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THE NASA-JPL ADVANCED PROPULSION PROGRAM

Presentation to the
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Propulsion Engineering Center
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ABSTRACT

The NASA Advanced Propulsion Concepts (APC) program at the Jet Propulsion Laboratory (JPL) consists of two main areas. The first involves cooperative modeling and research activities between JPL and various universities and industry; the second involves research at universities and industry that is directly supported by JPL. The cooperative research program consists of mission studies, research and development of ion engine technology using C60 (Buckminsterfullerene) propellant, and research and development of lithium-propellant Lorentz-force accelerator (LFA) engine technology. The university / industry - supported research includes research (modeling and proof-of-concept experiments) in advanced, long-life electric propulsion, and in fusion propulsion.

These propulsion concepts were selected primarily to cover a range of applications from near-term to far-term missions. For example, the long-lived pulsed-xenon thruster research that JPL is supporting at Princeton University addresses the near-term need for efficient, long-life attitude control and station-keeping propulsion for Earth-orbiting spacecraft. The C60-propellant ion engine has the potential for good efficiency in a relatively low specific impulse (Isp) range (10,000 - 30,000 m/s) that is optimum for relatively fast (< 100 day) cis-lunar (LEO/GEO/Lunar) missions employing near-term, high-specific mass electric propulsion vehicles. Research and modeling on the C60-ion engine is currently being performed by JPL (engine demonstration), Caltech (C60 properties), MIT (plume modeling), and USC (diagnostics). The Li-propellant LFA engine also has good efficiency in the modest Isp range (40,000 - 50,000 m/s) that is optimum for near- to mid-term megawatt-class solar- and nuclear-electric propulsion vehicles used for Mars missions transporting cargo (in support of a piloted mission). Research and modeling on the Li-LFA engine is currently being performed by JPL (cathode development), Moscow Aviation Institute (engine testing), Thermacore (electrode development), as well as at MIT (plume modeling), and USC (diagnostics). Also, the mission performance of a nuclear-electric propulsion (NEP) Li-LFA Mars cargo vehicle is being modeled by JPL (mission analysis; thruster and power processor modeling) and the Rocketdyne Energy Technology and Engineering Center (ETEC) (power system modeling). Finally, the fusion propulsion research activities that JPL is supporting at Pennsylvania State university (PSU) and at Lawrenceville Plasma Physics (LPP) are aimed at far-term, fast (< 100 day round trip) piloted Mars missions and, in the very far term, interstellar missions.

ADVANCED PROPULSION CONCEPTS

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OUTLINE

- Overview of the NASA-JPL Advanced Propulsion Concepts (APC) Program
- Cooperative Research Activities with University / Industry
  - Mission Studies
  - C60-Propellant Ion Thruster
  - Li-Propellant Lorentz Force Accelerator (LFA)
- University / Industry – Supported Research
  - Advanced Long-Life Electric Propulsion
  - Fusion
- Summary

