8 Propulsion Systems

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8.1 Introduction

In the design of most spacecraft, the propulsion subsystem is one of the key design considerations, especially when considering that the propulsion subsystem is many times the single most massive component of the spacecraft, comprising as much as 90% or more of the total spacecraft mass. Because of this, the propulsion subsystem performance affects both mission design and payload mass. There are a large number of different propulsion system types that are in use today or that have been proposed, and they cover a wide range of capabilities. The goal of this report is not to provide a detailed analysis of each type of propulsion type, but to classify and characterize various propulsion subsystem types and to assemble a database to provide the information necessary for the design of a new spacecraft's propulsion subsystem. The Propulsion System Database is available on disk for both the PC and the Macintosh.

8.2 Propulsion System Types

There are several rocket propulsion system types in common usage. All share the common characteristic of providing the propulsive force by the momentum of ejected matter, the propellant. The major difference in various propulsion systems lies in the method of supplying energy to the propellant. Energy is added to increase the kinetic energy of the propellant. This increase in energy results in an increase in velocity of the propellants being expelled, meaning an increase in propellant momentum. Since momentum is conserved for the system, the vehicle momentum in the opposite direction must also increase. Energy for the propellants can be supplied in a number of ways, including chemical combustion, nuclear reaction, solar radiation, and others. These different energy sources can be used to categorize various propulsion systems. Additionally, the function of the engine may be used for characterization. These functions include apogee or perigee kick motors, attitude control, station keeping, precision pointing, reboost, landing, retro-rockets for deorbit, and others.

To help give the designer a clearer perception of the choices available when developing a propulsion system, the following page contains a schematic breakdown of the major propulsion system types organized in a tree form. Three major types of systems are included in the tree; Chemical , Non-Chemical and Exotic/Theoretical. Each of these categories is then broken down into more descriptive subcategories, showing the relationships between the various propulsion systems. The specific impulse and thrust range figures shown are only ranges of performance which categorize the specific propulsion system type. All the elements with an * next to them are described in more detail in the following text.

****Scan Figure*****

Figure 8.2.1 Interface Document

****Scan Figure*****

Figure 8.2.2 Propulsion Tree

8.3 Chemical Propulsion Systems

Chemical rockets are the oldest form of rocket propulsion, invented over eight centuries ago by the Chinese for use in fireworks. Chemical rockets utilize chemical combustion to supply energy to the propellants. This combustion is typically the high pressure reaction between a fuel and an oxidizer. The combustion supplies heat energy to the combustion products, raising their temperature. To increase the combustion product momentum, a converging-diverging nozzle is used to expand the gases. Chemical propellant rockets can be grouped based on the physical state (solid, liquid, or gaseous) of their propellants. In the next four sections solid, liquid, gaseous, and hybrid propellant chemical systems are described.

8.3.1 Solid Fuel Rockets

Solid rocket motors are very common in American space operations. They are the simplest type of rocket engine as they have very few moving parts. The nozzle is connected directly to the propellant tank, with no pumps or other machinery between them. The propellant tank contains a mixture of fuel and oxidizer, which does not react until the engine has been ignited. Once ignited, the propellant burns continuously until depleted. The shape of the propellant is very important to the engine performance. A large burning area corresponds to a higher thrust than a smaller burning area. The propellant's shape may be tapered to provide periods of higher and lower thrust, according to the mission plan. The performance of the solid rocket is often measured by total impulse, which is the area under the Thrust vs Time curve. Solid rockets are often used when high reliability or long term storage of the motor is necessary. The specific impulses of typical solid rocket motors range from about 200 to 300 seconds, or only about 50%-75% as high as most liquid propellant engines. Table 8.3.1 contains theoretical performance numbers for a some common solid propellant combination. The primary advantages of solid engines are that they are the oldest rocket system, and thus are a well known and proven technology. They are easily sized, simple to operate, and reliable. On the other hand, the are not restartable, are dangerous and expensive to make, non or only partially throttleable, offer low specific impulse, and give off toxic emissions including chloro-fluorocarbons.

