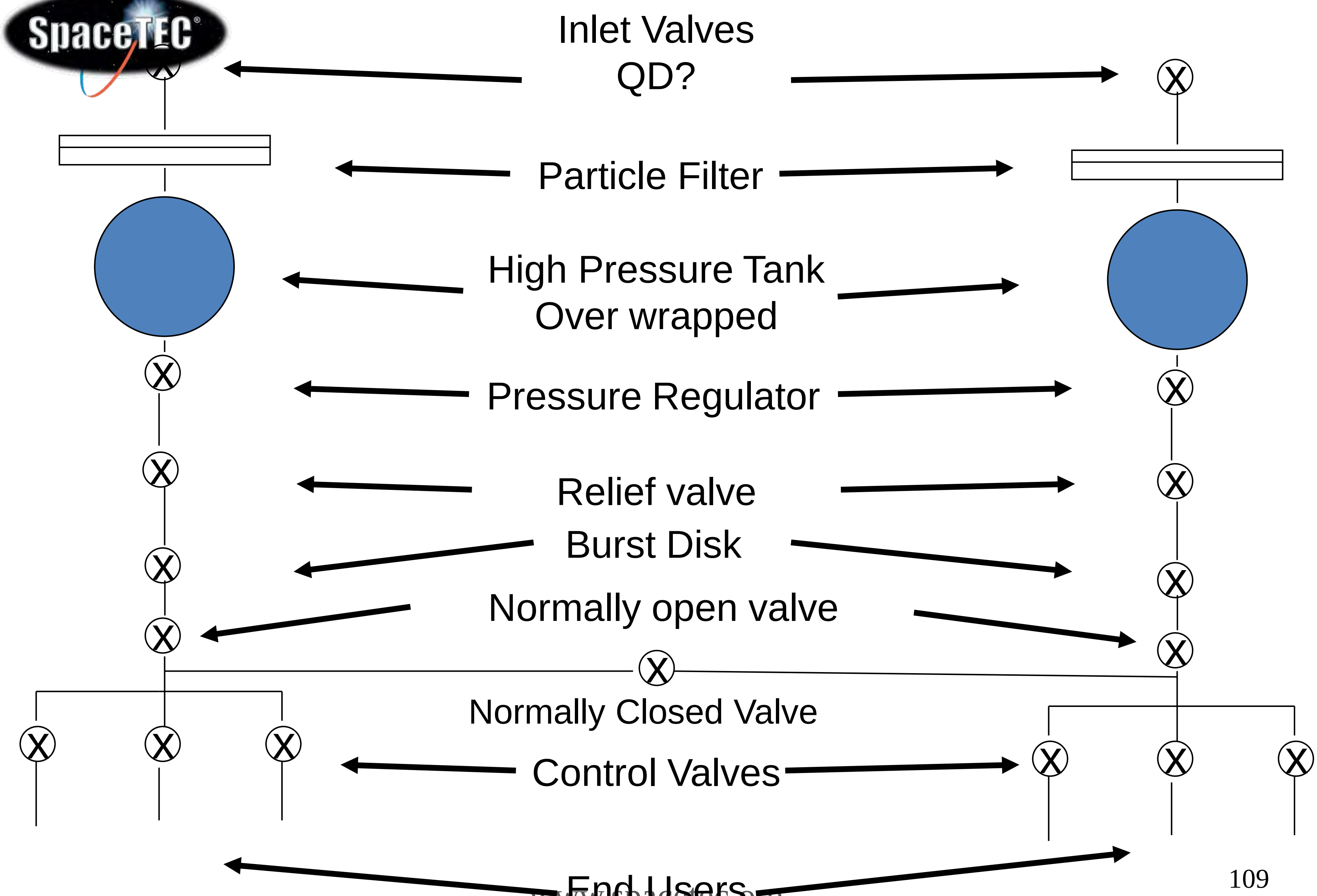
- High strength to weight ratio
- Good insulation properties (still state of the art)
- Effective in large temperature range

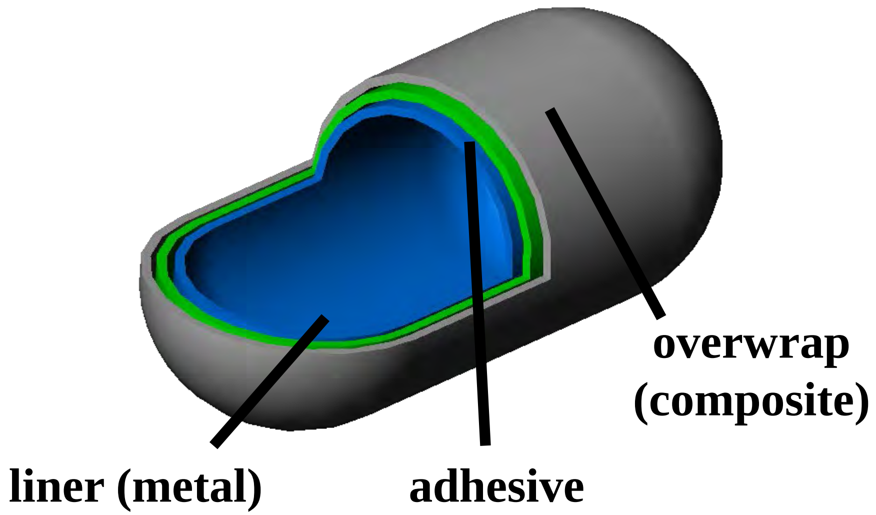
- Special tooling required
- Can not be bent or flexed sharply
- Degregration occurs upon exposure to water or solvents
- Subject to chaffing
- When shorted, arc-tracking occurs and continues as long as power is present, will burn in a vacuum
- Becomes brittle with age

- Gas and liquid specifications
- Valves
  - Burst disks/relief valves
  - Check valves
- Required Pressure Ratings of components
  - Safety requirements
- Pressure vessel construction
  - Over wrapped, vacuum jacketed
- Filters – use and sizes

- Loading Requirements
  - Volume vs. pressure vs. mass vs. temperature
- Definitions (hydraulics vs. pneumatics)
  - Pascal's Law
  - Incompressibility
  - Volume
  - Stroke
- Accumulators
- Effects of trapped air in hydraulic system
- Uses of pneumatic and hydraulic systems

http://propellants.ksc.nasa.gov/gases.htm


Inlet Valves
QD?
Particle Filter
High Pressure Tank
Over wrapped
Pressure Regulator
Relief valve
Burst Disk
Normally open valve
Normally Closed Valve
Control Valves
End Users


overwrap
(composite)
liner (metal)
adhesive

www.spacetec.org

Typical Product Range

Material: Wire cloth in a full range of alloys (stainless steel, plain steel, copper and brass) in plain, twill and Dutch weaves.
Synthetics polyester, nylon 6 and nylon 6,6
screens along with high performance fabrics made of ETFE, ECTFE, PTFE, PVDF and PEEK. In cases where the available range of alloys and polymers cannot meet your requirements, specialty materials and constructions can be produced to your specifications.
Pore sizes: 1 to 12,000 microns
Thickness: 40 microns and up
Weights: 0.5 oz/sq yd and up

A micron rating for a fluid filter is a generalized way of indicating the ability of the filter's media to remove contaminates by the size of particles it is exposed to. The micron rating does not properly or fully describe either the efficiency or the contaminant-holding capacity of the filter media. **AIR FILTER MEDIA IS NOT RATED BY MICRON SIZE.** (Refer to TSB-04-3, Air Filter Life and Efficiency Ratings)

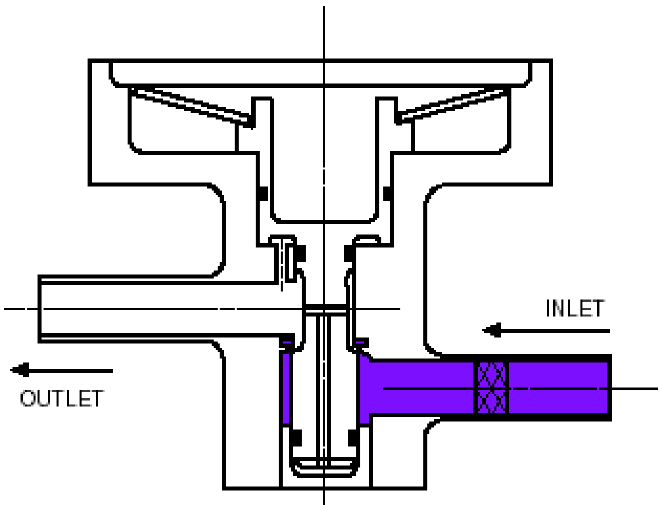
What does the word micron mean? The word micron is another term for micrometer (1 millionth of a meter). A micrometer is a unit of linear measure in the metric system used to measure distance from one point to another. It is used like the inch, foot, centimeter and millimeter to measure length, width or diameter of objects. Its scientific notation is μ. Some linear equivalents are 1 inch is 25,400 microns and 1 micron is .000039 inches. Some comparative sizes are:

Diameter of average human hair 70 microns
Lower limit of visibility (naked eye) 40 microns
White blood cells 25 microns
Talcum powder 10 microns
Red blood cells 8 microns
Bacteria 2 microns
Carbon black 0.6 microns
Tobacco smoke 0.5 microns

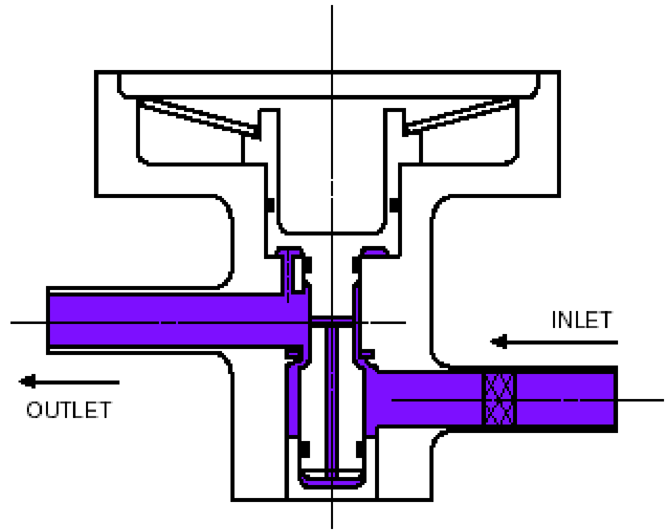

CIRCLE
SEAL

The **relief valve** (also called a **bypass valve**) is a mechanism used to control or limit pressure or vacuum in a system by allowing the media to flow from an auxiliary passage, away from the main flow path. The relief valve is designed or set to activate at a predetermined pressure or vacuum. When this pressure or vacuum setting is exceeded, the relief valve becomes the "path of least resistance" as the valve is forced open and a portion of the media is diverted through the auxiliary route. The diverted media is usually returned back to either the reservoir or the pump inlet. The relief valve and bypass path can be internal (an integral part of the pump) or external (installed as a component in the media path).

Lockup Position

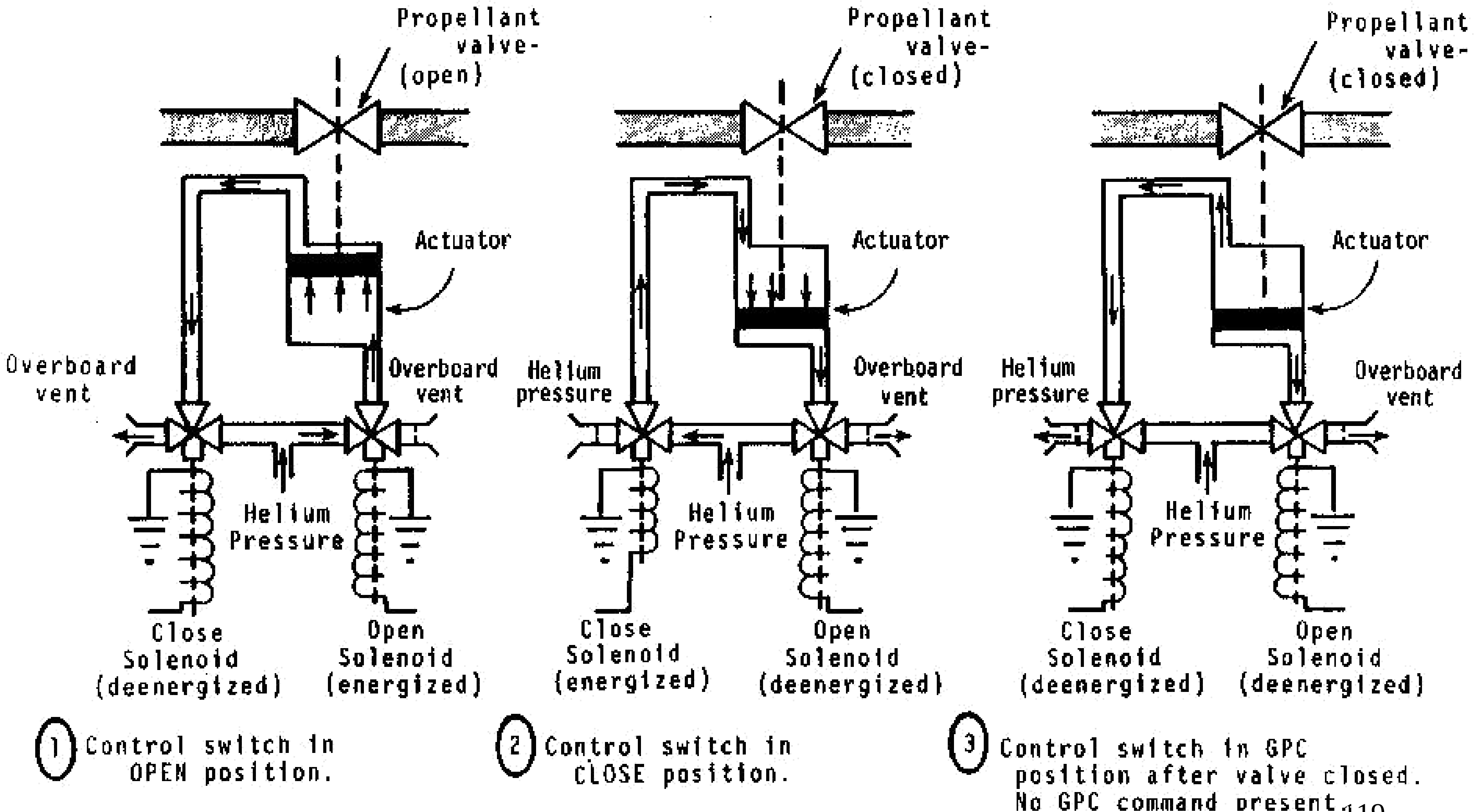


Flowing Position



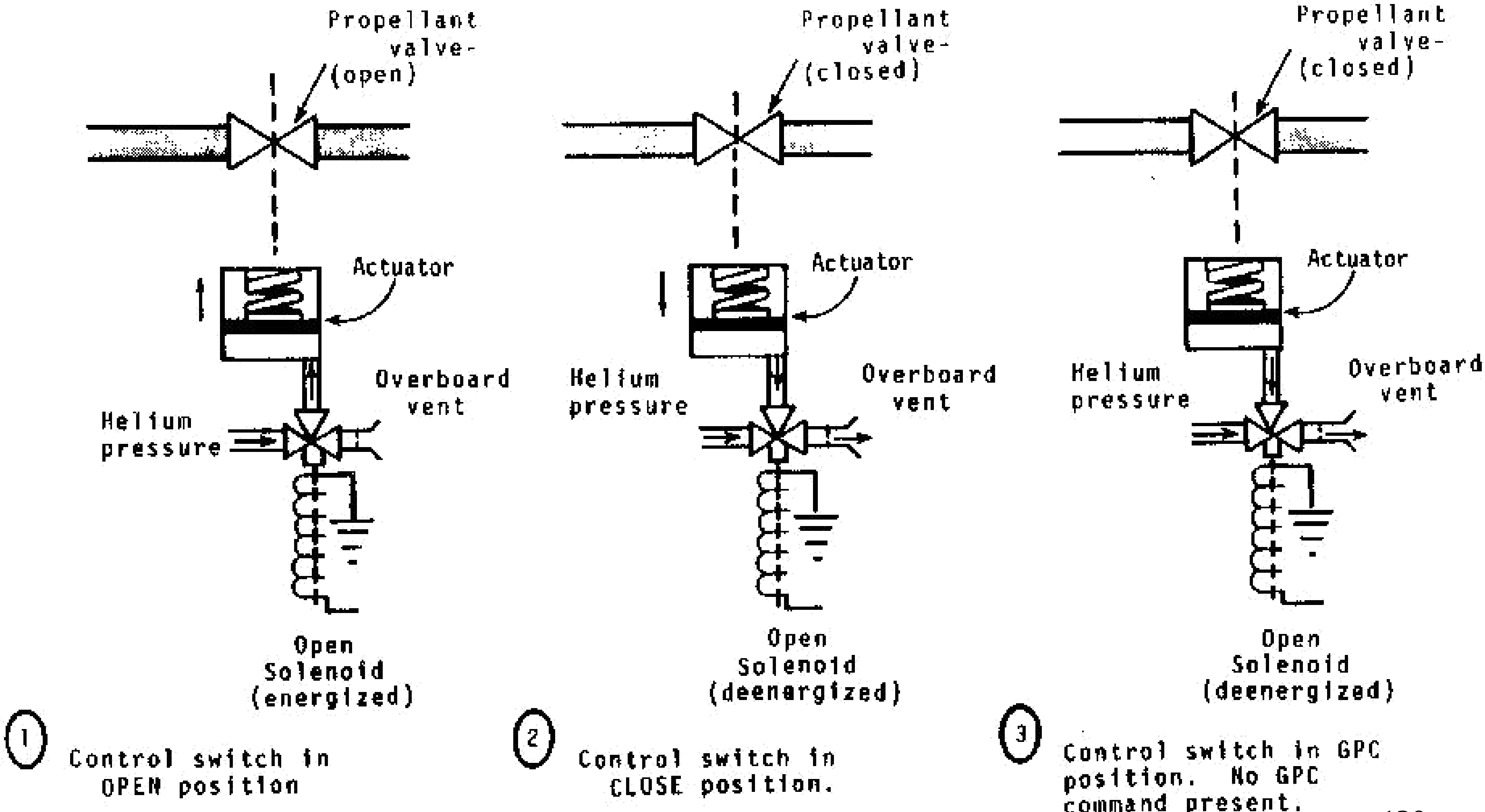
Operational Description

Begin with an initial condition of steady state flow and pressure across the regulator seat. If the outlet pressure increases due to a reduced downstream demand, this pressure increase is sensed by the piston area as a force increase, which will start to compress the belleville spring. This piston motion causes the poppet to start to close against the seat, thus causing a decrease in gas flow. This motion continues until force equilibrium is achieved. If the outlet pressure increases to a value above the set point, the force imbalance will be sufficient to close the poppet against the seat, thus preventing flow. If the outlet pressure decreases due to increased demand, the force balance on the piston will cause the poppet stroke to increase, thus allowing greater flow to the outlet which enables an increase in the outlet pressure. Once the set point pressure is achieved and a steady state flow is in place, the regulator once again assumes steady state operation.