ADVANCED PROPULSION CONCEPTS INTRODUCTION

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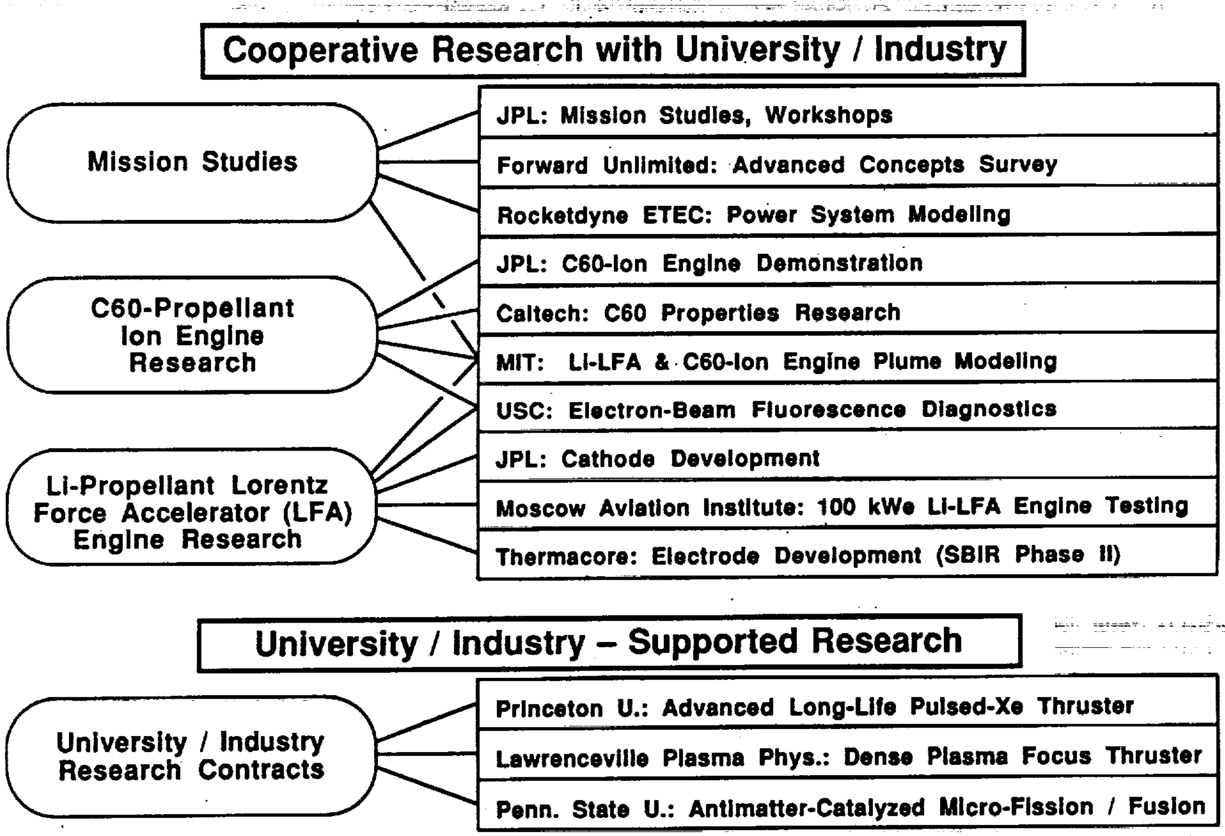
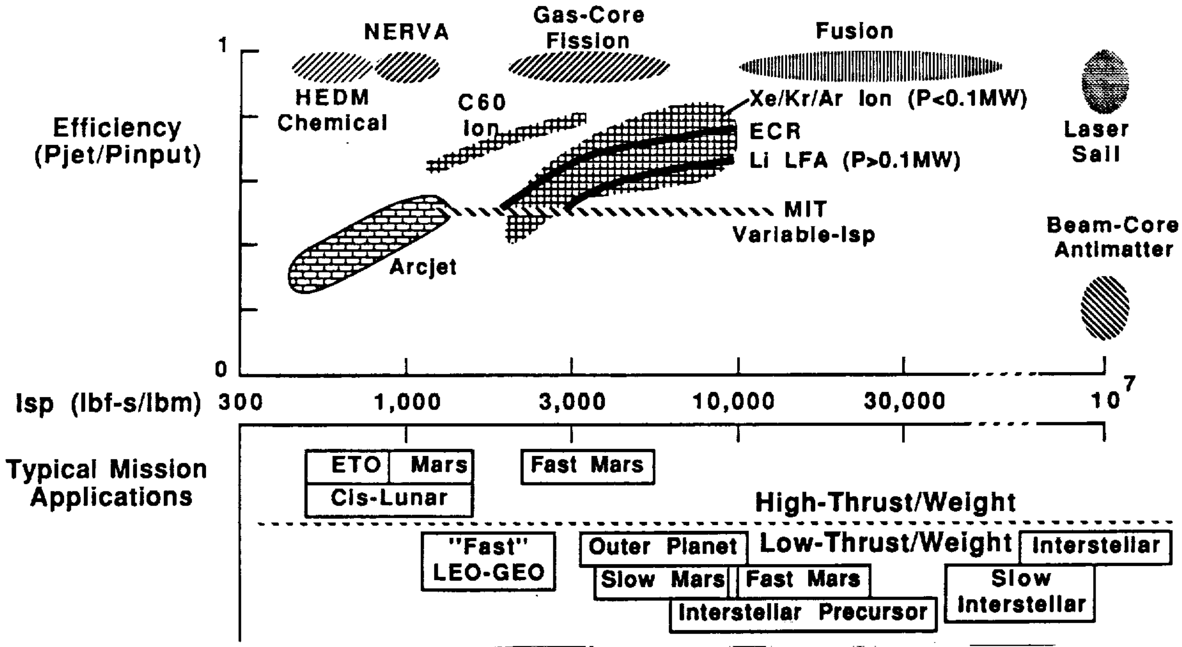
APC PROGRAM