Oxidizer	Fuel	Average Specific Gravity (g/cc)	Chamber Temp. Tc (˚K)	Exhaust Velocity C* (m/sec)	Molecular Weight (kg/mole)	Specific Impulse I_{sp} (sec)	k
Ammonium Nitrate	11% binder and 7% additives	1.51	1282	1209	20.1	192	1.26
Ammonium Perchlorate 78 to 66%	18% organic polymer binder and 4 to 20% aluminum	1.69	2816	1590	25.0	262	1.21
Ammonium Perchlorate 84 to 68%	12% polymer binder and 4 to 20% aluminum	1.74	3371	1577	29.3	266	1.17

Combustion chamber pressure of 1000 psia with optimum expansion to 1 atm (14.7 psia) Frozen equilibrium

Table 8.3.1 Theoretical Performance of Solid Rocket Propellant Combinations [Sutton 1986]

****Scan Figure*****

Figure 8.3.1 Schematic cross sections of a typical solid porpellant motor with case bonded grain [Sutton 1986, p. 265]

8.3.2 Liquid Fuel Rockets

Liquid fuel rockets, as with other chemical systems, utilize a chemical reaction to supply energy to the working fluid, the gaseous chemical reaction product, to obtain thrust. Liquid fuel rockets may be classified in several ways. One method to classify liquid rockets is by the number of chemicals involved in the reaction, either monopropellant, bipropellant, or multipropellant. Liquids may also be grouped as either storable or cryogenic.

Monopropellants are those chemicals which may be used alone to obtain a chemical reaction. These may be a mixture of several compounds or a single chemical. In general they are decomposed by heating or exposing to an appropriate catalyst, thus doing away with the typical ignitors necessary for other liquid propellants. This makes them ideal for systems needing high reliability and simplicity, such as attitude and trajectory control jets. They also have the advantage of only needing to store one propellant. Along with these advantages come the disadvantages that they usually have lower specific impulses than many bipropellants. They are also generally highly toxic substances involving special handling and storage. Some monopropellants which have been used include hydrogen peroxide, ethylene oxide, and nitromethane. By far the most common monopropellant is hydrazine, which offers a specific impulse of about 245.9 seconds at a chamber pressure of 1000 psia and expansion to vacuum.

Bipropellants are the most common type of liquid fuel rocket. As the name suggests, bipropellants use two components as reactants, an oxidizer and a fuel. In general, bipropellants the use of some type of ignitor to initiate the chemical combustion. However, there are certain combinations of propellants which will react upon contact. Such propellants are known as hypergolic propellants. Table 8.3.2 contains a listing of commonly used bipropellant combinations, along with some interesting theoretical combinations. Liquid bipropellants offer the highest specific impulses of all chemical systems at the cost of more complexity than monopropellant systems.

Existing liquid chemical propellant types can also be divided into two main classes, cryogenic and storable. **Cryogenic** propellants are gases which have been liquified under very low temperatures thus they must be refrigerated to remain in liquid form. Because of their low boiling points provisions must be made to account for boil-off losses during long space missions and to vent this boil-off, possibly for attitude or trajectory control as a gas jet which will be discussed later. Storable liquid propellant components have relatively higher boiling points and so do not require cryogenic refrigeration. These categories can be further divided into Earth storable and space storable. **Earth storable** propellants are liquids at Earth ambient temperatures and so are relatively easy to handle. **Space storable** propellants include those that are Earth storable and those which must be refrigerated on Earth but will remain liquid in space without refrigeration. Storable propellants are more suitable for missions in which the propellants must be held in reserve for long periods.

Additional considerations in the design of liquid chemical rocket engines are the propellant feeding and ignition systems. Propellants may be fed into the combustion chamber by pressure alone or by some type pump. Pressure fed systems offer increased reliability and simplicity but not all propellant combinations can be pressure fed. Pump fed systems offer slightly higher engine performance at the cost of some reliability. They operate with a much lower propellant tank pressure so that they can make use of light-weight, thin-walled tanks and eliminate the requirement for a pressurization system. Calculations have shown that pump fed systems provide a greater payload than pressure fed systems for missions requiring more than 450 kg of propellant.