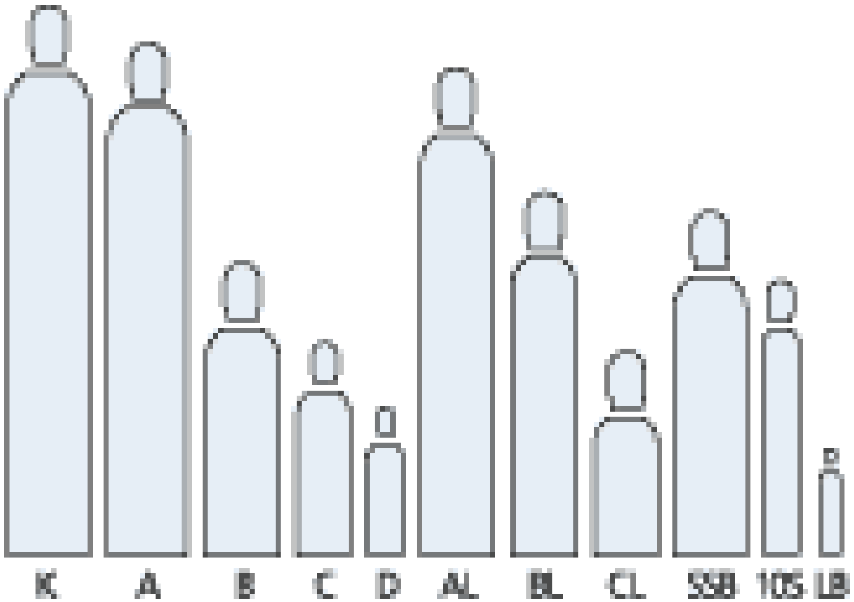


Propellant valve-(open)
Actuator
Overboard vent
Overboard vent
Helium Pressure
Close Solenoid (deenergized)
Open Solenoid (energized)
1 Control switch in OPEN position.
Propellant valve-(closed)
Actuator
Helium pressure
Overboard vent
Helium Pressure
Close Solenoid (energized)
Open Solenoid (deenergized)
2 Control switch in CLOSE position.
Propellant valve-(closed)
Actuator
Helium pressure
Overboard vent
Helium Pressure
Close Solenoid (deenergized)
Open Solenoid (deenergized)
3 Control switch in GPC position after valve closed. No GPC command present.

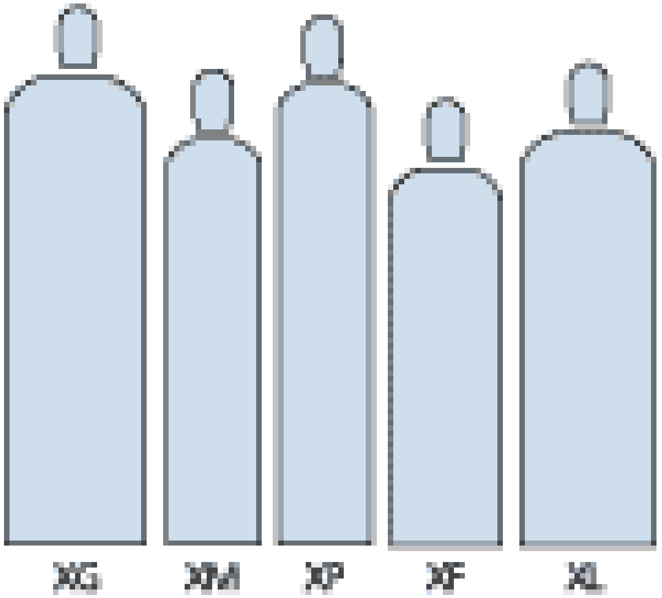
Normally closed valve



- Pressurize other systems (propellants0
- Operate Valves or actuators
- “Cold Gas” propellants
- Purge



High Pressure Cylinders



Low Pressure Cylinders

Cyl. Size	Nominal Size* Dia X Height (inches)	Nominal* Tare Weight (lbs.)	Water Capacity (lbs.)	Internal Volume @ 70 F (21 C), 1 ATM (liters/cubic feet)		US DOT Specs
K	9.25 X 60	135	110	49.9	1.76	3AA2400
A	9 X 56	115	96	43.8	1.55	3AA2015
B	8.5 X 31	60	37.9	17.2	0.61	3AA2015
C	6 X 24	27	15.2	6.88	0.24	3AA2015
D	4 X 18	12	4.9	2.24	0.08	3AA2015
AL	8 X 53	52	64.8	29.5	1.04	3AL2015
BL	7.25 X 39	33	34.6	15.7	0.55	3AL2216
CL	6.9 X 21	19	13	5.9	0.21	3AL2216
XL	14.5 X 50	75	238	108	3.83	4BA240
SSB	8 X 37	95	41.6	18.9	0.67	3A1800
10S	4 X 31	21	8.3	3.8	0.13	3A1800
LB	2 X 15	4	1	0.44	0.016	3E1800
XF	12 X 46	180	--	60.9	2.15	8AL
XG	15 X 56	149	278	126.3	4.46	4AA480
XM	10 X 49	90	120	54.3	1.92	3A480
XP	10 X 55	55	124	55.7	1.98	4BA300
QT	3 X 14**	2.5**	2.0	0.900	0.0318	4B-240ET
LP5	12.25 X 18.25	18.5	47.7	21.68	0.76	4BW240

Hydraulic Fundamentals

- “Hydraulics” is used to describe the transmission of fluid power from one location to another
- The fluid can be either liquid or gas.

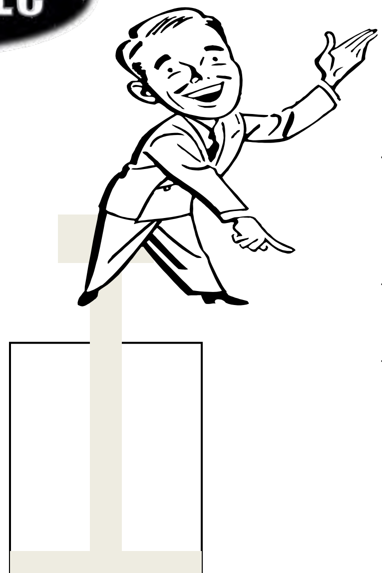
- Incompressibility: Under high pressures the volume of a fluid can decrease in a small proportion, but is considered to be negligible.
- Expansion: Fluids will expand and contract with changes in temperature.
- Pressure transmission: When pressure is applied to a confined body the fluid is transmitted equally in all directions.

- Area: Measurement of a surface. Knowing the area we can determine the amount of force required to move an object.
- Force: Amount of push or pull on an object
- Unit pressure: Amount of force on an object, usually measured in one square inch.

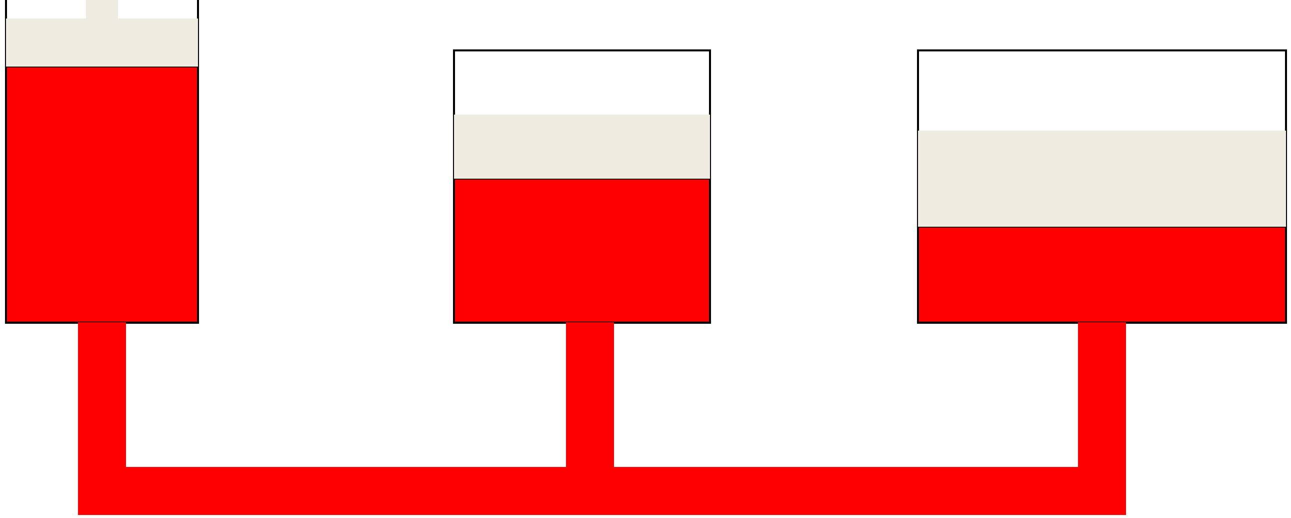
- Stroke: Represents the distance of a piston traveling in a cylinder -- usually expressed in inches
- Volume: Expressed in cubic inches, it represents the amount of fluid contained in a reservoir displaced by an actuating cylinder or pump.

- Pascal’s Law

  When a force is exerted on a confined fluid, the pressure is transmitted equally and undiminished in all directions.



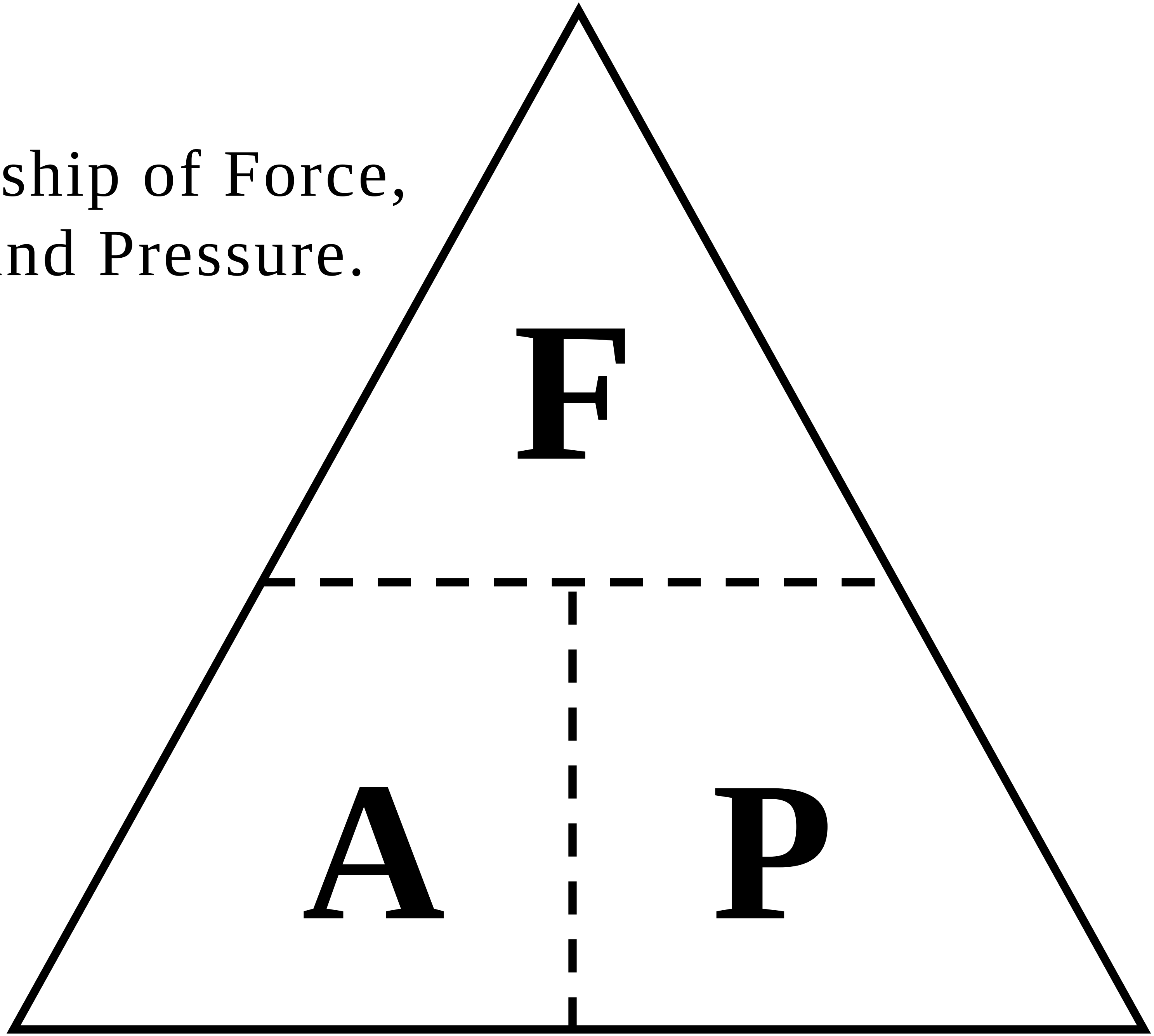
As a force is applied on the piston in cylinder 1 the pressure transmitted through the confined fluid is exactly the same at all points throughout the system.

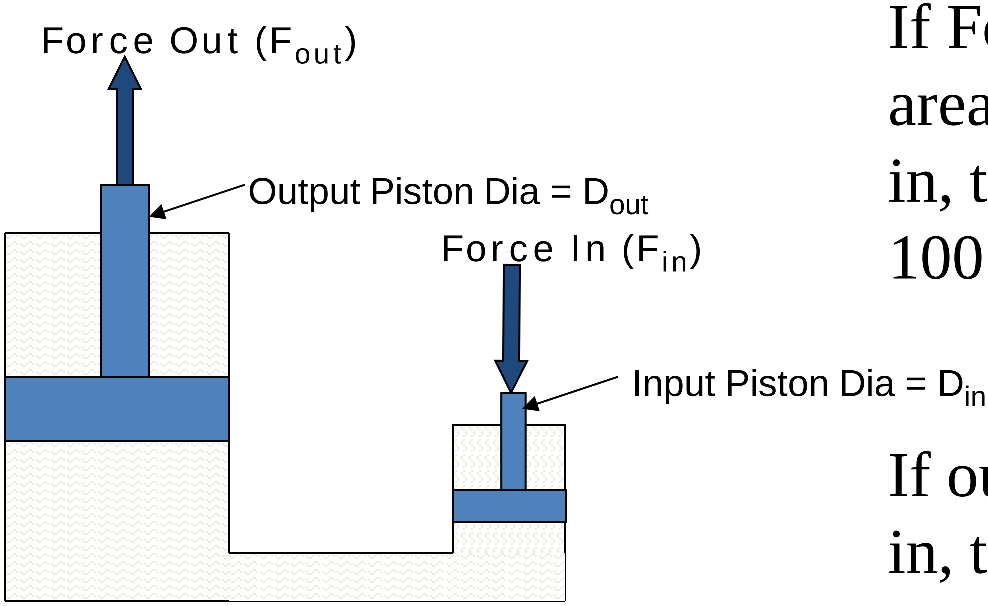


Cylinder 1 Cylinder 2 Cylinder 3

SpaceTEC®

Relationship of Force, Area, and Pressure.