JPL SELECTION CRITERION REQUIRED TO DOWN-SELECT AMONG MANY COMPETING EP CONCEPTS

- Performance which offers unique capabilities for a well defined class of missions



JPL SELECTION CRITERIA

Criteria \ Concepts	Adv. Long-Life EP	C60-Ion	Li-LFA	Fusion
Must have projected performance which offers unique capabilities for a well defined class of missions	Very long-life attitude control, station-keeping	Good eff. in Isp range optimum for "fast" (< 100 day), high-specific mass EP near-Earth (LEO/GEO/Lunar) missions	Good eff. in Isp range optimum for high-power (>1 MWe), high-specific mass EP Mars missions	"Fast" (< 100 day R.T.) piloted Mars missions; interstellar missions
Must use an environmentally acceptable propellant (no Hg, etc.)	Xe	C60 (Spacecraft contamination)	Li (Spacecraft contamination)	Some tritium, negligible amount of antiprotons
Must be an area where small amounts of funding can have a large impact, especially with co-funding from other agencies		Leverage funding from AFOSR, Caltech Pres. Fund	Leverage funding from DoE (SP-100) Leverage Russian expertise	Leverage funding from AFPL, AFOSR

NEAR-TERM ⟹ FAR-TERM

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INTRODUCTION TO MISSION STUDIES

- "Mission Studies" is a generic term for feasibility analyses aimed at assessing the "benefit" of an advanced propulsion concept
  - "Benefit" typically expressed as reduction in mass ($ per kg to LEO) or trip time (operations & reliability $, crew safety)
  - In general, advanced concepts show biggest benefit for ambitious missions with high ΔVs and/or large payloads
    - Propulsion-intensive robotic missions
    - Piloted Lunar and Mars missions
- Assess high-performance advanced propulsion concepts (Those beyond near-term electric propulsion and fission thermal)
  - Advanced NEP & SEP
  - Adv. Chemical
  - Adv. Fission
  - Fusion
  - Antimatter
  - Beamed Energy / Momentum
  - ET Resources
  - Others
- Use results of mission studies to guide technology programs :
  - High-leverage / critical technologies
  - Long-lead time technologies
  - Critical feasibility / proof-of-concept experiments