Oxidizer	Fuel	O/F Ratio by Mass	Average Specific Gravity (g/cc)	Chamber Temp. Tc (˚K)	Exhaust Velocity C* (m/sec)	Specific Impulse Is (sec)	k
Oxygen (O_2)	75% Ethyl Alcohol	1.43	1.01	2957	1670	279	1.22
	H_2	4.02	0.8	2724	2432	391	1.26
	CH_4	3.15	0.81	3528	1865	310	
	C_2H_2	1.60	0.86	4144	2009	330	
	C_2H_4	2.45	0.88	3806	1859	312	
	C_2H_6	2.95	0.90	3600	1844	307	
	C_3H_8	2.75	0.91	3622	1835	305	
	C_4H_8	2.55	0.92	3667	1829	305	
	C_5H_{12}	2.90	0.94	3611	1817	302	
	RP-1	2.56	1.02	3399	1804	300	1.24
	N_2H_4	0.90	1.07	3400	1896	313	1.25
	MMH	1.40	1.01	3550	1875	311	1.25
	UDMH	1.67	0.98	3606	1865	310	1.25
	50%N_2H_4 and 50% UDMH	1.29	1.02	3522	1881	312	1.25
	NH_3	1.41	0.83	3100	1792	295	
	Be	1.40	1.35	5406	1475	255	
	53%Be + 47%H_2	0.93	0.25	2961	2774	454	
Fluorine (F_2)	H_2	7.60	0.45	3596	2549	410	1.33
	CH_4	4.35	1.02	4233	2057	345	
	C_2H_4	2.50	1.03	4239	1942	329	
	C_3H_8	3.25	1.10	4189	1975	334	
	RP-1	2.56	1.21	4139	1884	318	
	B_2H_6	5.45	1.09	4989	2246	371	
	B_5H_9	4.60	1.20	5067	2173	360	
	N_2H_4	2.25	1.31	4678	2219	364	1.33
	MMH	2.38	1.24	4556	2085	347	1.33
	UDMH	2.45	1.19	4317	2015	339	1.33
	50%N_2H_4 and 50% UDMH	2.40	1.26	4533	2115	351	1.25
	NH_3	3.27	1.12	4578	2198	360	
	Li	2.54	1.00	5656	2313	380	
	39%Li + 61%H_2	1.07	0.21	2294	2640	438	
Ozone (O_3)	H_2	3.8	0.28	3239	2615	423	
Nitrogen Tetroxide (N_2O_4)	N_2H_4	1.33	1.21	3261	1786	292	1.26
	MMH	2.17	1.19	3394	1747	288	
	UDMH	2.60	1.17	3439	1731	287	
	50%N_2H_4 and 50% UDMH	2.00	1.19	3361	1750	289	1.24
	NH_3	2.00	0.98	2922	1673	273	

Oxidizer	Fuel	O/F Ratio by Mass	Average Specific Gravity (g/cc)	Chamber Temp. Tc (˚K)	Exhaust Velocity C* (m/sec)	Specific Impulse Is (sec)	k
Oxygen Difluoride (OF_2)	H_2	5.75	0.38	3439	2499	402	
	CH_4	5.0	1.06	4422	2158	356	
	C_2H_6	4.4	1.15	4544	2164	355	
	C_3H_8	4.35	1.17	4583	2149	354	
	B_2H_6	3.67	0.99	4639	2240	372	
	N_2H_4	1.62	1.27	4078	2088	345	
	MMH	2.4	1.25	4361	2118	350	
	50%N_2H_4 and 50% UDMH	2.1	1.24	4278	2115	350	
Hydrogen Peroxide H_2O_2 (100%)	B_2H_6	1.84	0.80	2711	1969	333	
	B_5H_9	2.25	1.02	3028	1859	313	
	N_2H_4	2.27	1.27	2928	1759	288	
Inhibited Red Fuming Nitric Acid (HNO3) 15% N_2O_4	RP-1	5.00	1.33	3150	1579	263	
	UDMH	3.1	1.26	3156	1649	272	
Chlorine Trifluoride ClF_3	N_2H_4	2.80	1.50	3894	1820	293	
	UDMH	3.00	1.37	3572	1692	278	
Perchloryl Fluoride ClO_3F	N_2H_4	1.45	1.21	3456	1801	295	

Combustion chamber pressure of 1000 psia with optimum expansion to 1 atm (14.7 psia)
Shifting equilibrium