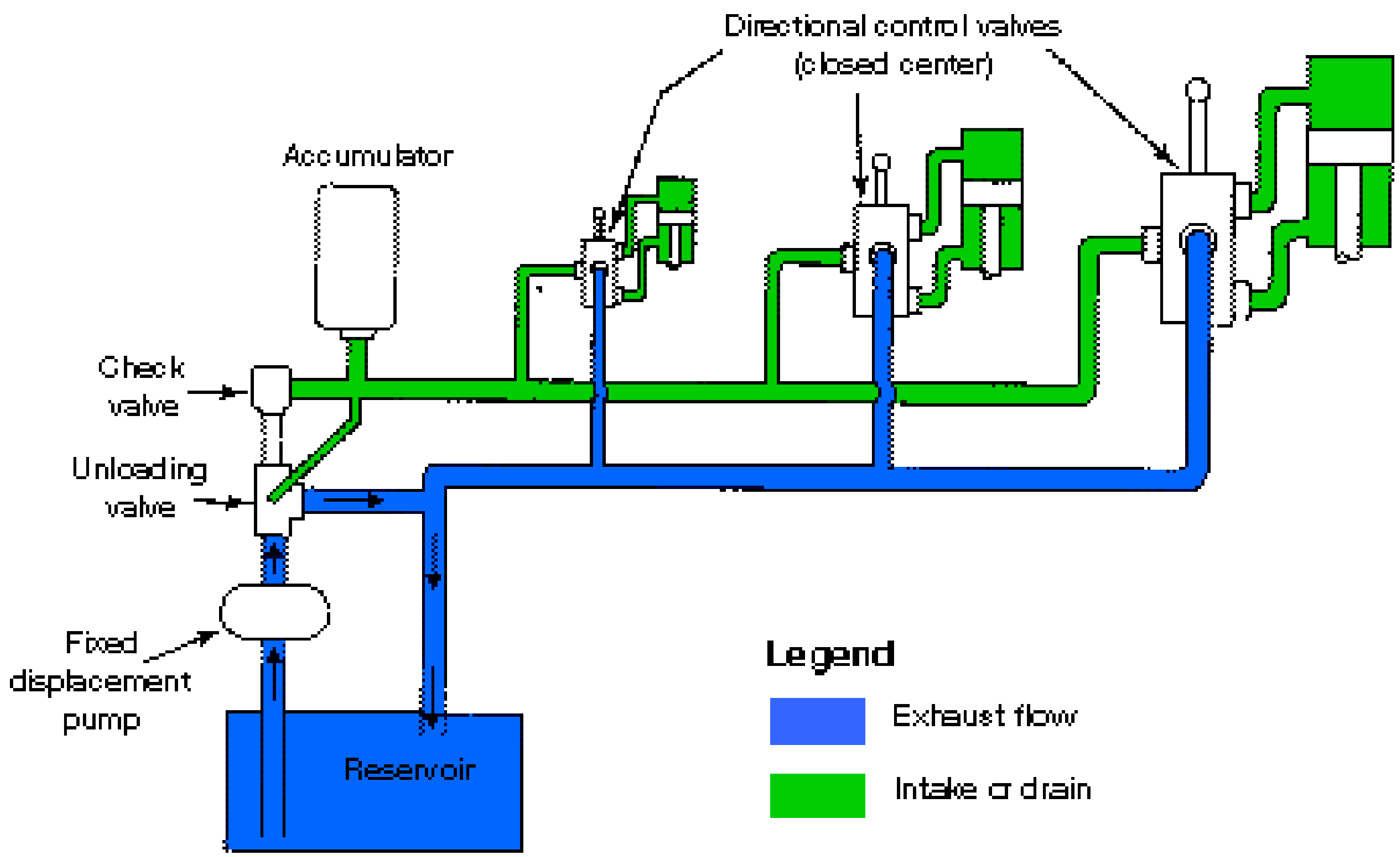


If Force In = 100 lbs and area of in put piston is 1 sq in, then input pressure is 100 psi.

If output piston is 5 sq in, then output force is 500 lbs (maintain 100 psi pressure)

If input piston moves 10 in, then output piston moves 2 in

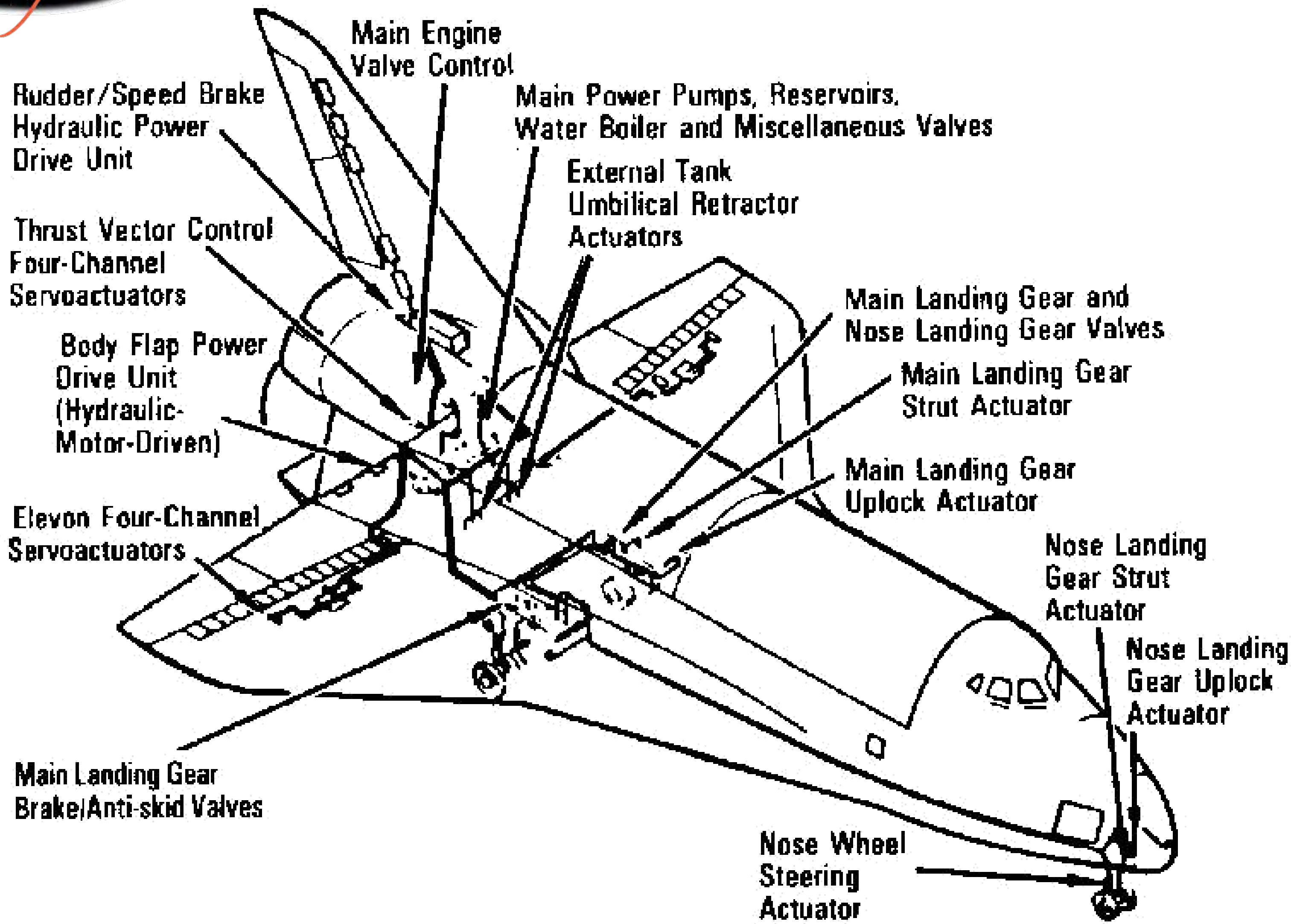
- A hydraulic accumulator stores potential power (liquid under pressure), for future conversion into useful work.
- This work can include operating cylinders and fluid motors, maintaining the required system pressure in case of pump or power failure, and compensating for pressure loss due to leakage.
- Accumulators can be employed as fluid dispensers and fluid barriers and can provide a shock-absorbing (cushioning) action.

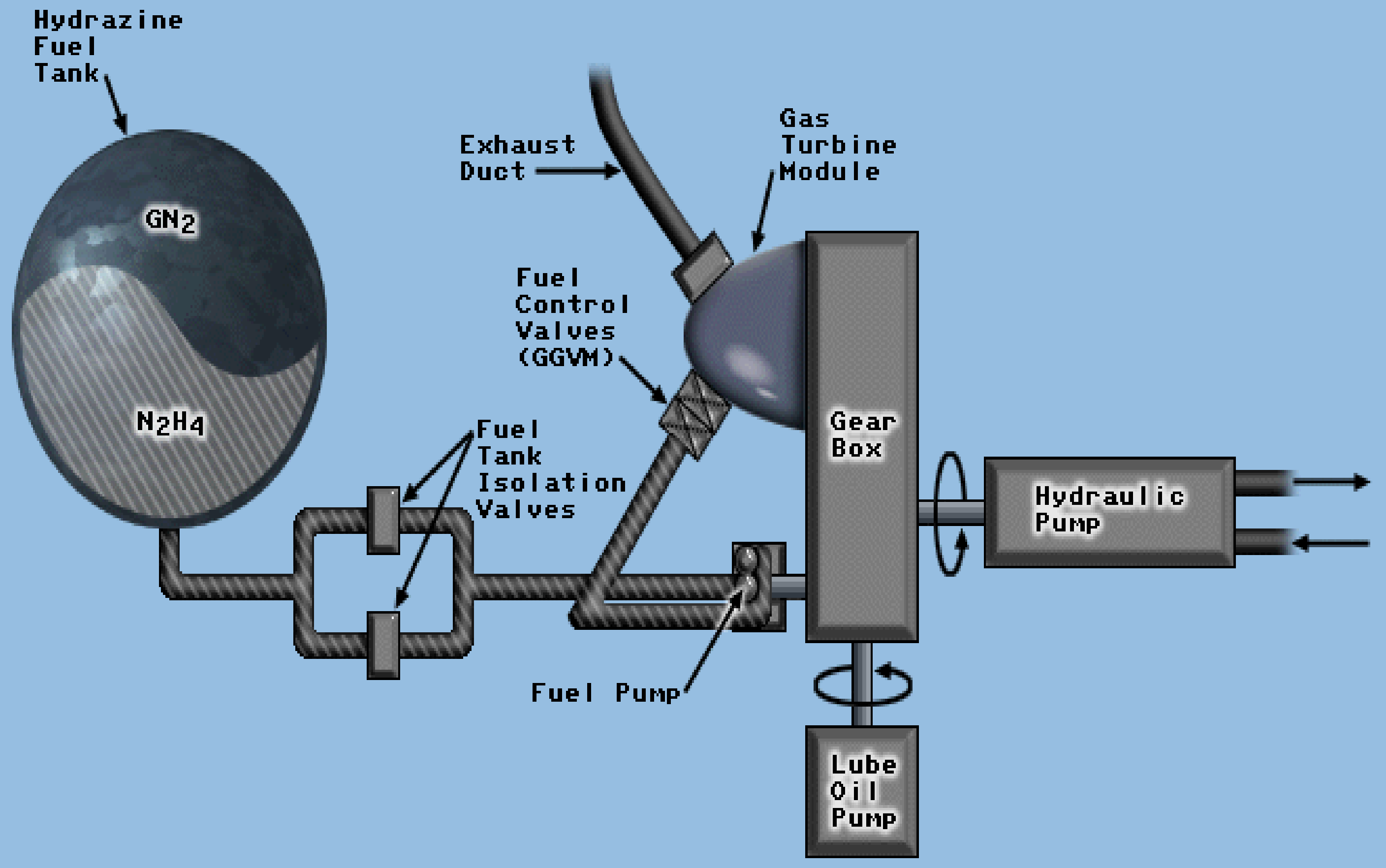


Directional control valves
(closed center)
Accumulator
Check
valve
Unloading
valve
Fixed
displacement
pump
Reservoir
Legend
Exhaust flow
Intake or drain

- In this system, a pump of small but constant volume charges an accumulator.
- When an accumulator is charged to full pressure, an unloading valve diverts the pump flow back to a reservoir. A check valve traps the pressured oil in the circuit.
- When a control valve is operated, an accumulator discharges its oil and actuates a cylinder.
- As pressure begins to drop, an unloading valve directs the pump flow to an accumulator to recharge the flow.
- This system, using a small capacity pump, is effective when operating oil is needed only for a short time.

- Accumulators frequently precharged with pressurized gas
- Large capacity pump to operate system


Main Engine Valve Control
Rudder/Speed Brake Hydraulic Power Drive Unit
Main Power Pumps, Reservoirs, Water Boiler and Miscellaneous Valves
External Tank Umbilical Retractor Actuators
Thrust Vector Control Four-Channel Servoactuators
Body Flap Power Drive Unit (Hydraulic-Motor-Driven)
Main Landing Gear and Nose Landing Gear Valves
Main Landing Gear Strut Actuator
Main Landing Gear Uplock Actuator
Elevon Four-Channel Servoactuators
Nose Landing Gear Strut Actuator
Nose Landing Gear Uplock Actuator
Main Landing Gear Brake/Anti-skid Valves
Nose Wheel Steering Actuator

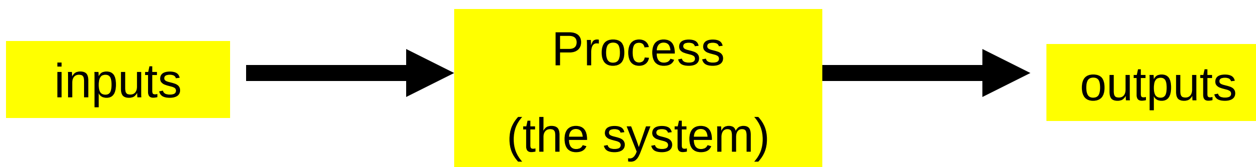


APU System Layout

- Four major functions of a control system
- Typical control systems on a satellite
- Telecommunications systems
  - Typical components
  - Modulation of data
  - Antenna systems

- Attitude control requirements
  - accurate orientation in space to:
    - » provide solar power
    - » provide thermal control
    - » point antennas
    - » point science instruments
  - Name environmental disturbances that affect satellites
  - Sensors to measure attitude control (sun, earth, horizon, etc.)
  - Name methods of attitude control
    - » Active vs. passive

- System – Collection of things working together to produce something



  - Open loop system – no feedback
  - Closed loop system - feedback

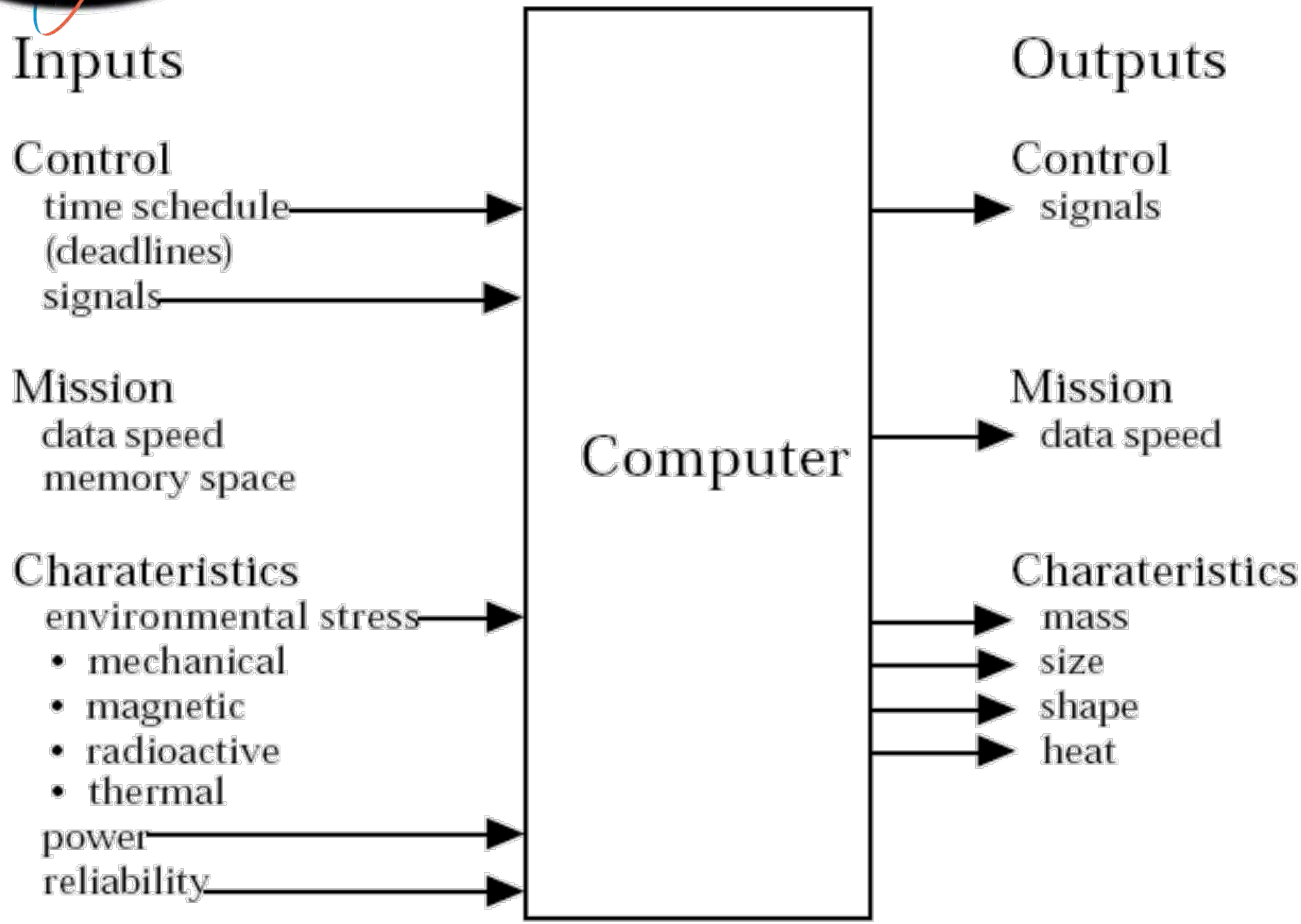
- Understand system behavior
  - Ground rules (e.g., temperature specs)
  - Model (e.g., power available, fuel available)
  - Changes as mission requirements change
    - Deep Space Mission - Cruise mode vs. Science Mode
- Observe system current behavior
  - Sensors
- Decide what to do
  - Decision making – central computer
  - Ground Command
- Do it
  - Actuators
- (Repeat)

- Flight Control
  - Spacecraft Computer
  - Guidance, Navigation and Control
  - Attitude and Orbit Control
  - Communications and Data Handling
- *Power

- *Environment
  - Thermal control and life support
- *Structures and Mechanisms
  - Electro mechanical systems
- *Propulsion
- *Payload*
  - *Scientific instruments*
- *Mission Control*

Not Covered

- Spacecraft Computer
  - Central computer
- Sequence Storage
  - Flight Commands
- Spacecraft Clock
- Telemetry Packaging and Coding
- Data Storage
- Fault Protection and Safing


Inputs
Control
time schedule
(deadlines)
signals
Mission
data speed
memory space
Charateristics
environmental stress
• mechanical
• magnetic
• radioactive
• thermal
power
reliability
Computer
Outputs
Control
signals
Mission
data speed
Charateristics
mass
size
shape
heat

Telemetry, Tracking and Command Subsystem

- Need uplink to tell satellite what to do (ground segment)
- Telemetry downlink tells operators what satellite is doing, and allows instrument data transmission
- Need to track location of satellite (from satellite data and other information)

- The motion of a spacecraft is described by four parameters: position, velocity, attitude, and attitude motion
- GNC analysis is divided into three sub-areas: guidance, navigation, and control.