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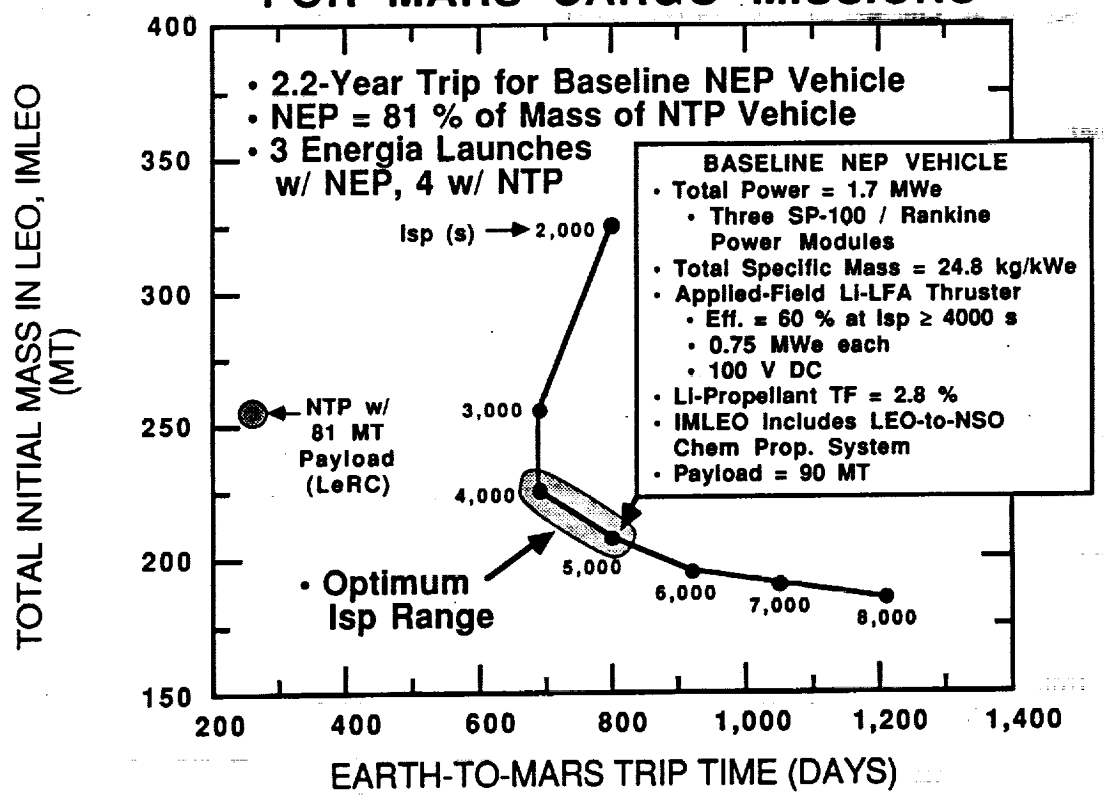
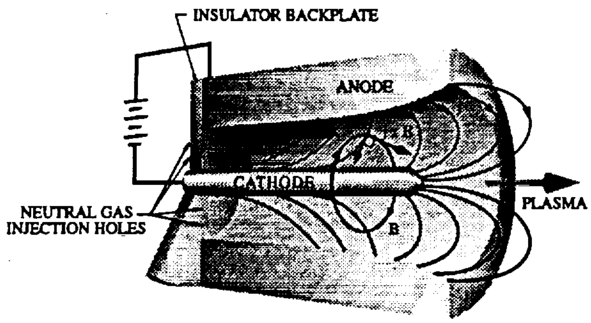
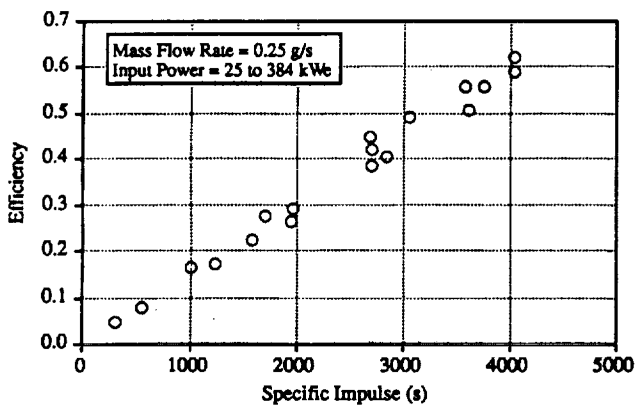
SP-100 / Li-LFA NEP MASS vs TRIP TIME FOR MARS CARGO MISSIONS



Li LORENTZ FORCE ACCELERATORS OFFER HIGH PERFORMANCE AND EXTENDED LIFETIME



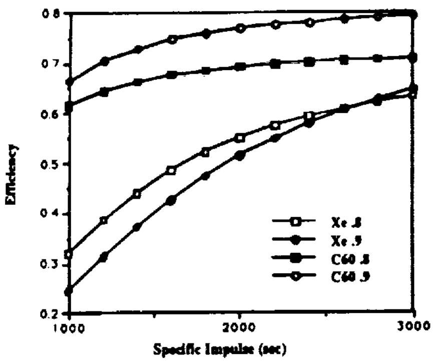


- Use of electromagnetic body forces to accelerate a quasineutral plasma permits very high power processing capability (100's of kW to MW in a single engine)
- The low ionization potential of Li propellant results in very high efficiencies at high specific impulses
- Tungsten cathodes have low operating temperatures with Li propellant because Li adsorbed on tungsten significantly reduces the work function of the surface
- Li condenses on vacuum chamber walls at room temperature, resulting in significantly reduced pumping requirements and lower ground test costs
- Primary technical issues:
  - Verification of high performance
  - Demonstration of adequate engine life
  - Potential for spacecraft contamination