Table 8.3.2 Theoretical Performance of Liquid Rocket Propellant Combinations [Sutton 1986]

Ignition systems are required for most propellant combinations and they add complexity and reliability concerns to the design of a spacecraft. Hypergolic propellants ignite spontaneously when they come in contact with each other and so do not require a separate ignition system. Monopropellants frequently utilize a solid catalyst to release the chemical energy of the propellant and so these systems also do not require separate ignition systems. Liquid propellants have the advantages of being a well known and tested technology, versatile and reliable. The main disadvantages are a maximum specific impulse of approximately 500 seconds, the need for complicated plumbing, and possible toxic emissions.

An alternative to the oxidizer/fuel type of liquid engine makes use of the energy released from the combination of free radical species. The recombination of hydrogen radicals to form H_2 has a theoretical specific impulse of 2,130 seconds, but no working versions of radical hydrogen engines have been tested.

8.3.3 Gas Jets

Rockets may use a compressed gas as the propellant. Typically these systems are primarily used for station-keeping and attitude control purposes. Gaseous rockets can be divided into two categories, cold (inert) gas jets and warm (heated) gas jets. Both systems expand high pressure compressed gases through a supersonic nozzle. The most common type of gas jet is the cold gas jet, and systems such as this have been used for periods up to three years on some spacecraft. Warm gas jets are similar to cold gas jets except that a heat source such as an RTG or heater is used to heat the propellant storage tank. Gas jets provide low thrust (<10 Newtons) and low total impulse (< 4,000 Newton Seconds). Cold gas jets provide specific impulses in the range of approximately 65 to 75 seconds and warm jets provide specific impulses of about 105 to 230 seconds [Sutton 1986]. Gases such as hydrogen can provide significantly higher specific impulses, but in general any advantage gained is negated by the bulk of the storage systems necessary to contain them due to their very low densities. Table 8.3.3 contains some possible gases for use in gas jets.

Propellant	Molecular Mass	Density† (lb/ft^3)	Theoretical Specific Impulse (sec)
Hydrogen	2.0	1.21	296
Helium	4.0	2.37	179
Methane	16.0	12.10	114
Nitrogen	28.0	17.37	80
Air	28.9	19.3	74
Argon	39.9	27.60	57
Krypton	83.8	67.20	39
Freon 14	88.0	60.01	55
Carbon dioxide	44.0		67

†At 3500 psia and 0˚C.

Table 8.3.3 Cold Gas Jet Properties [Sutton 1986]

8.3.4 Hybrid engines

Hybrids combine some of the advantages of liquid and solid propellants. The liquid (usually the oxidizer) is stored in one container with the solid (usually the fuel) in a second. The separation of propellants eliminates the dependence of burning time on the grain area while the absence of oxidizer in the solid grain improves its structural properties. The hybrid combines the start-stop advantages of liquid propellants with the high density, instant readiness, and potentially high thrust of solid propellants. The drawback is designing the proper flame pattern without degrading performance. The theoretical specific impulse of a solid lithium/liquid flourine and oxygen mixture engine is about 375 seconds.

8.4 Non-Chemical Systems

Non-chemical systems function fundamentally the same as chemical systems, but the difference is in the source of energy for the working fluid and in the working fluid itself. Non-chemical systems obtain their energy by processes other than the combustion or decomposition of chemical reactants. Non-chemical systems energy sources include such things as thermal, electrical, magnetic, electromagnetic, and other forms of energy. The working fluid is also different. The working fluid can be a gas such as hydrogen, or it can even be ions. In the following sections, various non-chemical systems will be discussed. The first system to be examined is the nuclear thermal rocket.