- Navigation is the subject of computing the orientation and position of the spacecraft with respect to either some inertial coordinate system (such as a distant star) or a rotating reference system (such as the Earth in the Earth observing satellites).
  - This computation involves three things:
    - several types of sensors to collect data,
    - local (on board) or remote (on the ground) computers to process the data,
    - mathematical algorithms (software) to interpret the data

- Control is the process of orienting and moving the spacecraft in the desired direction depicted by the guidance.
  - Attitude stabilization (maintaining the attitude in a desired state)
  - Attitude maneuver control (changing the attitude from one orientation, or the old state, to another orientation, the new state)
  - Moving the spacecraft to the desired trajectory (firing engines)

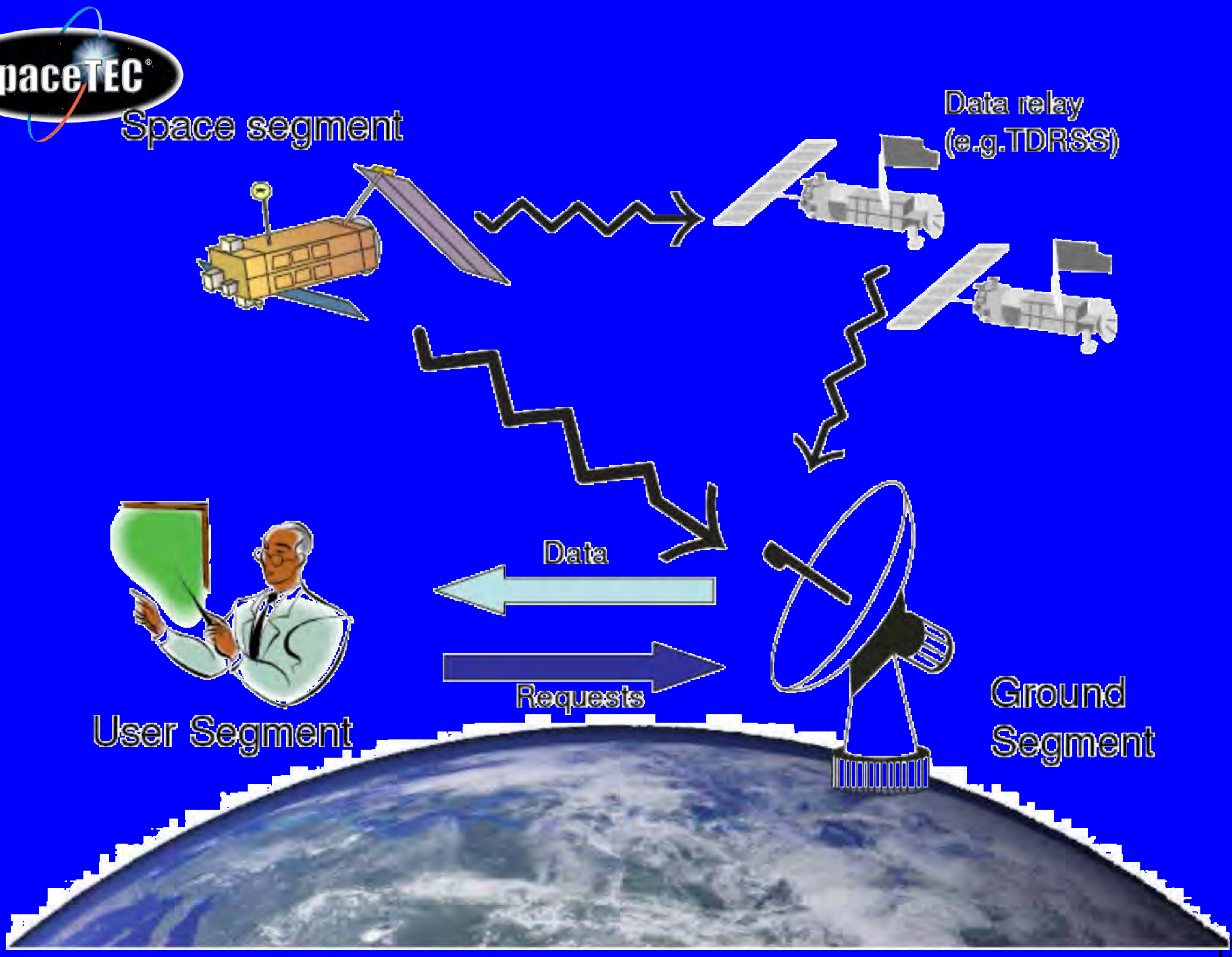
Attitude Reference Subsystem

- Satellite must be accurately oriented in space
  - To point solar array for optimum power
  - To point coms antenna to ground station
  - To point instruments
- Sun, Earth and stars acts as reference frame
- Satellites can “drift”
- Movement of satellite from small rocket thrusters (liquid fuel) for corrections, adjustments, “manoeuvres”.

- Sensors
  - Earth sensor (0.1^{o} to 1^{o})
  - Sun sensor (0.005^{0} to 3^{o})
  - star sensors (0.0003^{o} to 0.01^{o})
  - magnetometers (0.5^{o} to 3^{o})
  - Inertial measurement unit (gyros)

- Active control (< 0.001°)
  - thrusters (pairs)
  - gyroscopic devices
    - reaction & momentum wheels
  - magnetic torquers (interact with Earth’s magnetic field)
- Passive control (1° to 5°)
  - Spin stabilization (spin entire sat.)
  - Gravity gradient effect

Communications and Data Handling


Space segment
Data relay
(e.g.TDRSS)
Data
Requests
User Segment
Ground
Segment

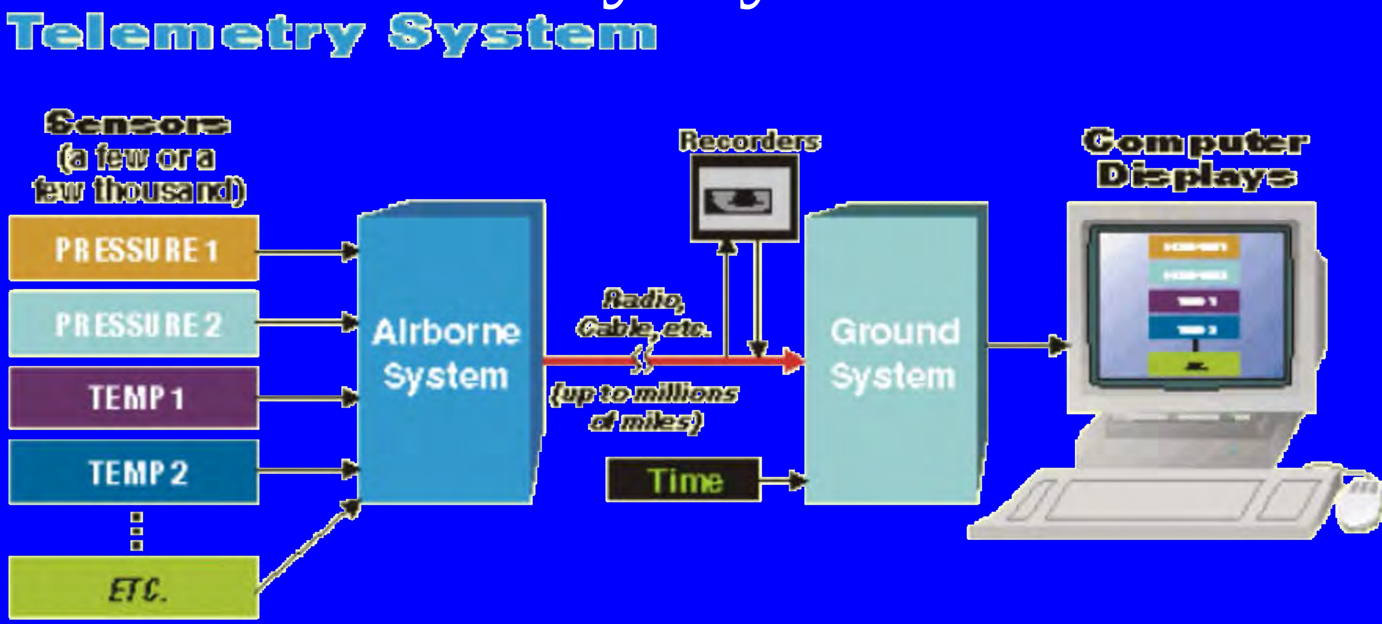
Communications Subsystem

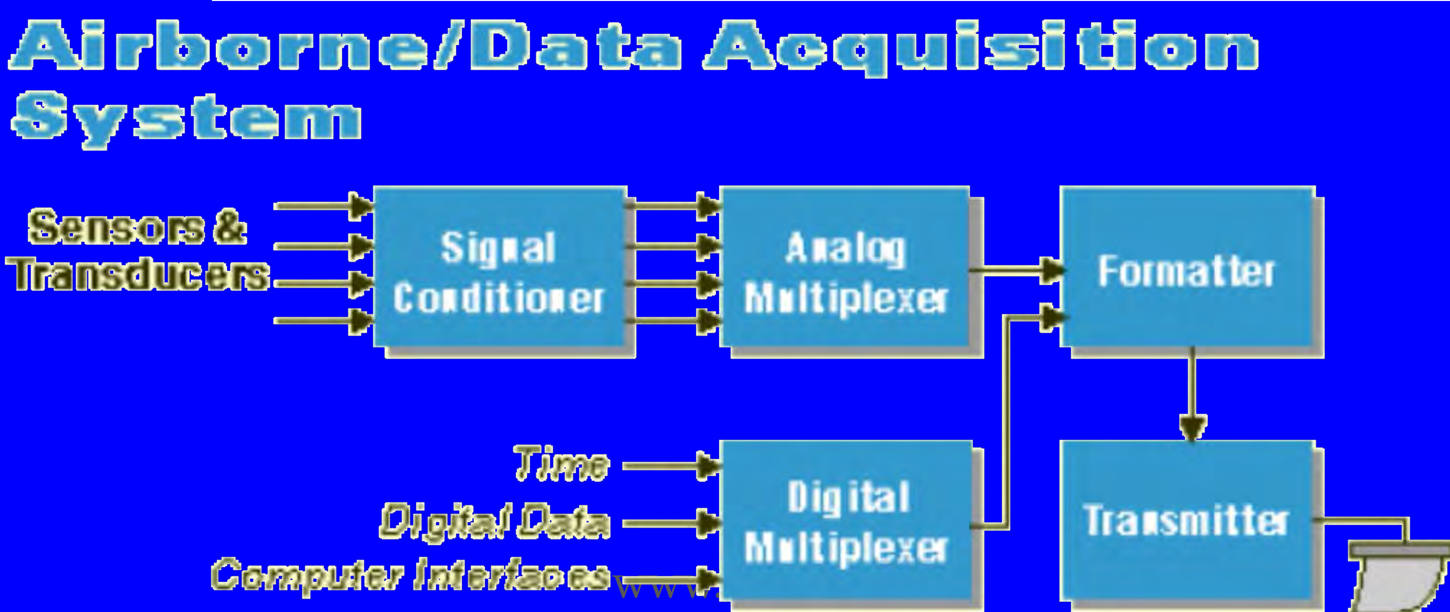
- The communications subsystem is perhaps the most vital aspect of the operation of a spacecraft
  - System which allows data transfer to and from extravehicular sources
  - Only link between an operational vehicle and the ground control station or other satellites

Data Handling

- Multiplex—Demultiplex
- Encryption—Decryption
- Encoding—Decoding
- Data Compression
- Time Tagging
- Data storage
- Data quality monitoring

Telemetry System





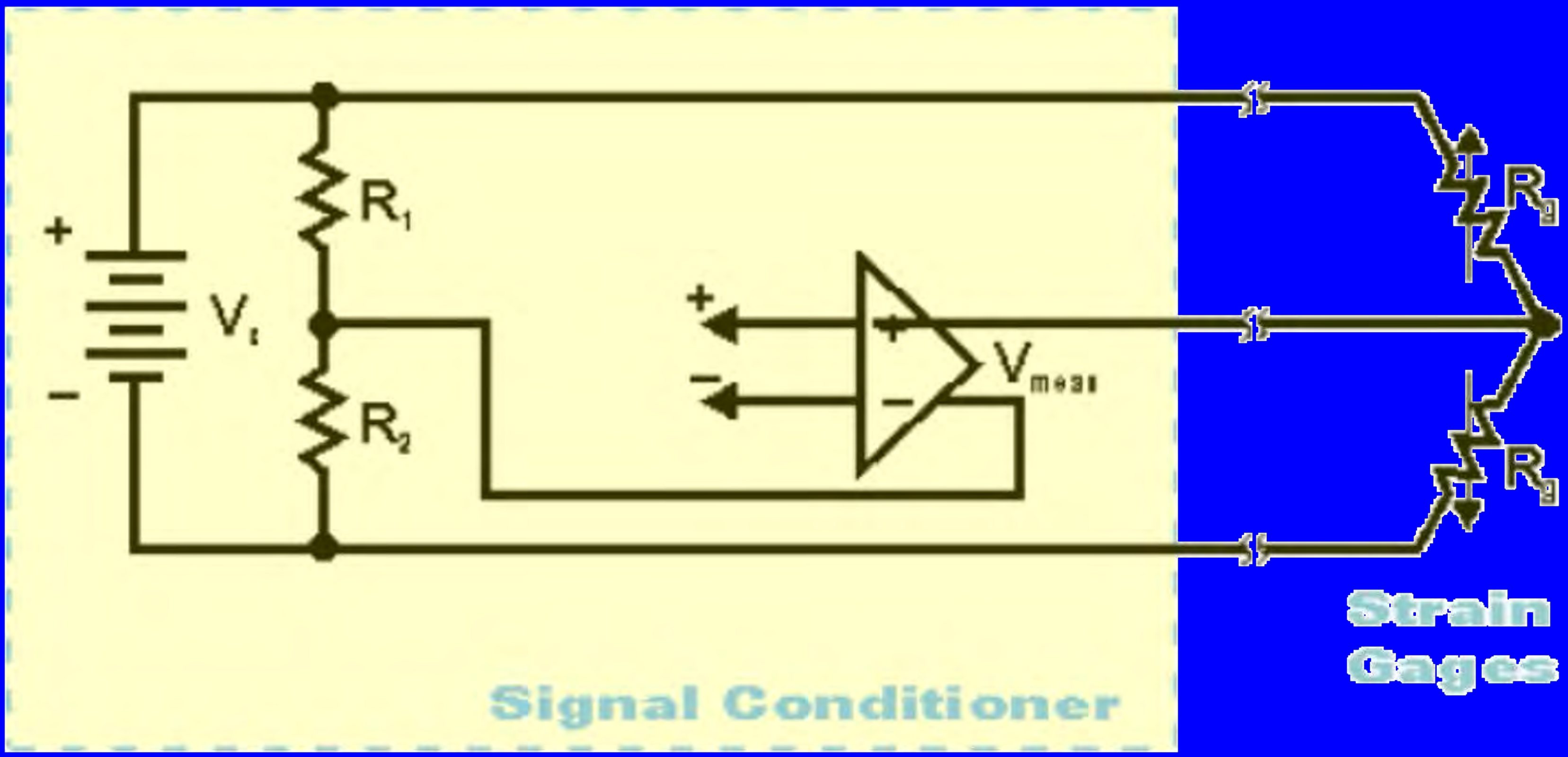
Data Acquisition

- Variety of sensors (also known as transducers) are used to measure and acquire a physical property's value.
- Device selected to meet the environmental, response, accuracy, size, and cost specifications for the application.
- Signal conditioners serve as the interface of the data acquisition system from the transducers.