ADDRESSING THE KEY TECHNICAL ISSUES IN LFA TECHNOLOGY

- Li thruster peformance characterization at the Moscow Aviation Institute
  - First NASA-funded contract for electric propulsion with a Russian institute initiated June 1994
  - The research will provide detailed characterization of a 100 kWe-class Li thruster with a performance goal of 45% at 4000 s
- Examination of the potential for spacecraft contamination
  - Li backflow calculated for a high power thruster using a plume model developed by the Space Power and Propulsion Laboratory at MIT
  - Preliminary results indicate that spacecraft surface temperatures of 500-540 K are required to prevent bulk condensation and that plume shields can significantly reduce the Li flux to the spacecraft
- Characterization of life-limiting cathode failure mechanisms
  - Models of cathode erosion phenomena, cathode thermal behavior and near cathode plasma characteristics being developed at JPL
  - Experimental verification of model assumptions and predictions being performed in a dedicated high-current cathode test facility
- Development of cathodes for Li engines
  - Porous tungsten cathode and anode with integral Li vaporizers being developed by Thermacore, Inc. in a Phase II SBIR
  - Electrode testing to be performed by Princeton University

JPL ELECTROSTATIC PROPULSION USING C60 MOLECULES



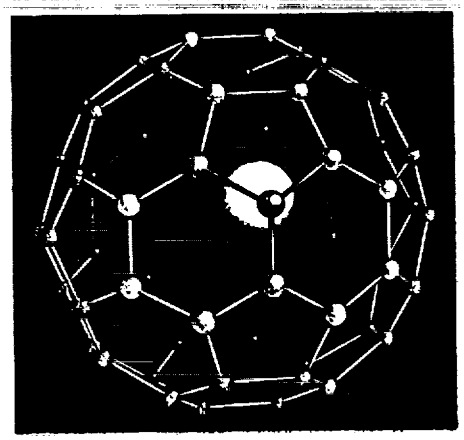
CALCULATED PERFORMANCE OF C60 AND XENON ION THRUSTERS FOR TWO PROPELLANT UTILIZATION EFFICIENCIES

OBJECTIVES:

- DEVELOP AN ELECTROSTATIC THRUSTER WHICH USES C60 AS A PROPELLANT
    - HIGH MASS TO CHARGE RATIO OF C60 SUGGESTS IT WILL DELIVER HIGH EFFICIENCY AT MODERATE SPECIFIC IMPULSE