8.4.1 Nuclear Thermal Rockets

Nuclear thermal rockets obtain their energy in the form of thermal energy from a nuclear reaction. Thrust is produced by feeding a gas over a nuclear reactor and then accelerating this heated gas through a converging-diverging nozzle, just as the reaction products are in a chemical system. The specific impulse increases with higher chamber temperatures and with a decrease in the molecular weight of the exhaust gas, therefore hydrogen is usually used as the working fluid, or propellant. A solid core nuclear rocket can produce specific impulses up to 1000 seconds, which is twice that of the best chemical rockets. Several solid core nuclear rockets were developed and tested during the 1960's. A second type of nuclear rocket is the gaseous core rocket. This type engine operates at much higher temperatures and produces Isp from 1,000s to 6,000s (Angelo). These rockets have not been tested, but do look promising for interplanetary missions. The main advantages of theses systems are the very high specific impulses of which they are capable coupled with the fact that they produce high thrust and are reusable. On the other hand these systems use nuclear reactors and thus require much shielding, especially for manned missions, thus negating some of the advantages. There are also strong political and environmental groups which are opposed to the use of nuclear energy for any purpose.

8.4.2 Electric Thrusters

Electric thrusters' source of power is electricity. This electricity may be used to supply thermal energy or electrostatic/electromagnetic energy to the working fluid. The following two sections discuss both electrostatic, electrothermal, and electromagnetic systems.

8.4.2.1 Electrostatic/Ion

The working fluid in ion engines are ions. Ion engines develop very high specific impulses on the order of 2,000 to 10,000 seconds but at very low thrust levels. These engines produce very low accelerations over long periods of time. Ion engines produce thrust by pumping a neutral propellant into an ion production chamber where ions and electrons are separated into two different streams. The ions pass through a strong electrostatic field and are accelerated into an exhaust stream. The thrust is the total reaction to the accelerating forces [Hill]. A large amount of electricity is required to produce this electrostatic field, therefore a nuclear reactor is often used to supply the power to the engines. Another option is to use solar power to generate the electricity; this is given the name, "Solar electric ion propulsion." Figure 8.4.1 shows a schematic of an ion engine [Sutton 1986].

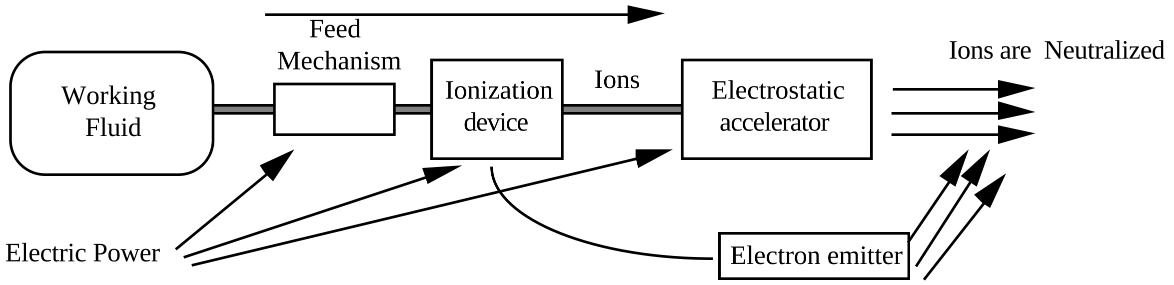

Figure 8.4.1 Ion engine schematic

8.4.2.2 Electrothermal

Electrothermal motors operate by adding thermal energy directly to the propellant and expanding it through a conventional nozzle just as in chemical and nuclear thermal systems. A simple example of such a motor is the resisto jet. In this example electricity is used to resistively heat filaments which in turn heat the propellant. The thermal limitations of the filaments allow such a design to reach a maximum specific impulse of about 800 seconds. Another more common form of electrothermal motor is the arc jet thruster. In this design the electrical current is made to pass directly through the propellant to heat it. This bypasses the limitations of the heater filament and theoretically allows specific impulses of approximately 1500 seconds to be achieved. Unfortunately problems arise due to the fact that the electricity is passing through the propellant thus causing it to ionize. This dissociation of the propellant in turn leads to other problems. Figure 8.4.2 shows a resisto-jet schematic.

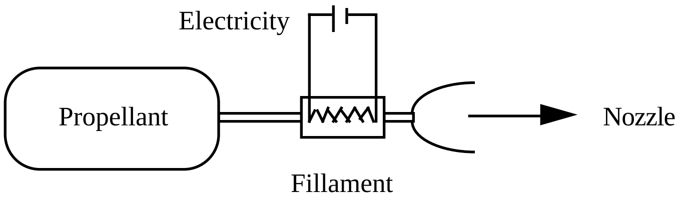

Figure 8.4.2 Resisto jet.