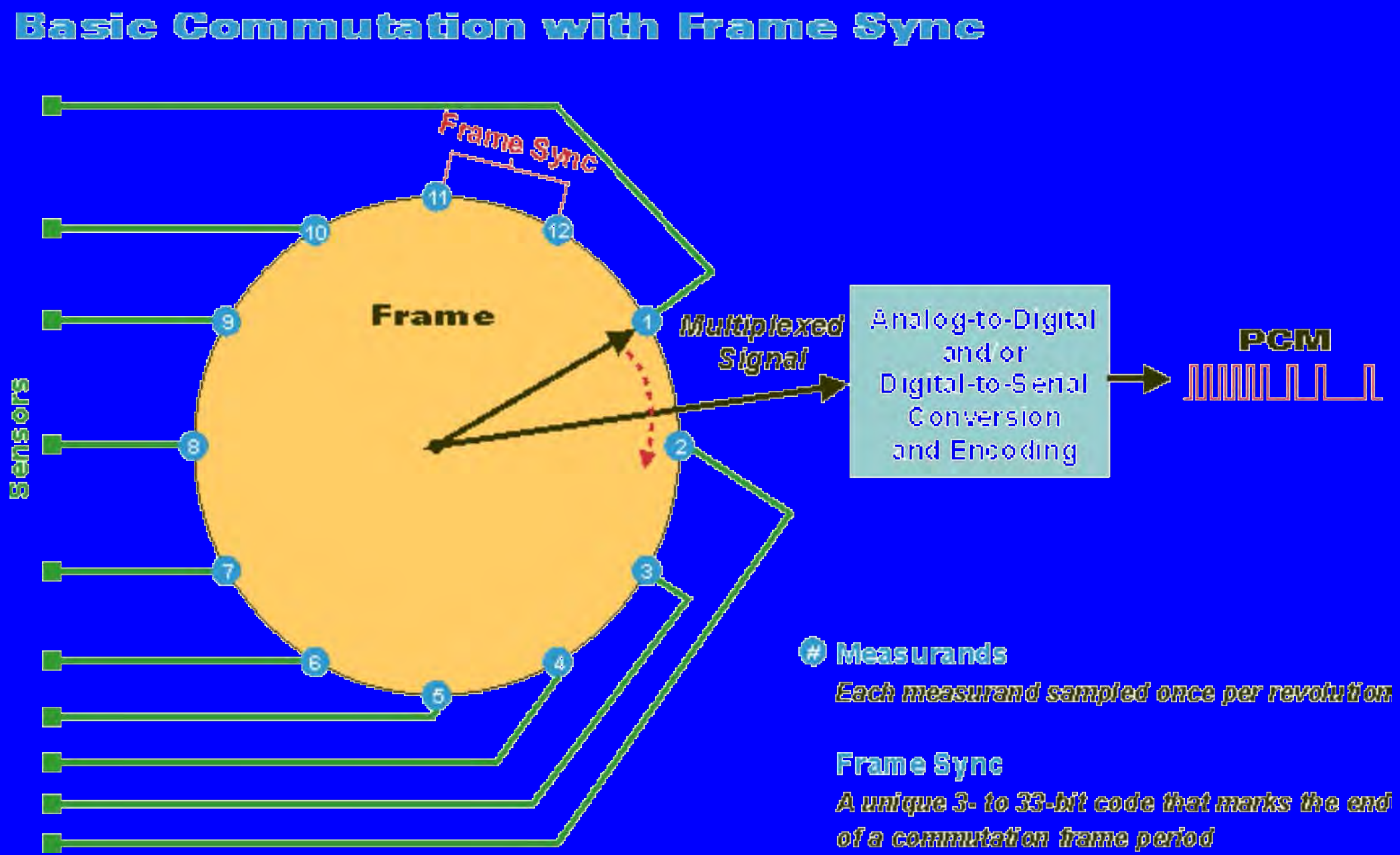
Data Acquisition

- Transducers may require ac or dc power (e.g., strain gages)
  - Others generate signals (tachometers, thermocouples)
- In data acquisition, sensor output characteristics must be transformed, filtered, or modified for compatibility with the next stage of the system.
  - Signal conditioners also incorporate calibration features

Strain Gage



Multiplexing



Data Storage

- Missions are not provided with of real-time tracking.
  - Spacecraft data handling subsystems are provided with one or more data storage devices
    - Tape recorders,
    - Solid-state equivalent of tape recorders which store large quantities of data in banks of RAM without any moving parts..

Data

- Storage (can you transmit the data as you collect it, or do you need to record it?)
- Data transmission, example:
  - MLS radiometer, 100 kbps
  - ERS SAR, 100 Mbps
  - (can be limited by ground segment)
- Ground segment (received, archives, distributes)
- Processing
  - Data level definitions

Telecommunications Subsystems

- High-Gain Antennas (HGA)
- Low-Gain Antennas
- Spacecraft Transmitters
- Spacecraft Receivers
- Communications Relay

Thermal Control, Environmental Control, Venting and Purging

- Major heat sources on earth orbiting satellite
- Define MLI and its construction
- Purpose of vent systems during flight

Thermal Control

- Space Environment
  - Cold -270 +
  - Hot +150 +
- Heat Generators
  - Aerodynamic
    - Launch
    - Reentry 3500+ degrees
  - On Board
    - Electronics
    - Humans – Manned Vehicle

Thermal Control

- Requirement
  - Humans and electronics need stable environments and safe environment

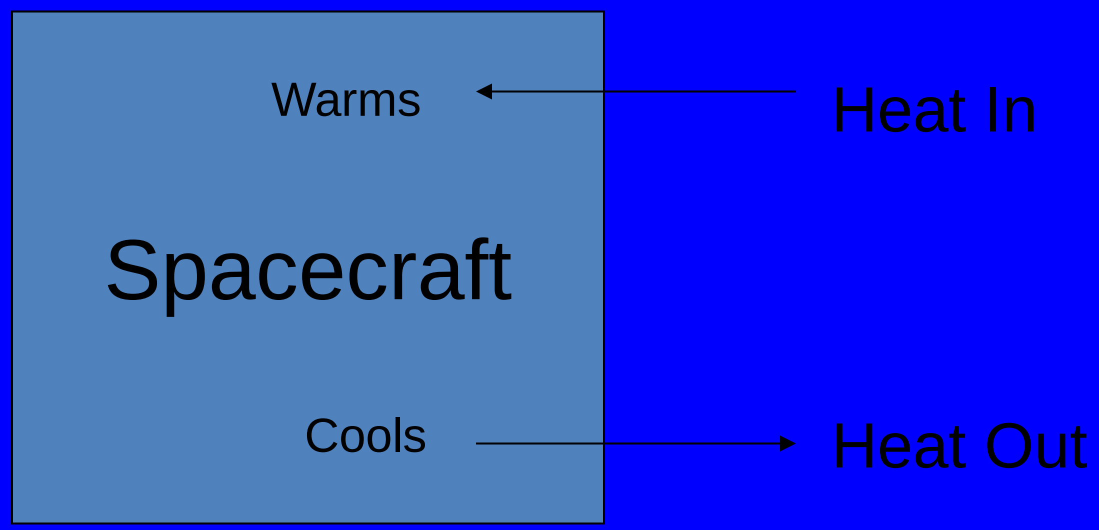
Thermal Control

- Control
  - Aerodynamic
    - Tiles
    - Thermal Blankets
    - Insulation
      - Cork – nose fairings
      - Blankets
  - On board
    - Active Cooling
    - Radiators
    - Insulation
    - Etc

Environmental Control and Life Support

- Successful mission require livable environment
  - Hardware
  - People
- Two Tasks
  - Thermal Control
  - Life Support

Thermal Control



Heat out = Heat in + Internal heat

Want to maintain constant spacecraft temperature then must maintain ***Thermal Equilibrium***

Why Thermal Control?

- Spacecraft operational requirements:
  - Temperature level: strict temperature ranges for S/C subsystems
  - Temperature gradients: distortions in structure or payloads, pointing alterations
  - Temperature stability: measurement accuracy
- A hostile environment:
  - Extremely cold deep space sink temperature (3K)
  - Rapidly changing illumination conditions
  - Absence of conduction or convection

Temperature Ranges for S/C Components

Component	T_{max} (C)	T_{min} (C)
Electronics	+50	-20
Batteries	+25	-5
Fuel	+40	+10
Mechanism	+80	-100
Solar cells	+70	-150
Infrared detectors	-80	-250

Thermal Control

- Heat sources
  - Sun (1358 W/m^2)
  - Earth
    - Reflection (407 W/m^2)
    - Earth Temperature (237 W/m^2)
  - Internal
    - Spacecraft Systems
    - Human (58.2 w/m2)
    - The surface area of skin of an "average" adult is 1.8 m2 The total heat production of an "average" person at rest per hour is 58.2 x 1.8 = 104.76 = 105 watts

Thermal Control

- Biggest Problem may be removing heat
- 2nd biggest problem is getting heat where we want it

Thermal Control

- Space temperatures (-270^{o}C to +2000^{o}C)
- Heat Transfer
  - Conduction
  - Convection
  - Radiation

Thermal Control

- On the ground, thermometers will mark the temperature of the environment, balanced by convective exchange
- If the thermometers are located under the direct influence of the Sun, the readings will depend on their thermo-optical properties
- As the altitude increases, convection gives the way to radiation as the main mechanism of exchange
- Therefore, temperature in space is mainly determined by the radiative balance with the environment

Thermal Control

- To maintain all the elements of a S/C system within the temperature limits which guarantee their reliable performance for all mission phases
- The objective is achieved by controlling the S/C thermal balance:
  - Thermal exchange among external & internal S/C surfaces, environmental heat fluxes and power dissipations
  - Component time constants (thermal inertia)
- Heat fluxes and not temperatures are the subject of control!

Other Protection Criteria

- UV radiation
- Electron and proton fluxes
- Atomic oxygen
  - Dominant atmospheric species in LEO (<600 km), less important at higher altitudes
- Out gassing:
  - Vaporization of a material's surface atoms, occurring when the environmental pressure is of the same order than the material's vapor pressure (10-11/10-15Pa, typical of S/C altitudes)

Other Protection Criteria

- Micrometeroid Protection
- Pressurization/Venting

Thermal Control Approaches

- Selection of the coatings of the S/C surface
- Insulation the S/C in order to minimize the temperature fluctuations caused by variable environmental fluxes and to reduce the gradients produced by non-uniform heating
- Rejection of heat surplus by means of radiators (from a few KW in typical telecom satellites to 30 KW at the ISS)
- Maintenance of the minimum allowable temperatures, especially during cold case conditions, with heaters.

Thermal Control Methods

- Passive systems, the basis of all thermal control:
  - Based on the thermal behavior of the S/C surfaces
  - Low mass, volume and cost requirements
  - High reliability
  - Lifetime limited only by degradation of thermo-optical properties
- Active systems, complementing passive systems:
  - Requiring power input and/or mechanical moving parts
  - Able to cope with large heat loads and variations in power dissipation
  - High mass, volume, power and cost requirements
  - Reliability and lifetime issues

Thermal Control Methods

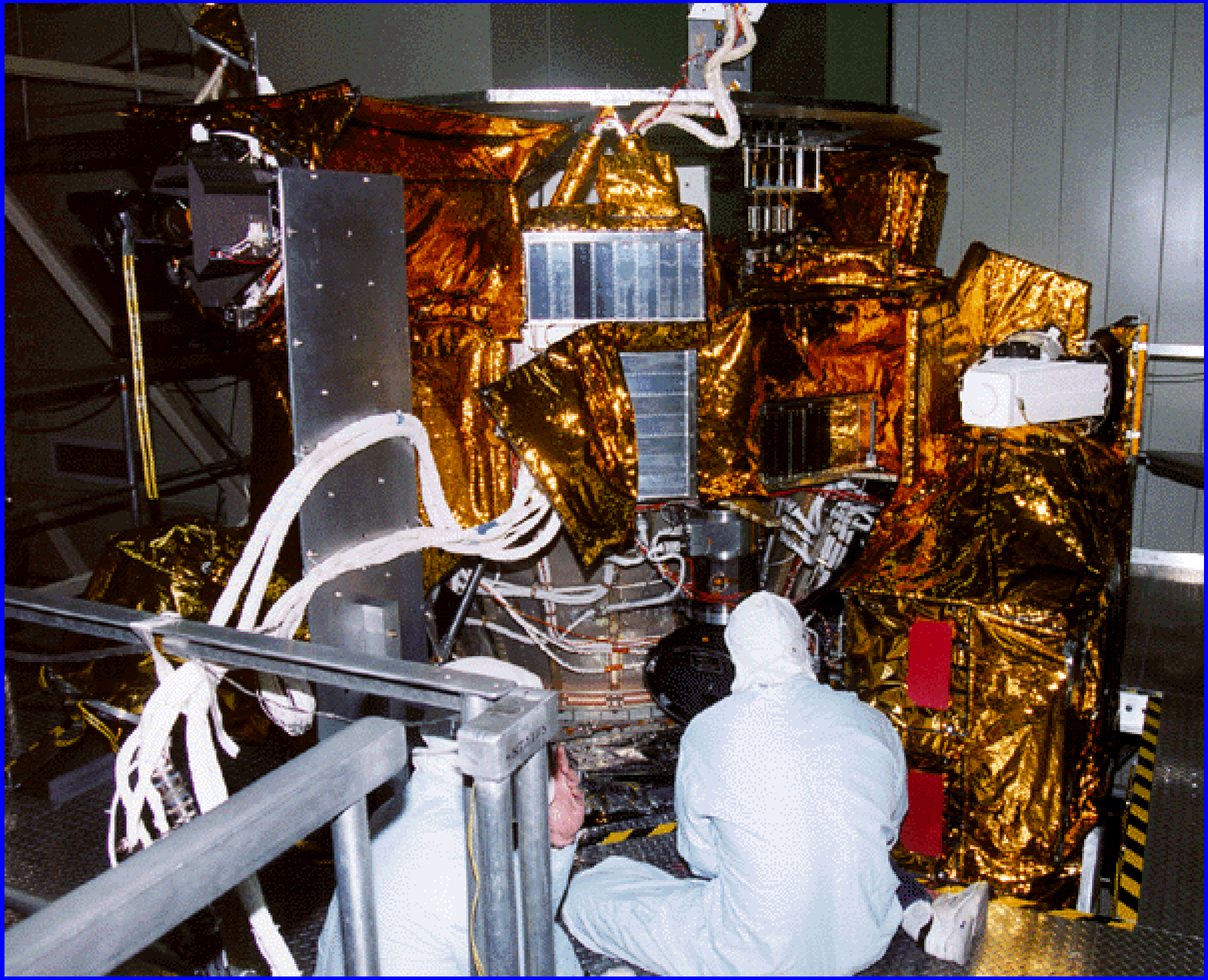
- Passive Systems
  - Coatings
  - Multi Layer Insulation
  - Beta Cloth
  - Radiators
  - Phase Change Devices
  - Thermal Doublers

- Active Systems
  - Fluid Loops
  - Heaters
  - Heat Pipes
  - Louvers
  - Second Surface Mirrors
  - Cold Plates
  - Thermal Switch
  - Water Evaporators
  - Heat Exchanger

Multilayer Insulation (MLI)

- MLI consists of 10-20 layers of closely spaced low-emissivitythin foils
- To avoid conduction between shields, low conductivity spacers or crinkled foils are used and adequate venting is provided to decrease gas pressure within the MLI
- Evacuated MLI provides, for a given mass, insulation which is orders of magnitude greater than given by conventional materials (foams, fibre-glass)

Cassini MLI

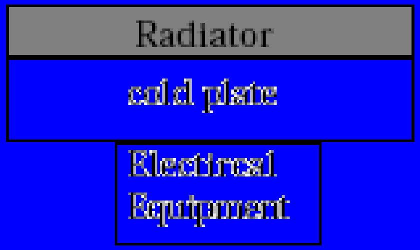


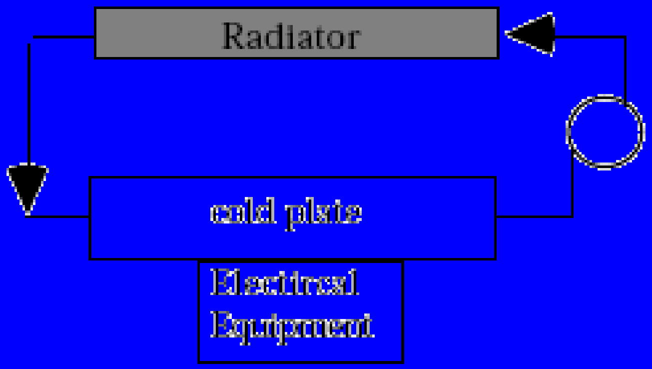
Cassini MLI MLI

For Cassini, the blankets consist of as many as 24 layers of different fabrics, including aluminized Kapton, mylar, Dacron and other special materials.