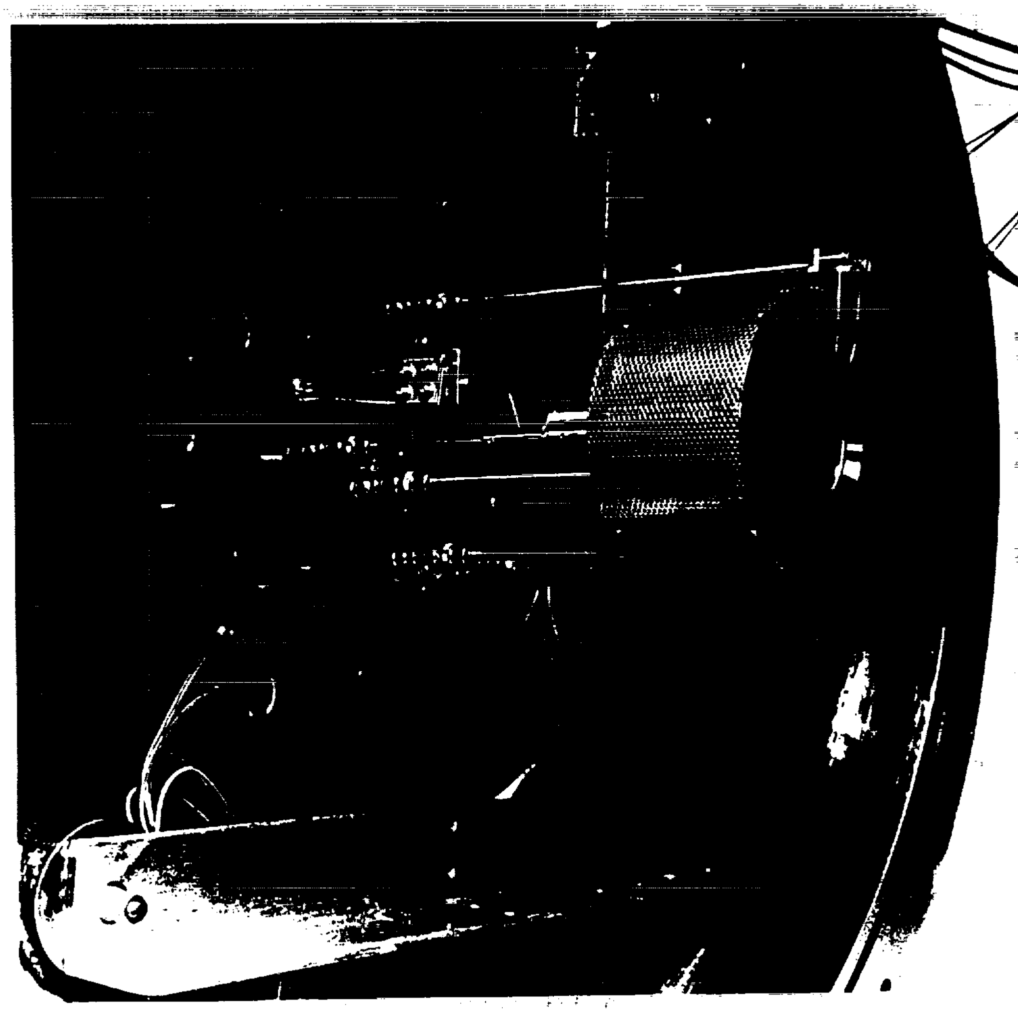
APPLICATIONS:

