ELECTRIC PROPULSION TECHNOLOGY

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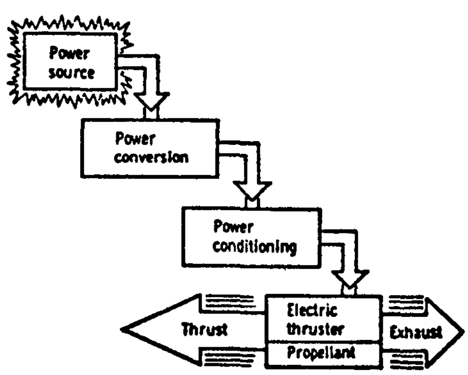
Propulsion systems can be classified into two basic categories:

I. Endogenous; which use energy stored within the propellants to create thrust. Solid rockets, liquid rockets, cold gas systems, etc. are all well known examples of endogenous systems.

II. Exogenous; in which the energy is supplied to the propellant from an outside power source. Al electric propulsion systems are exogenous although some like electrically augmented hydrazine are a combination of the two.

WHAT IS ELECTRIC PROPULSION?

ELECTRIC PROPULSION IS A PROCESS IN WHICH ELECTRICAL ENERGY IS USED TO ACCELERATE A PROPELLANT TO HIGH VELOCITY CREATING THRUST.



The most significant advantage of an exogenous system is that if external energy is available for accelerating a propellant, the resulting specific impulse and total impulse can be greatly in excess of that that can be stored in an endogenous device. Thus an ion thruster system with an I_{sp} of 3000 sec would require 2000 kg of propellant as compared to 15,000 kg of propellant for a Centaur with equivalent total impulse. The dry weights of the two systems are also similar, resulting in a significant advantage for the ion thruster system.

Electric propulsion devices are inherently low thrust devices. A cluster of ten 30-cm thruster systems provides a 0.3 pound thrust to the system for up to 15,000 hours of operation. The low level continuous thrusting characteristic of Electric Propulsion allows very fragile large space structures to be transported by these class of propulsion systems, assembled, from LEO to GEO.

In addition, since propellant is a very small fraction of overall system mass, weight growth of the payload during the construction phase of the project can be accommodated by thrusting for a longer period of time; increased mass then merely requires longer trip times.

CHARACTERISTICS OF ELECTRIC PROPULSION

- HIGH SPECIFIC IMPULSE

  LARGE TOTAL IMPULSE FOR LOW MASS

  MINIMUM PROPELLANT REQUIREMENTS

- LOW THRUST

  LOW "G" LOADING ON SPACECRAFT STRUCTURES

  PRECISION POINTING CAPABILITY PROVIDED

- HIGH POWER REQUIRED

  EXCELLENT MATCH WITH HIGH POWER PAYLOADS

- ORBIT TRANSFER TIME/PAYLOAD TRADE AVAILABLE

- COMPATIBLE WITH LONG TERM SPACE STORAGE/OPERATIONS

There are three generic classes of electric propulsion devices, all of which are capable of high impulse. The electrostatic devices, in particular are capable of a wide range of specific impulses.

- ELECTROTHERMAL

  In the electrothermal rocket electric power is used to heat the propellant to a high temperature. The heating may be accomplished by producing an electric discharge through the propellant gas (arcjet) or by flowing the propellant gas over surfaces heated with electricity (resistojet).

  The electrothermal rocket is similar in some respects to the chemical rocket. Although there is no combustion, the propellant gas is heated to high temperatures and expanded through a nozzle to produce thrust. This rocket can achieve propellant exhaust velocities higher than those of chemical rockets because the energy added to the gas molecules may be larger than the energy available from combustion. Material failure at high temperature, however, places a practical upper limit on the amount of energy that can be added to the propellant. Other factors, such as breakup, or dissociation, of the propellant gas molecules, which absorbs energy without raising gas temperature much, also limit the exhaust velocity.

- ELECTROMAGNETIC

  The second general type of engine is the electromagnetic thruster, often called the plasma thruster. In this thruster, the propellant gas is ionized to form a plasma, which is then accelerated rearward by electric and magnetic fields.

  In a plasma, the electrons and the ions are swirling about in a random manner much like atoms in a gas. The plasma can conduct electric current just as a copper wire can conduct current. It is this conductivity that makes possible accelerating the plasma electrically and magnetically. When an electric current is made to pass through a plasma in the presence of a magnetic field, a force is exerted on the plasma. Because of this force, the plasma is accelerated rearward. Thus, a plasma thruster is quite similar to an electric motor with the plasma replacing the moving rotor.