8.4.2.3 Electromagnetic (Magnetoplasmadynamic)

Electromagnetic thrusters were developed to try to circumvent the ionization problems of the electrothermal motors. In this concept the Lorentz force (X**B**) resulting from the interaction of an electrical current with a magnetic field is used to add to the electrical energy directly in kinetic form. Significant engineering limitations have limited the advantages and potential of this system. These systems can provide high specific impulses, but at the expense of high power requirements, low thrust levels, and thus long travel times

8.5 Exotic/Theoretical Systems

Included in this category are systems which are novel or in the distant future. Some of the systems include in this system use solar wind or thermal radiation as the means of propulsion. Another uses discrete solid particles as opposes to a fluid for the propellant. The first system to be discussed is solar sails.

8.5.1 Solar Sails

The solar sail is a unique propulsion system that takes advantage of the Sun's radiation pressure. The Sun produces a gradient of radiation pressure, with the magnitude decreasing outward from the Sun. This pressure produces a small force on an object in space, but it is usually regarded as nothing more than a perturbation to the object's orbit. However, a large sail (sometimes on the order of several square kilometers in area) could exploit this free solar wind. For example, the sail could provide a thrusting force for a ship on an Earth-Mars trajectory. Although the thrusting force is still small, it can now be controlled and made to contribute to the mission. A great advantage of the solar sail is obviously that it doesn't require any propellant, but there are several drawbacks as well. The sail is virtually useless beyond the orbit of Mars, as the radiation pressure dwindles at large distances from the Sun. Also, the sheer size of the solar sail will pose new problems in construction and control. Finally, a large object such as a sail is likely to collect debris and perhaps suffer damage from such encounters. A small scale solar sail experiment is slated for a Space Shuttle mission in the early 1990's. Solar sails potentially can provide very large specific impulses and are reusable, but they produce very small thrust levels and the structures are quite fragile and massive.

8.5.2 Solar/Laser Thermal Propulsion

In a solar or laser thermal rocket, solar or laser light is collected and focused to heat a propellant working fluid such as hydrogen. The collector mirrors are very large structures which serve to concentrate the light energy on the propellant. Lasers could be based on the ground, in an airplane or in space. Very high pointing accuracy is required for the laser, and a laser thermal rocket could be used only near the source of the laser. Specific impulses in the range of 800 to 1,500 seconds are possible and thrust to weight ratios of about 10^{-2} are expected.

8.5.3 Rail Guns

Rail guns use electromagnetic fields to rapidly accelerate payloads to very high velocities on the order of kilometers per second and could provide specific impulses in range from 600 and 1,500 seconds. Rail guns require very large and complex systems to set up the electromagnetic fields and manipulate them to produce the high accelerations, thus suggesting probably a stationary propulsion system. But on the negative side, payloads would be subjected to very high g-loadings and large thermal loads due to atmospheric heating if used from the earth. Environmentalist would also be quite displeased with the multiple sonic booms which would be created.

8.5.4 Antimatter

Antimatter propulsion is a theoretical concept in which propulsion is derived from the annihilation energy of matter-antimatter reactions. The theoretical specific impulse that could be obtained from such a reaction is on the order of 3.0×10^7 seconds and velocities approaching the speed of light could be obtained. The major obstacles in the production of antimatter engines are in the production and storage of the antimatter. Current production rates would require 1.0×10^8 years to produce one kilogram of antiprotons. Magnetic storage would also be required to contain the antimatter and prevent contact with any physical container.

8.6 Selecting a Propulsion System Type and Size

This section provides a spacecraft designer with information for obtaining a first approximation of the engine size and engine type that will best suit the mission requirements. Figure 6.1 has been provided to illustrate some of the important characteristics of different propulsion types. It may be used to eliminate one or more propulsion types from consideration, narrowing the scope of the search for the best propulsion system type based only on top-level mission characteristics.

The following steps will help determine the mass of the engine and the propellant mass that will be required for the mission:

1. Calculate the change in velocity (ΔV) that the propulsion system will be expected to deliver.

2. Estimate the maximum thrust the spacecraft structure can withstand.

3. Refer to the selection tree presented earlier to select the type of engine that may be best suited for the spacecraft based on performance requirements and structural strength.