Cold Plates

- Cold plates are used for mounting heat dissipating equipment.
- In an active system, there are fluid passages within the plate itself.
- The fluid is then pumped to a radiator.
- For a passive system, the cold plate is usually combined with the radiator.



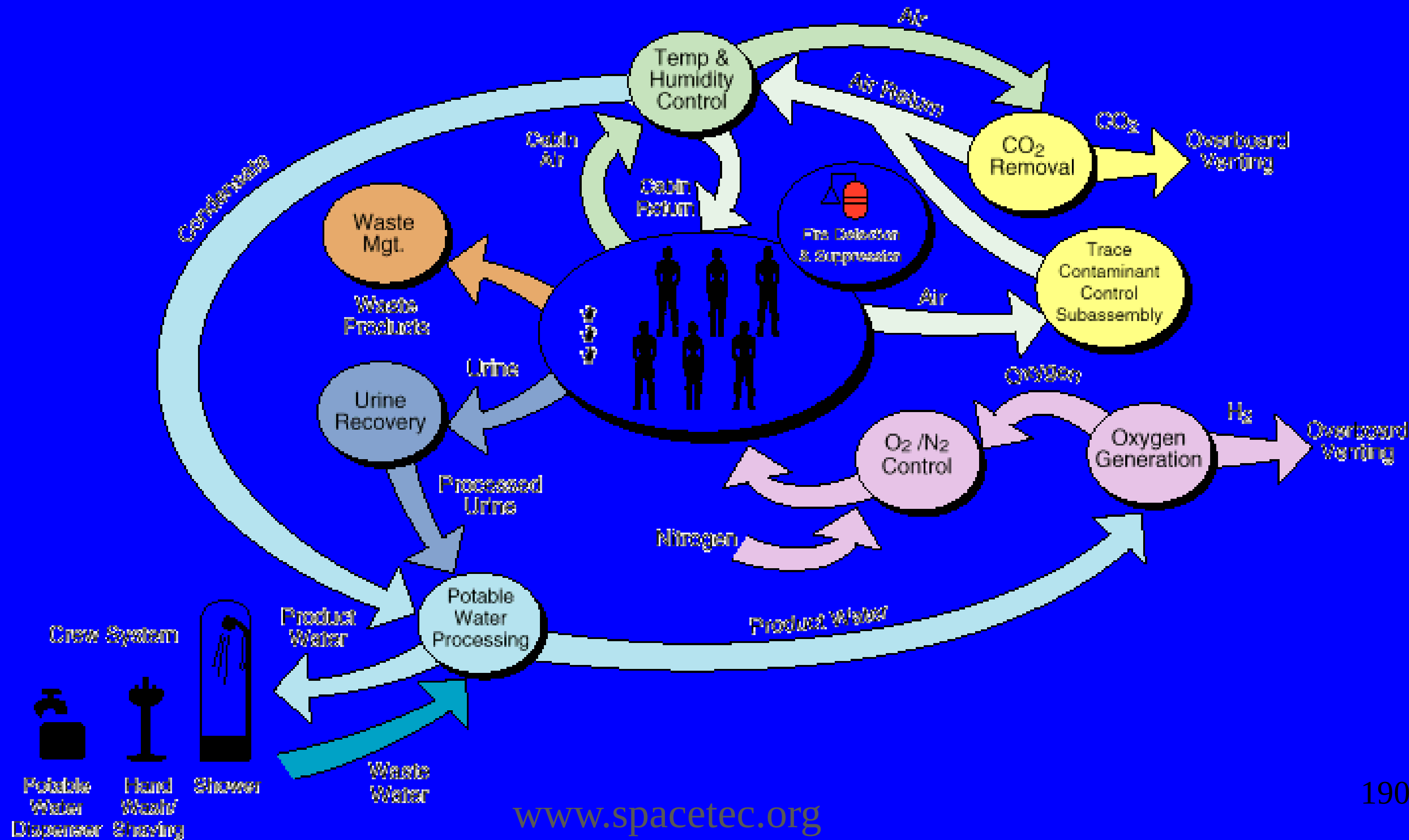


Mid Body Cold Plates

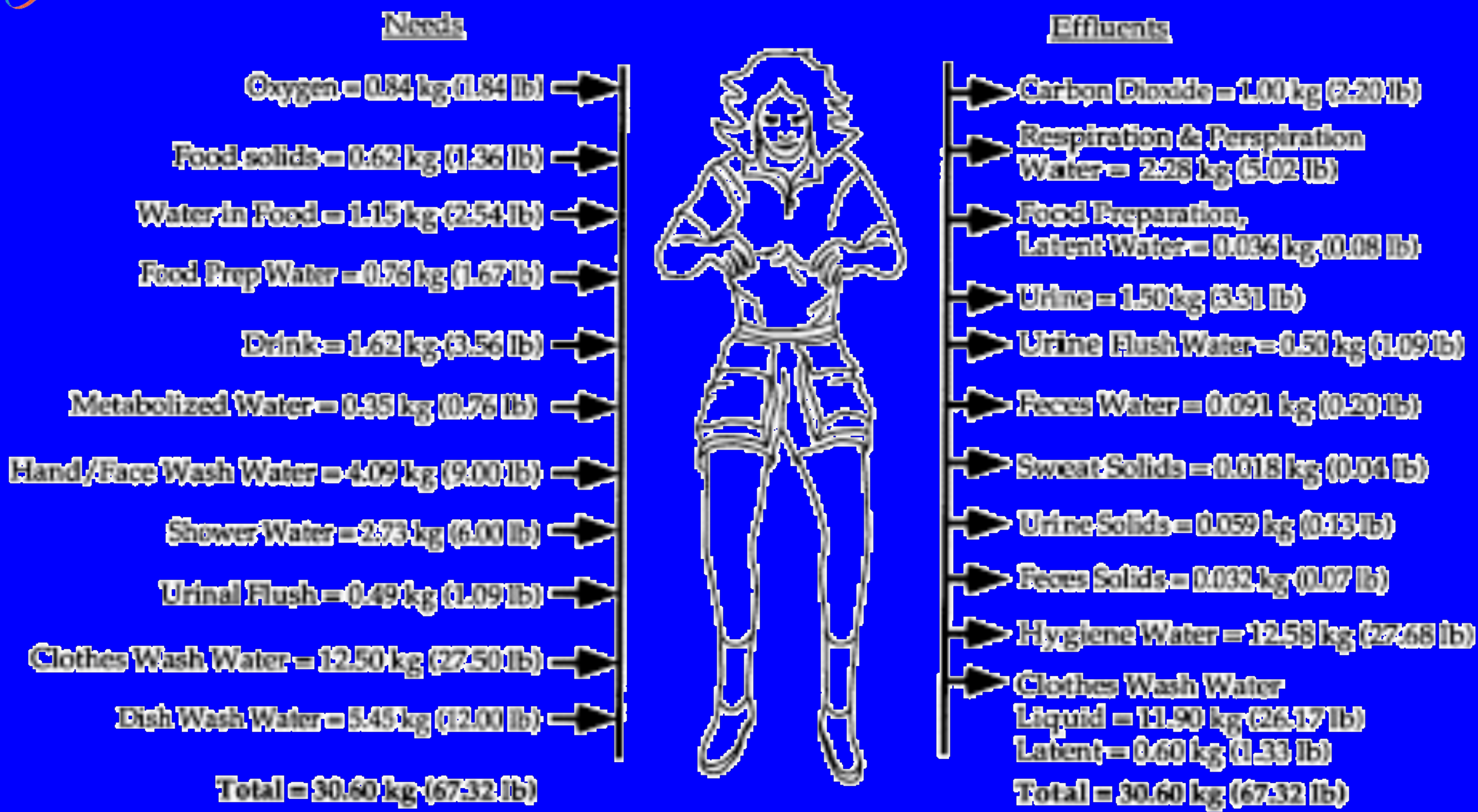
Essentials of Life Support

- Air
  - Constituent control
    - CO_2 scrubbing
    - Humidity control
    - Particulate scrubbing
    - O_2, N_2 makeup
  - Temperature control
- Water
- Food
- Waste Management

Space Station Regenerative ECLSS Flow Diagram (Current Baseline)



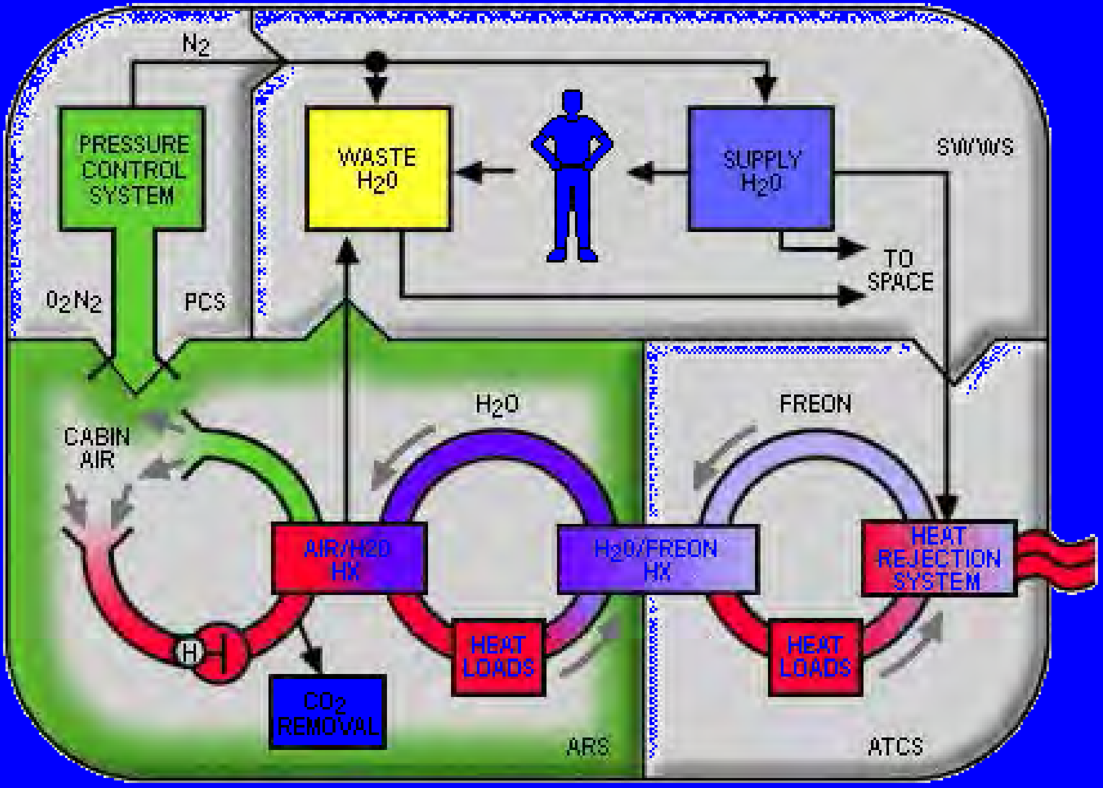
Mass Balance



Note: These values are based on an average metabolic rate of 136.7 W/person (11,200 Btu/person/day) and a respiration quotient of 0.87. The values will be higher when activity levels are greater and for larger than average people. The respiration quotient is the molar ratio of CO_2 generated to O_2 consumed.

Four Major Subsystems:

- Pressure Control System (PCS)
- Atmospheric Revitalization System (ARS)
- Active Thermal Control System (ATCS)
- Supply and Waste Water System (SWWS)



Heating, Ventilation, and Air Conditioning

1. Purge System
2. Vent System
3. Drain System
4. Provides:
   - Thermal conditioning
   - Moisture control
   - Hazardous gas dilution

Active Vent System

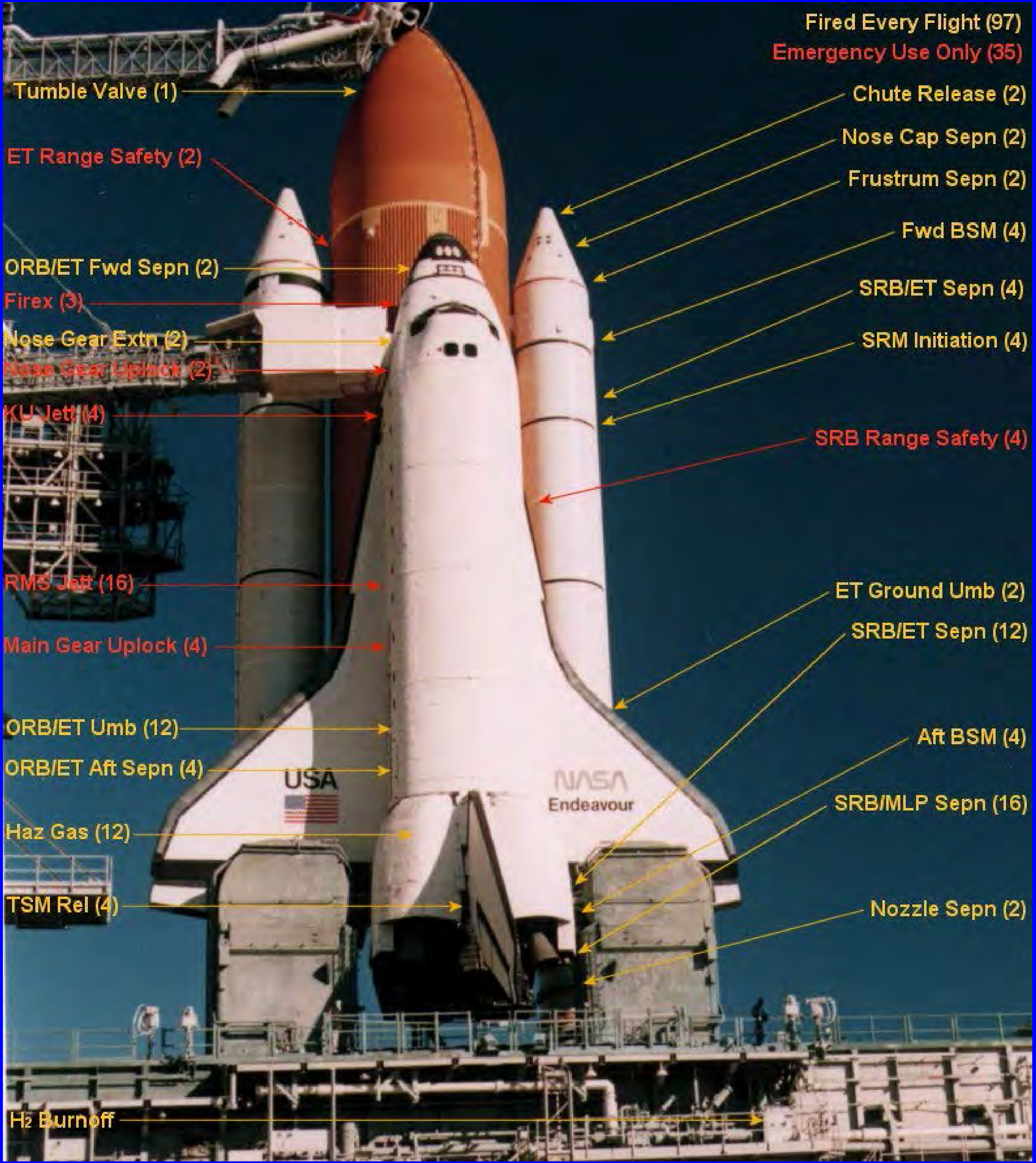
- Active vent system controls venting of the orbiter structural components.
  - Prelaunch: Controls purge flow
  - Launch through Ascent: Equalizes to atmospheric pressure
  - Prevents concentration of SSME exhaust gasses
  - Orbit: Permits molecular venting of the OMS/RCS compartments

Drain System

- Disposes of water and moisture that collects in the orbiter compartments
- Consists of a <u>passive</u> “Thru-hole” and <u>active</u> “vacuum line” systems
- Required to collect and dispose of unacceptable quantities of water and moisture that collects in orbiter compartments during ground operations

PYROTECHNICS DEFINITION, CONSIDERATIONS FOR APPLICATIONS

- In aerospace technology pyrotechnics refer to a broad family of sophisticated devices utilizing explosive, propellant and pyrotechnic compositions to accomplish:
  - initiation
  - release
  - severance/fracture
  - jettison
  - valving
  - switching
  - time delay
  - actuation



Fired Every Flight (97)
Emergency Use Only (35)
Tumble Valve (1)
ET Range Safety (2)
ORB/ET Fwd Sepn (2)
Firex (3)
Nose Gear Extn (2)
Nose Gear Uplock (2)
KU Jett (4)
RMS Jett (16)
Main Gear Uplock (4)
ORB/ET Umb (12)
ORB/ET Aft Sepn (4)
Haz Gas (12)
TSM Rel (4)
H_2 Burnoff
Chute Release (2)
Nose Cap Sepn (2)
Frustrum Sepn (2)
Fwd BSM (4)
SRB/ET Sepn (4)
SRM Initiation (4)
SRB Range Safety (4)
ET Ground Umb (2)
SRB/ET Sepn (12)
Aft BSM (4)
SRB/MLP Sepn (16)
Nozzle Sepn (2)
USA
NASA
Endeavour

Pyrotechnics Are Extensively Applied Because of Their High Efficiency

- High energy delivered per unit weight
- Small volume, compact
- Long-term storable energy
- Controllable initiation and output energies