- ELECTROSTATIC

  The third type of electric rocket engine is the electrostatic thruster. (Best known of this type is the ion thruster or ion engine.) As in the plasma thruster, propellant atoms are ionized by removing an electron from each atom. In the electrostatic thruster, however, the electrons are removed form the ionization region at the same rate as ions are accelerated rearward.

  The most successful electrostatic thruster presently available is an electron-bombardment thruster conceived and developed at the NASA-Lewis Research Center. This thruster operates as follows. When heated, the propellant evaporates and forms a vapor, which is fed into the thruster discharge chamber. In the chamber, electrons are knocked out of many of the propellant atoms to form ions. This ionization is accomplished in a gentle electric discharge wherein electrons in the discharge hit electrons in the atom and displace them from the structure of the atom. The electrons and the ions form a plasma in the ionization chamber. The electric field between the screen and the accelerator draws ions from the plasma. These ions are then accelerated out through many small holes in the screen and accelerator electrode.

WHY - ELECTRIC PROPULSION?

- CHEMICAL ENERGY IS LIMITED TO SPECIFIC IMPULSES 500 SEC.
- ELECTRIC PROPULSION IS CAPABLE OF A BROAD RANGE OF SPECIFIC IMPULSE.

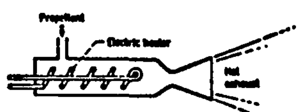
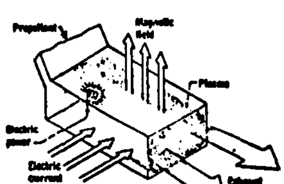


Figure 12.



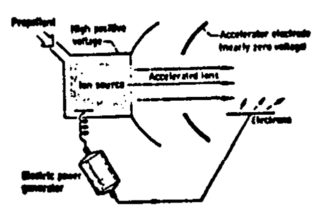


Figure 14.

- ELECTROTHERMAL
  350 - 1200 SEC
- ELECTROMAGNETIC
  200 - 2000 SEC
- ELECTROSTATIC
  1500 - 100,000 SEC

ELECTROSTATIC

Applications of electric propulsion are many and varied. Electrostatic thrusters with their capability for a broad range of specific impulse and ability to scale and throttle over a wide thrust range, are suitable for primary propulsion applications for planetary and earth orbital missions and as auxiliary propulsion devices for attitude control and stationkeeping of geostationary spacecraft. Operation with a wide variety of propellants has been demonstrated from the heavy metals such as mercury or cesium to gases such as argon, xenon, neon and nitrogen.

With an electrostatic thruster system, it is possible to tailor the thruster systems very closely to the application.

ELECTROMAGNETIC

Electromagnetic thruster systems offer the promise of reduced complexity of power systems and high thrust density. In general they are plasma devices and are thus self-neutralizing eliminating the need for a neutralizer system.

One sub-class of electromagnetic thruster can accelerate solid project files. This class represented by the rail gun and mass driver may make possible the direct launch of payloads from earth to space, or the augmentation of booster capabilities via an electric catapult device.

ELECTROTHERMAL

Electrothermal thrusters most resemble the classical chemical rocket. Many such as electrically augmented catalytic hydrazine are techniques to increase the I_{sp} from chemical reaction by the addition of electric power. Others, such as the free radical propulsion concept represent a way to use electrical energy to dissociate H_2 and utilize the high temperatures of recombination to obtain high I_{sp} at high thrusts.

	PLANETARY	ADVANCED PLANETARY	ORBIT TRANSFER	DIRECT LAUNCH	EXTRA SOLAR SYSTEM	ON-ORBIT OPS.
ELECTROSTATIC						
BASELINE HG	●		●			●
ADVANCED HG		●	●			●
INERT GAS			●			●
ELECTROMAGNETIC						
M P D		●	●			
MASS DRIVER			●	●	●	
RAIL			●	●	●	
ELECTROTHERMAL						
FREE RADICAL		●	●			
RESISTOJET			●			●

LSS PROPULSION REQUIREMENTS

Scenarios presently being considered for Large Space Structures (LSS) will require technology advancements to enhance the capabilities of existing propulsion systems, both for orbit raising and for on orbit applications. Almost all studies of LSS have indicated that for balancing out solar pressure, configuration control and maintaining required pointing accuracy will require propulsion systems with a specific impulse well beyond that obtainable from chemical systems.