4. Choose a specific impulse which falls within the range of the engine selected.

5. Use the graph of Thrust vs. Engine Mass shown in Figure 2 to obtain an estimate of engine mass.

6. Use the following equation to estimate the propellant mass for one burn.

$$m_{prop} = (e^{\frac{\Delta V}{I_{sp} g}} - 1)\left(m_{struct} + m_{engine}\right)$$

7. Calculate the total impulse.

$$I = m_{prop} U_{eq} = m_{prop} I_{sp} \Delta V$$

8. Consult the Propulsion System Database to select a specific engine that meets the criteria of specific impulse, total impulse, and/or thrust that you have determined.

   a) Solid Motors
      (1) Eliminate all solid motors that produce more thrust than the spacecraft structure will be designed to withstand.
      (2) Pick a motor with the same or slightly more total impulse as found in equation (2).
      (3) Take the motor mass, propellant mass, and specific impulse from the Propulsion System Database.

    (4) Take or recalculate the total impulse using the engine mass and make sure it is high enough to accomplish the mission. If not, select another motor.

b) Liquid, Nuclear Thermal, Ion
    (1) Eliminate all engines with too much thrust.
    (2) Choose an engine with an acceptable thrust.
    (3) Divide the total impulse from equation (2) by the thrust of the engine to get the time of burn.
    (4) Multiply the time of burn by the mass flow rate the engine to get the mass of the propellant.
    (5) Check to see if the mission ΔV's can be obtained using the following equation:

$$\Delta V = I_{sp} g \ln\left(\frac{m_i}{m_f}\right) \quad \text{[Hill 1970, p. 322]}$$

Figure 6.2 shows the relationships between engine thrust and engine mass for three different types of liquid propellants, storable, LO2 Storable and LO2/LH2. These relationships can be used to estimate the masses of engines with thrusts different from those in the PSD.

figure 6.1   selection guide

Figure 2   Liquid Rocket Engine Masses vs. Thrust[Ref 8]

8.7 Space Systems Design Class Propulsion Database

The Propulsion System Database (PSD) is a personal computer based database of specific propulsion systems. It was designed to assist spacecraft designers in selecting a set of suitable propulsion system candidates. It contains specific information concerning mass and dimensions for already developed or under final development engines . The PSD remains to be completed. The main source of information is a catalog displaying characteristics of most of the current engines [Wilson 1991].

8.7.1 Database Characteristics

There are three distinct databases in the PSD : liquid propellant engines, solid propellant engines, and monopropellant thruster. "Exotic" means of propulsion are not yet taken into acoount. For some of the engines, only a few data where available. In general, when for a field several values are given, the value chosen is the biggest one in order to have a conservative estimation for the sizing of the spacecraft design (for example, the gas pressure in the chamber). The PSD has only to be used for a primary evaluation and choice for the design of the propulsion system. The manufacturer should be asked for further information, including new improvements of the current engines.

Most of the engines described exists in many different versions.

Field and description

Name (alphanumeric) - This field contains the common name or trade name of the particular engine or engine type.

Manufacturer (alphanumeric) - Engines that have been designed or produced by a particular company have the name of the manufacturer listed in this field.

Use (alphanumeric) - A primary use of the engine will be listed, when available.

First flight : year of the first launch using the oldest version of this engine

Dry mass (Kg) : for bi- and mono- liquid propellant engines only

Total mass and propellant mass (Kg) : for solid propellant engines only

Length (mm)

Diameter (mm)

Mounting : the way the engine is fixed on the structure.

Engine cycle : the feeding of the engine

Oxidizer, Ox. flow, Fuel , Fuel flow and O/F ratio : for liquid engines only

Propellant : for solid prop. engines and thrusters only

Propellant flow : for the thrusters only.

Thrust range (N)

Nominal Thrust (N)

Specific Impulse (Isp) at sea level and in vacuum (s)

Expansion ratio

Pressure in the combustion chamber (atm)

burn time (s) : for restartable engines, this is the total burn time possible over several starts. A very high burn time means that is unlimited : that the case for most of the small thrusters.

8.7.2 Database

8.7.2.1

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