Although Successful, Pyrotechnics Are Reluctantly Used

- Unique Characteristics
  - Single shot
  - Cannot be functionally checked before flight
  - Short-duration, impulsive loads (pyrotechnic shock)
  - Safety issues
  - Contain explosive materials

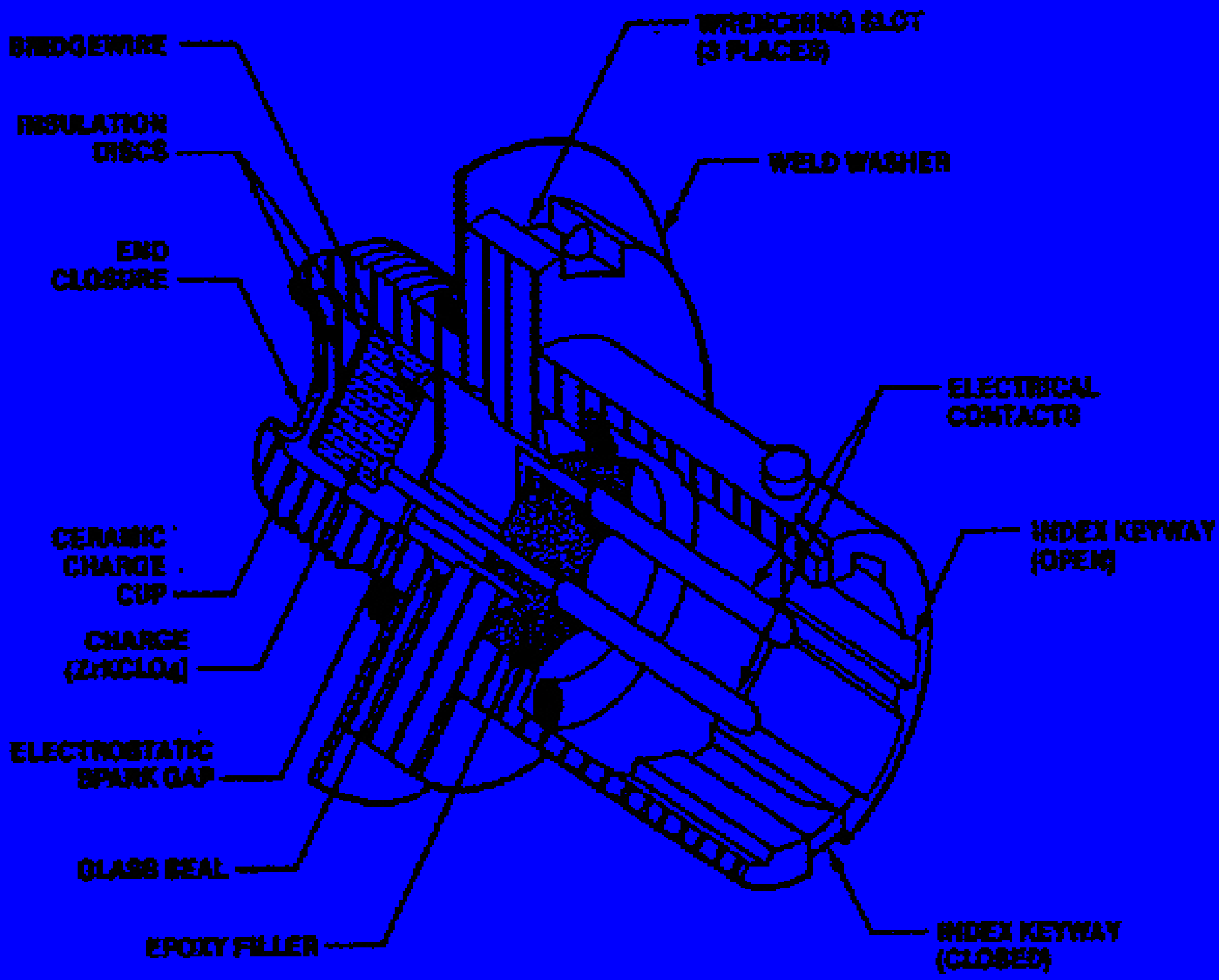
Although Successful, Pyrotechnics Are Reluctantly Used

- Inadvertent functioning:
  - only small forces sometimes required to initiate
  - static electricity
  - lightning
  - electromagnetically induced energy
  - stray energy in firing circuits
  - Limited engineering approaches/standards are available for pyrotechnic applications

Although Successful, Pyrotechnics Are Reluctantly Used

- Cannot apply approaches for commonly used energy sources (electric, hydraulic, pneumatic)
  - Lack of test methods and logic to demonstrate functional margin
  - Go/no-go testing
  - Failures continue to occur
  - Lack of understanding of mechanisms
  - Poor or no resolution of failures
  - Few sources for information (reliance on manufacturers)
  - Reliability estimate based on successful qualification

NASA Standard Initiator (NSI-1)



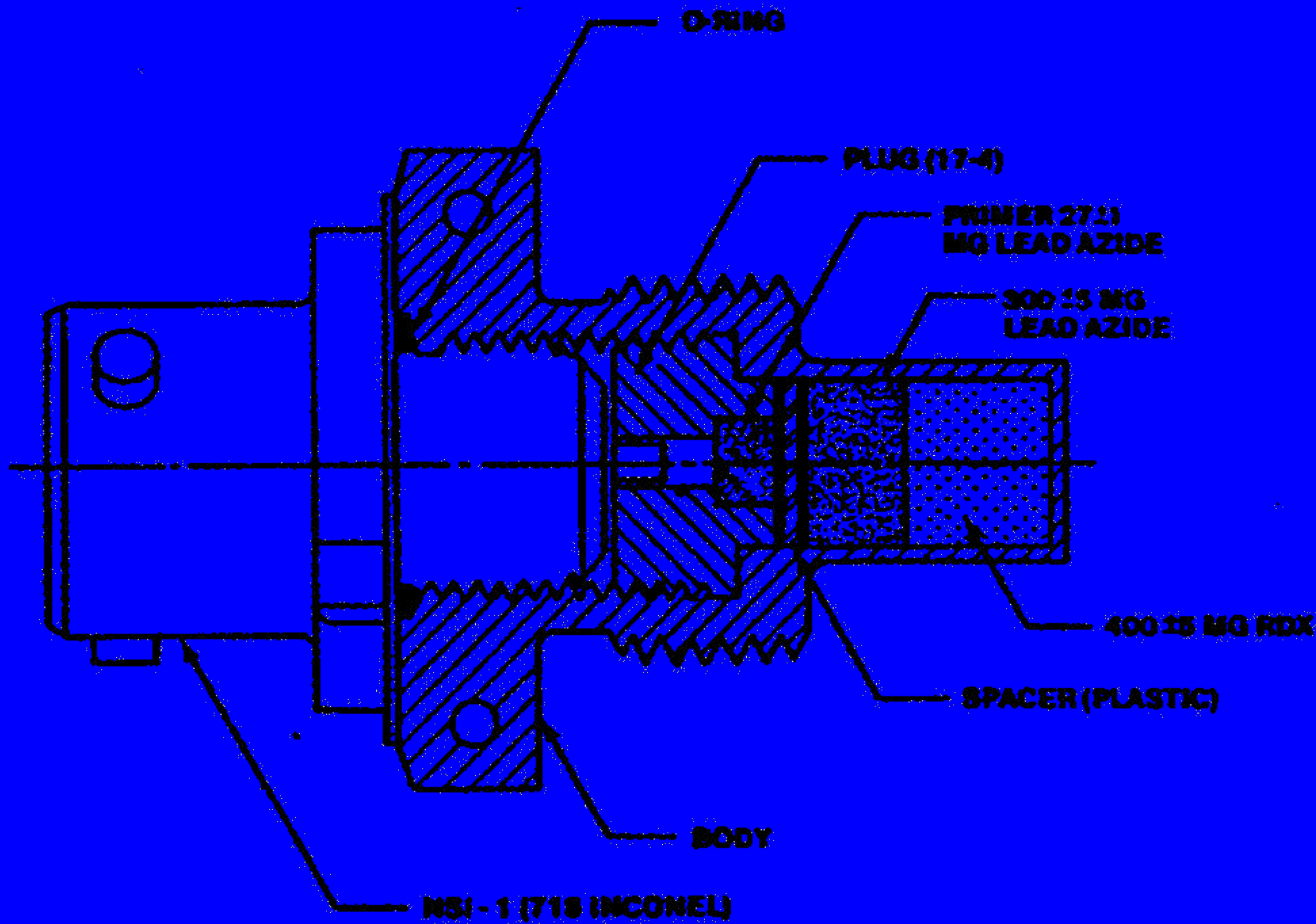
NASA Standard Initiator (NSI-1)

- NASA Standard Initiator (NSI-1)
  - designed for minimum probability of initiation by static electricity
  - designed with an all fire current of 5 amps, but will fire with little as 3.5 amps
- NSI-1
  - electrical explosive device (EED), which contains a primary explosive charge of 114 milligrams of Zirconium Potassium Perchlorate (ZrKCLO4)

NASA Standard Initiator (NSI-1) continued

- Resistances wire is .002" stainless steel and when appropriate amperage is applied, it will heat up to 450°F, causing charge to detonate
- When NSI-1 detonates, produces an output pressure of 650 psi in a 10 CC area

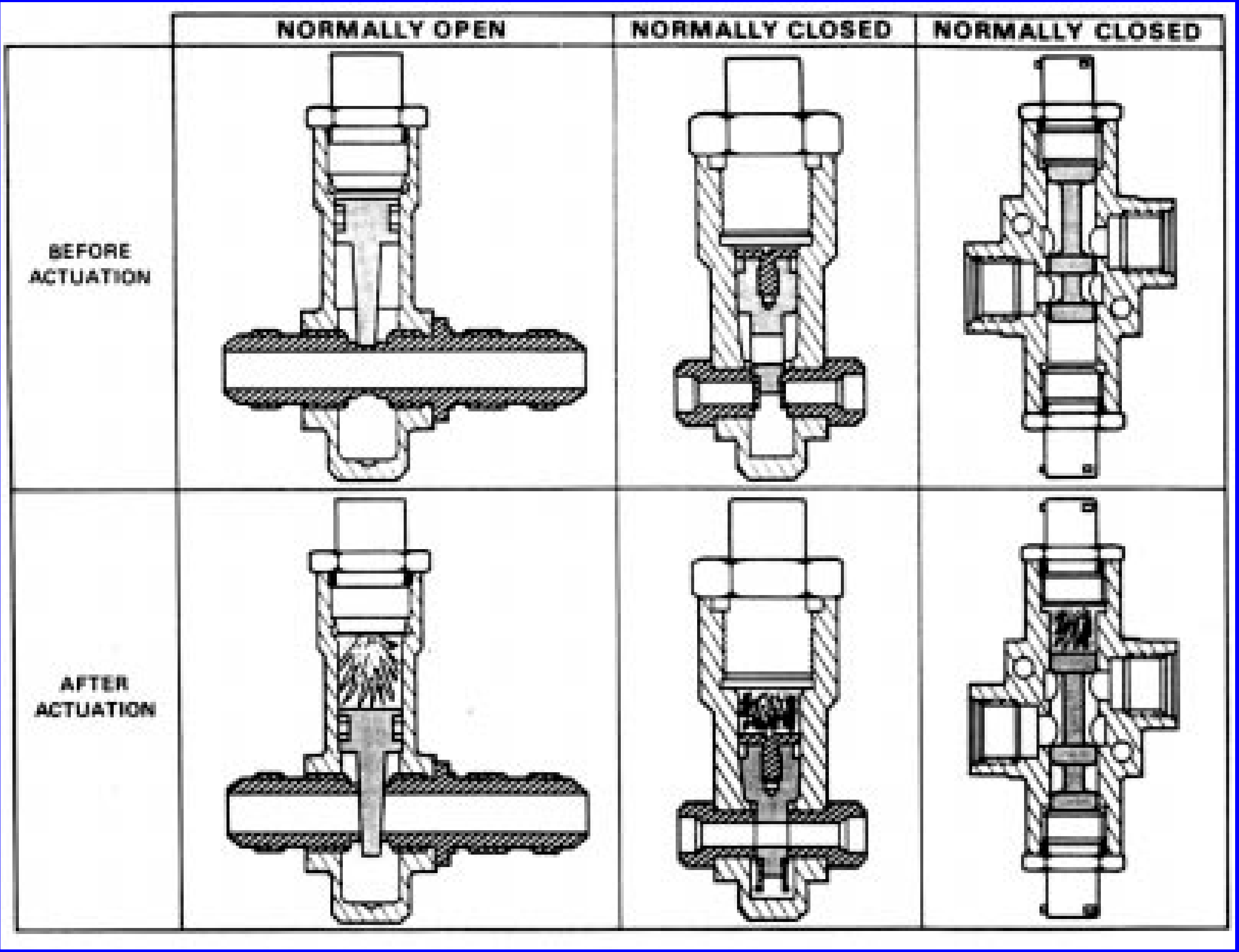
NSI Detonator



NSI Detonator

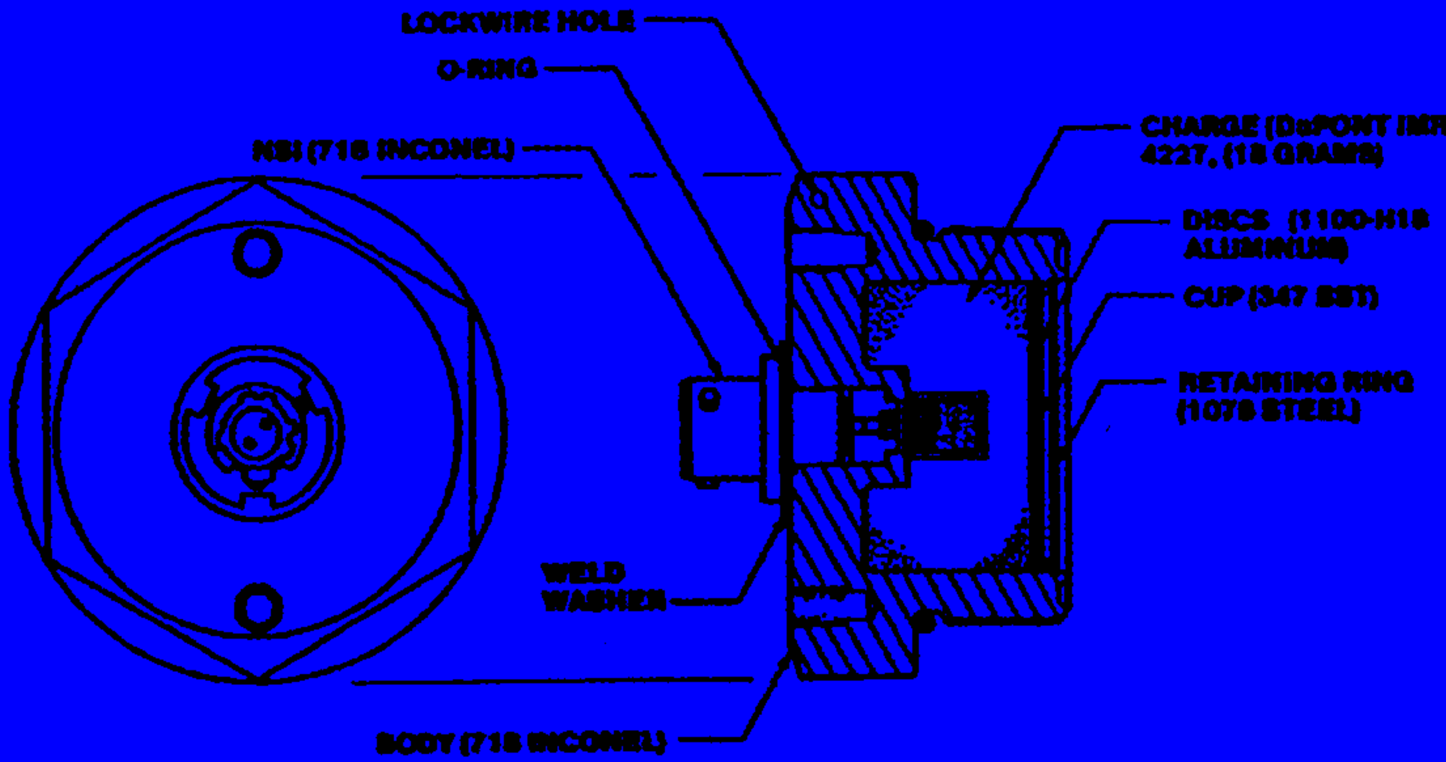
- NSI Detonator consists of NASA Standard Initiator (NSI) threaded into housing containing sensitive primary explosive train
- Output of NSI is amplified by Lead Azide column in explosive train
  - progresses to detonation of final RDX output charge
  - output is required to produce .045 inch dent in a steel block

Cross sectional views of pyrotechnically actuated linear actuators, describing function.



Cross sectional views of pyrotechnically actuated valves, describing function.