In addition, the cost of transporting heavy, high volume chemical propellant systems from earth to orbit will become prohibititve as system requirements increase.

In an attempt to minimize mass to orbit, LSS will be designed to be relatively fragile structurally. Large impulsive loads could literally destroy the LSS. In this respect, electric propulsion systems are well matched to LSS since accelerations produced by proposed and existing electric propulsion systems suitable for LSS are all less than 10^{-3} g's.

LSS PROPULSION REQUIREMENTS

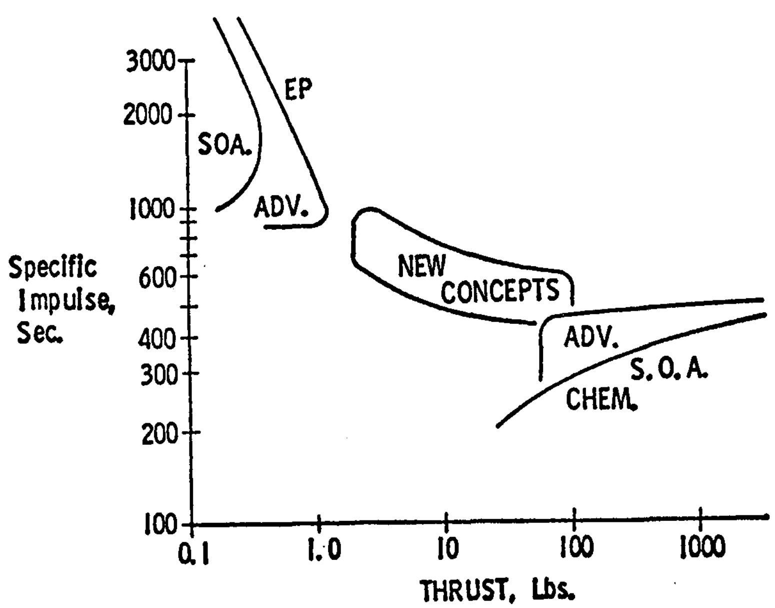
- TOTAL IMPULSE AND MISSION LIFE REQUIREMENTS WILL EXCEED PRESENT CAPABILITIES
- LIFE/CYCLE COSTS A MAJOR FACTOR
  - MINIMIZE TOTAL SYSTEM MASS REQUIRED IN SPACE
  - MINIMIZE PROPULSION SYSTEM VOLUME/LENGTH/MASS/COST
  - MAXIMIZE INHERITANCE AND UTILITY OF SYSTEM CONCEPTS(s)
- MANY LSS ORBIT TRANSFER AND ON-ORBIT APPLICATIONS REQUIRE LOW ACCELERATION
- PROPELLANT AVAILABILITY AND ECOLOGICAL CONCERNS.

PROPULSION CONCEPTS

The advanced chemical propulsion program is structured towards the development of technology for high I_{sp}, low thrust, long life thruster systems suitable for taking payloads from LEO to GEO orbit. The Advanced Electric Propulsion program is directed towards lowering the specific impulse and increasing the thrust per unit of ion thruster systems. In addition, electrothermal and electromagnetic propulsion technologies are being developed to attempt to fill the gap between the conventional ion thruster and chemical rocket systems.

Most of these new concepts are exagenous and are represented by rail accelerators, ablative teflon thrusters, MPD arcs, Free Radicals, etc. Endogenous systems such as metalic hydrogen offer great promise and are also being pursued.