- ELECTRIC THRUSTER FOR STATION KEEPING, ORBIT TRANSFER AND PLANETARY MISSIONS

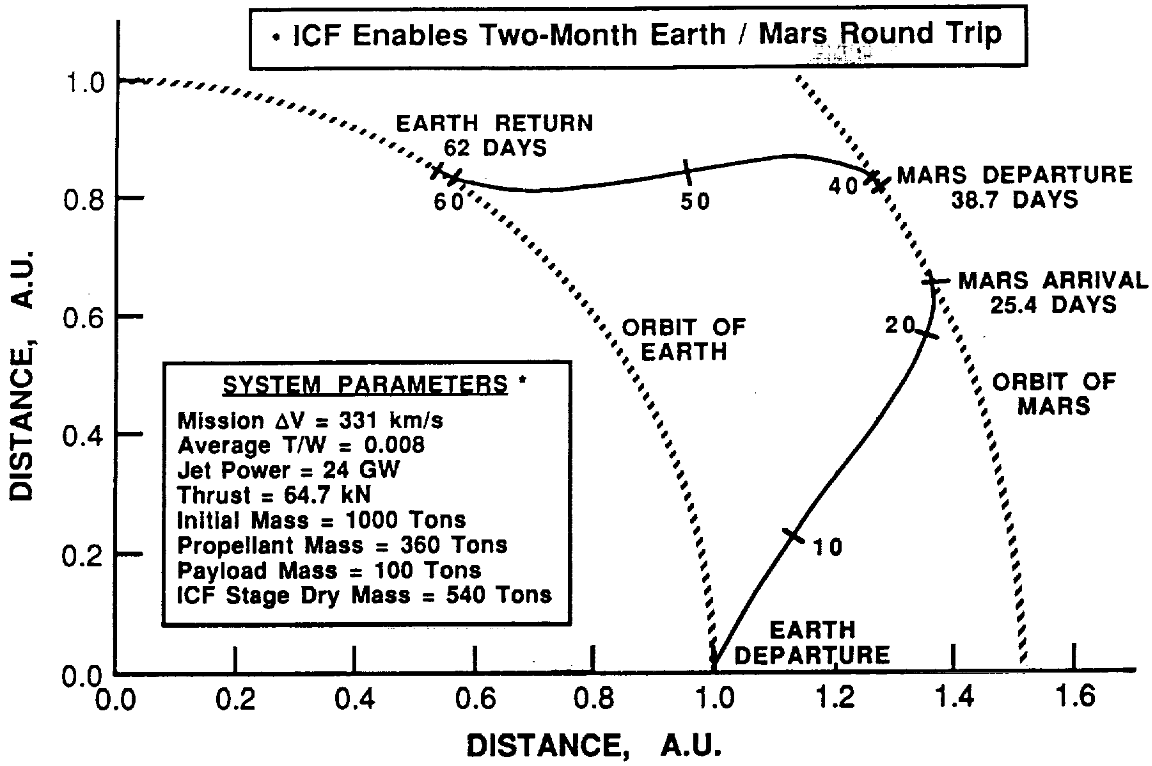


ACCOMPLISHMENTS:

- RADIO FREQUENCY AND ELECTRON BOMBARDMENT ION THRUSTERS BUILT AND OPERATED
- STUDIES OF C60 THERMAL PROPERTIES AND IONIZATION PHENOMENA CONDUCTED



JPL INERTIAL CONFINEMENT FUSION (ICF) PROPULSION CAN ENABLE RAPID HUMAN EXPLOARATION OF THE SOLAR SYSTEM



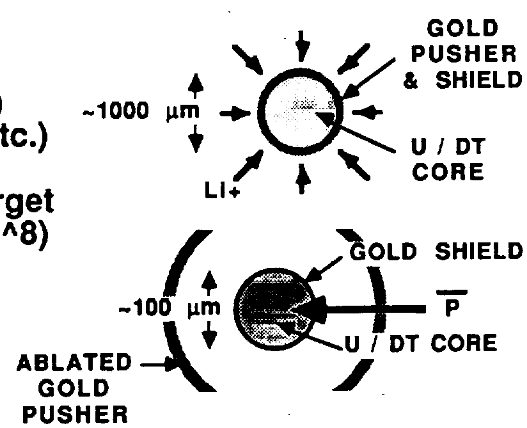
* Based on Joint JPL, LLNL, ETEC, JSC Study (VISTA ICF Concept)

ADVANCED PROPULSION CONCEPTS RESEARCH CONTRACTS

JPL PENN STATE ANTIMATTER-CATALYZED MICRO-FISSION/FUSION PROPULSION

Concept Description

- Uranium (or Pu) enriched DT (or D-He3) pellet is compressed (by ions, lasers, etc.)
- At the time of peak compression, the target is bombarded with a small number (~10^8) of antiprotons to catalyze fission
- The fission energy release triggers a high-efficiency fusion burn to heat the propellant



- The resulting expanding plasma is used to produce thrust

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- Use a small amount of antimatter - an amount that we could produce with existing technology and facilities
- Retain mission benefits of "conventional" ICF
  - Potential benefits of "easier" drivers / aneutronic fuels

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SUMMARY

- Current APC program contains a mix of near-term to far-term concepts in both cooperative and directly-supported university tasks

APPLICATION	COOPERATIVE	DIRECT-SUPPORT
Near-Term	C60 -Ion	Long-Life EP (Princeton)
Mid-Term	Li-LFA	
Far-Term		Fusion (PSU, LPP)

- Plans are to continue current activities and add (contingent on funding):
  - Transition from modeling to demonstration of LPP dense plasma focus thruster
  - Begin evaluation of alternate fusion driver / confinement concepts
  - Scale Princeton U. adv. long-life pulsed-Xe plasma thruster to micro-size