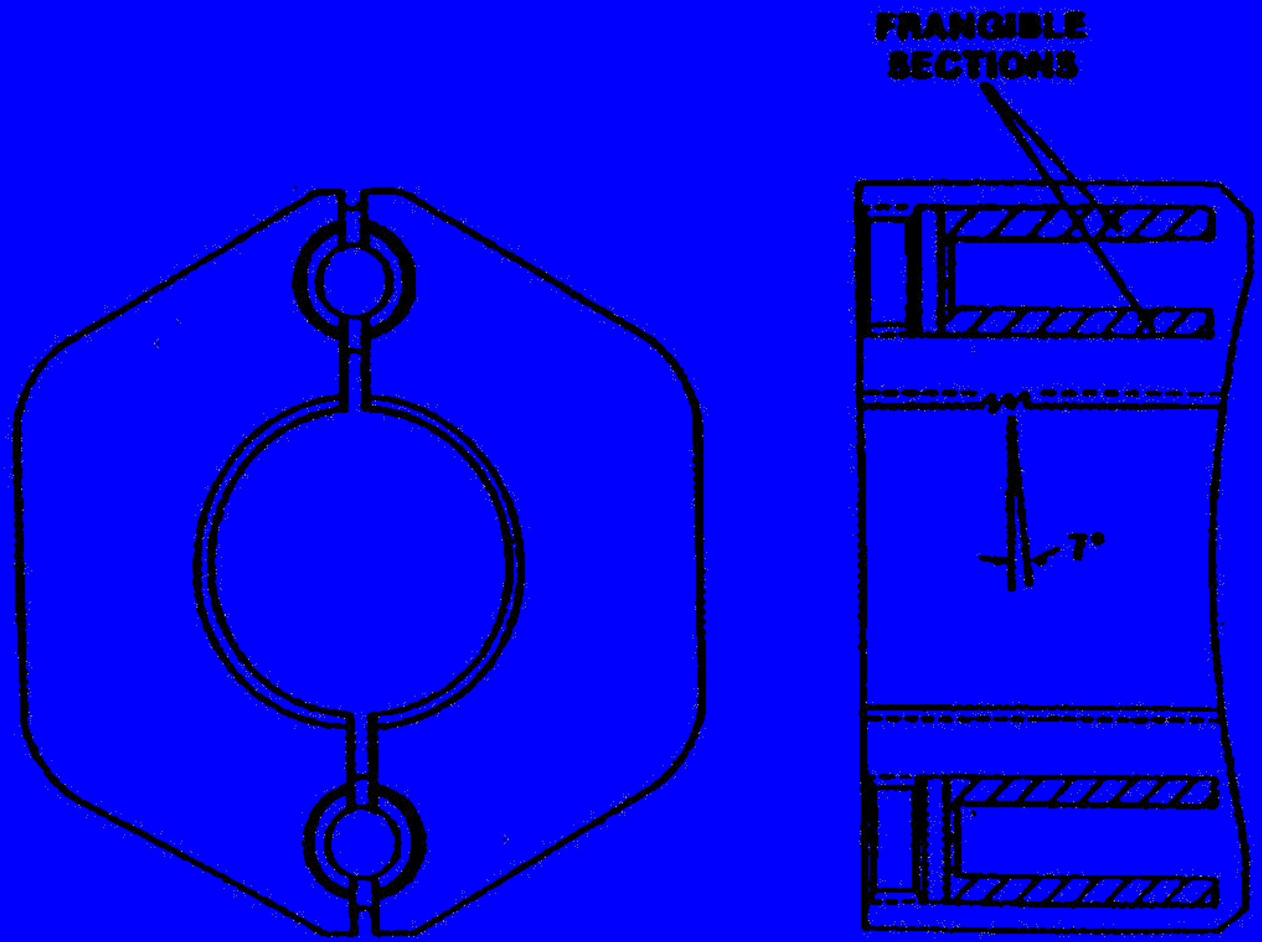
NSI Pressure Cartridge



NSI Pressure Cartridge

- NSI pressure cartridge, 10A00457-2161
  - used to activate both forward and aft SRB/ET separation bolts
  - uses NSI as the electroexplosive device
  - develops pressure within 1.0 msec after application of current
  - reaches acceptable peak pressure within 8.0 msec thereafter in a closed bomb
- Required peak pressure output as measured in a 104cc closed bomb will be 22,200-26,300 PSI

Frangible Nut



www.spacetec.org

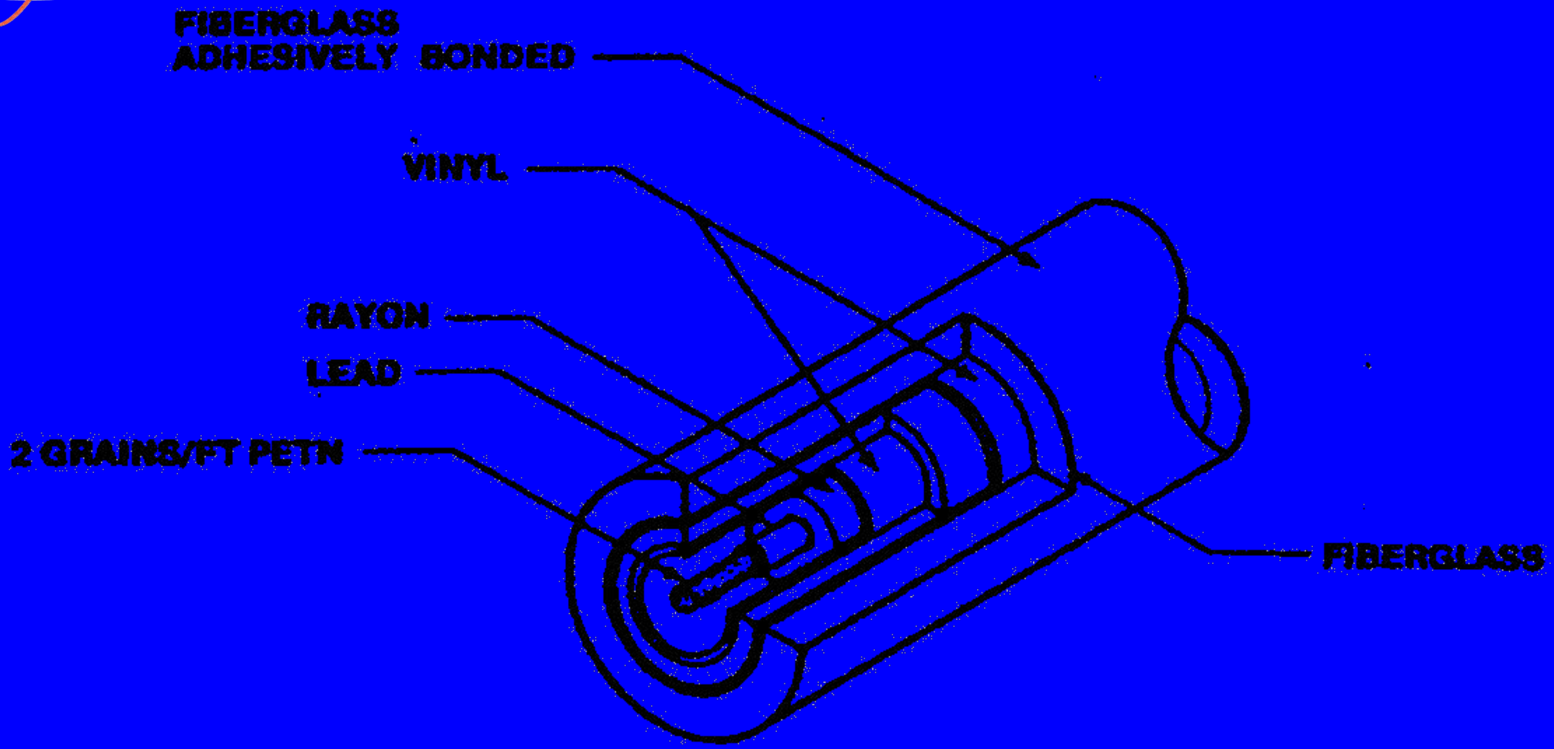
Frangible Nut

- Frangible nut
  - Inert, high-strength nut
  - Category “B” explosive device
    - not capable of injuring people or damaging property, either by itself or by initiating subsequent events
- NOTE: device may be Cat “B” device during handling and become Cat “A” device after installation into a system
  - Frangible Nut is an explosive device and cannot be dropped

Frangible Nut Booster Cartridge Assembly

- Frangible Nut Booster Cartridge Assembly
  - explosive device
  - when initiated by NSI detonator, will completely separate a frangible nut
- Booster cartridge consists of an explosive encased in a housing with a detonator port

Confined Detonating Fuse



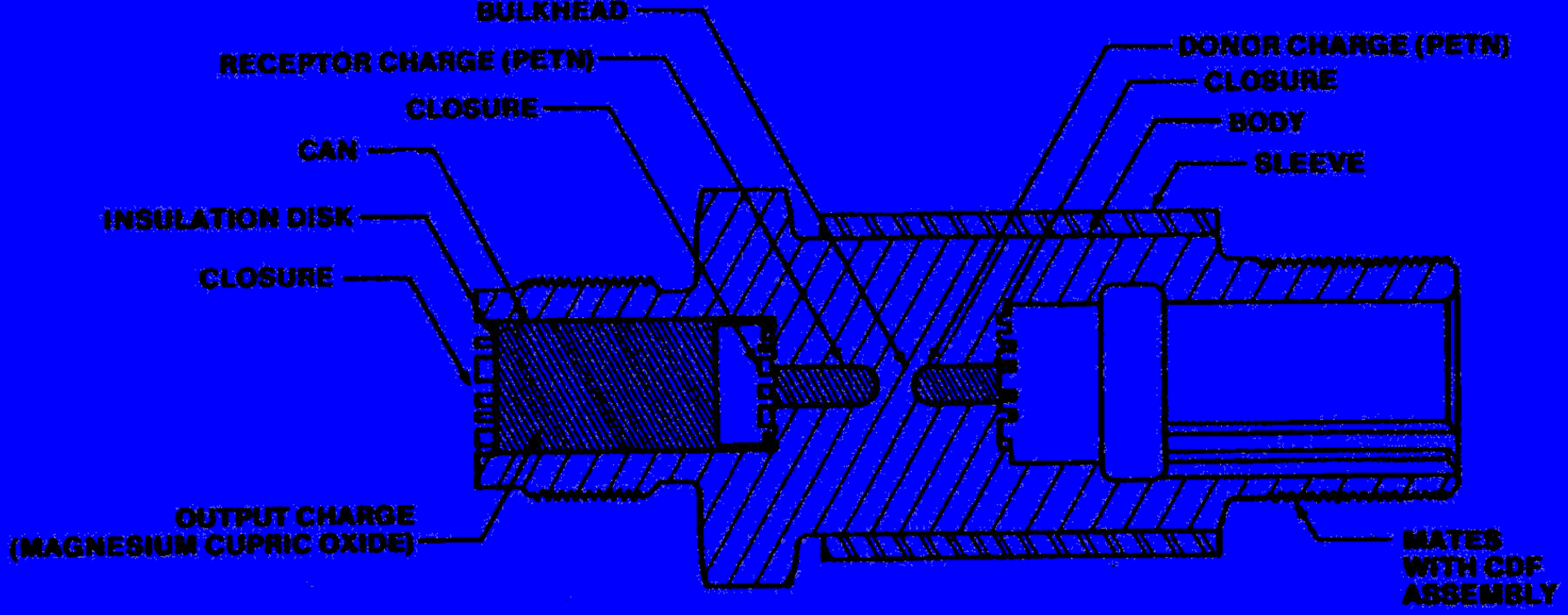
- CDF is excellent for transferring detonations past delicate instruments, other explosives, and personnel because the outer covering stays intact.

Confined Detonating Fuse Manifold

Confined Detonating Fuse Manifold

- Explosive train
  - 20 grain per foot mild detonating cord (MDC)
  - thin-wall (5-mil) guiding metal cups on the ends of MDC
- MDC
  - RDX, type A MIL-R-398 in a thin-wall led (Pb) tube swaged to final diameter
  - core loading of 20 grains per foot

CDF Initiator



Cross sectional views of mild detonating cord (MDC)-actuated severance and separation approaches.

Linear Shaped Charge

Linear Shaped Charge

- When a hallow cavity is made at end of explosive charge and fired with hollow facing the target, the explosive effect is "focused" along a line and destructive power is considerably increased
- As explosive wave travels down through the charge and reaches hollow, the explosive forces, which acts in equal force in all directions will have a resultant force normal to the surface of the cavity working progressively, down its apex

Separation Bolt

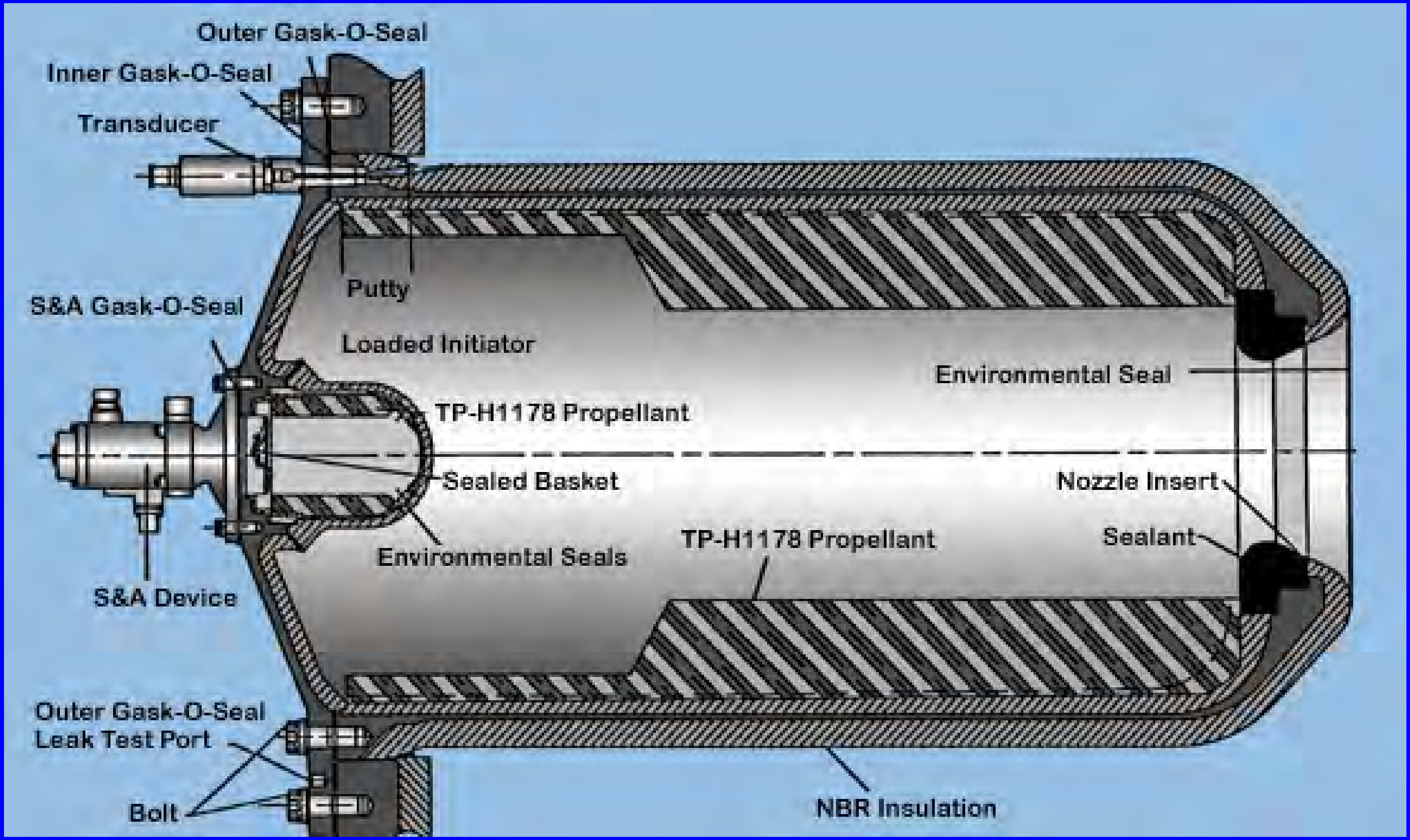
Cutter Assembly

Range Safety Safe and Arm (S&A)

Range Safety Safe and Arm (S&A) continued

- Range safety S&A device
  - Remotely controlled electromechanical device that is used to “safe” and to “arm” the SRB and ET and their destruct systems
  - Can complete or interrupt explosive train by remote control, provide position indications to remote monitoring equipment, and provide a visual position indication
  - Manual operation capability

SRM Igniter



Outer Gask-O-Seal
Inner Gask-O-Seal
Transducer
Putty
S&A Gask-O-Seal
Loaded Initiator
Environmental Seal
TP-H1178 Propellant
Sealed Basket
Nozzle Insert
Sealant
TP-H1178 Propellant
Environmental Seals
S&A Device
Outer Gask-O-Seal
Leak Test Port
Bolt
NBR Insulation

Ground Support Systems

- Definition
  - Anything but the flight hardware and personnel
- Purpose
  - Test, move, handle, service,
- Use of hydraset
  - Load positioning device (raise or lower)
  - Capable of accuracies of .001

Launch Weather Constraints

- Temperature
- Wind
- Precipitation
- Lightning (and electric fields with triggering potential)
- Clouds: (types known to contain hazardous electric fields)
- Range Safety Cloud Ceiling and Visibility constraints
- "Good Sense Rule"

Upper Air Winds

- Wind shear
  - Upper air winds can range well up into 100 mph and change direction rapidly with altitude. Vehicle has to control through these winds