PROPULSION CONCEPTS



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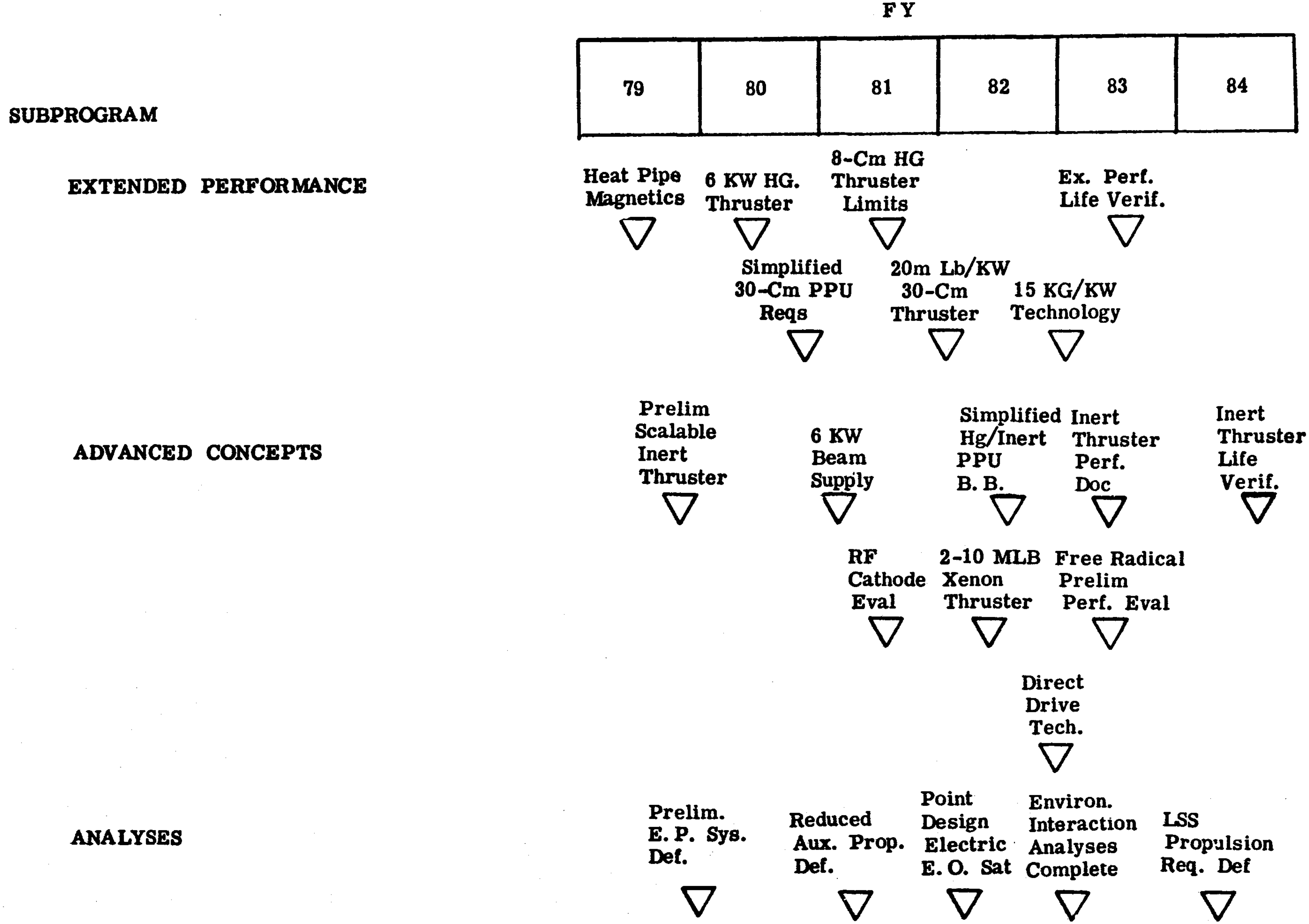

ELECTRIC PROPULSION - RESEARCH AND ADVANCED CONCEPTS

J - JPL Js - JSC
L - LEWIS M - MSFC
La- LANGLEY F - GSFC
SPACE SYSTEMS DIVISION

	FY 78	FY 79	FY 80	FY 81	FY 82	FY 83
o MPD ACCELERATOR		Complete Thrust Stand and Preliminary Efficiency Measurement (J)		Complete Concept Evaluation (J)		
o MASS DRIVER		Prelim. Design (L); 2-m Demo (L)	10-m Performance Evaluation (L)		Complete Concept Evaluation (L)	
o BASIC THRUSTER PHYSICS			Complete Parametric Study MPD Thruster (J); Complete Eval MESC-Thruster with Inert Gas (L)	Complete Theoretical & Experimental Study of Sputtering (L)		
o ION BEAM APPLICATIONS	Complete Large ION Source Development (L)			Complete Eval. Textured Dental Implants (L); Complete Eval. Textured Large Crystal Alignment Surfaces (L)	Complete Feas. Study of Prel. Diamond Films (L)	Complete Study Textured Surgical Implants (L); Complete Rectang. Indust. Ion Source (L); Complete Prelim. Study of an Adv. Propulsion Concept (L)