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LEO TO GEO AND RETURN TRANSPORT

MICROWAVE BEAM POWER

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LEO TO GEO AND RETURN TRANSPORT

<u>CHARACTERISTICS OF LOW THRUST PROPULSION</u>

- **ORBIT RAISING:**

  —REQUIRES INCREASED "ΔV" OVER IMPULSIVE HOHMANN TRANSFER BECAUSE OF THRUSTING THROUGH PLANETARY "POTENTIAL WELL".

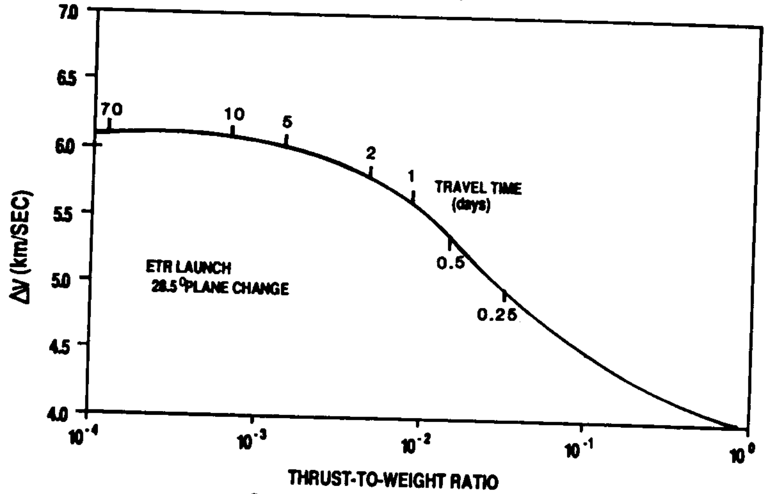
- **PLANE CHANGE MANEUVERS <u>DURING</u> ASCENT**

  —NON-OPTIMAL PLANE CHANGE-INCREMENTAL PLANE CHANGES MUST BE DONE INITIALLY AT HIGH ORBIT VELOCITIES WHICH REQUIRE GREATER IMPULSE FOR A GIVEN $\Delta\Theta$.

- **LOW THRUST PROBABLY NOT ADEQUATE FOR ORBIT RENDEZVOUS. VEHICLE NEEDS AN ORBITAL MANEUVERING SYSTEM FOR BOTH ORBIT INSERTION AND DOCKING.**

LEO TO GEO AND RETURN TRANSPORT

LEO-TO-GEO ORBIT TRANSFER PROPULSION
(ONE WAY)



Delta-V required for low-thrust orbital transfer

REFERENCE: P.W. GARRISON, J.F. STUCKY, FUTURE SPACECRAFT PROPULSION, JPL, PASADENA, CA JET PROPULSION, NO. 4, VOL. 6, 1987.

LEO TO GEO AND RETURN TRANSPORT

ASSUMPTIONS:

- POWER BEAMED TO VEHICLE
  - —TERRESTRIAL LOCATION
  - —ORBITING POWER STATION
- ELECTRIC PROPULSION VEHICLE
  - —90,000 KG MAX. WEIGHT IN LEO
  - —10,000 KW RECTENNA: 50,000 SQUARE METERS AREA
  - —TOTAL THRUST AVAILABLE 370 NEWTONS
    - * 1000 30 CM ION THRUSTERS
    - * XENON PROPELLANT
- LAUNCH TO LEO RENDEZVOUS FROM KSC
  - —28.5° PARKING ORBIT INCLINATION
  - —300 KM ORBIT ALTITUDE
  - —PAYLOAD RETURN GEO TO LEO - 25% OF MAXIMUM PAYLOAD

BEAM POWER APPLICATIONS: LEO TO GEO AND RETURN TRANSPORT

Reference/Baseline: Brown, Wm. C., "LEO to GEO Transportation System Combining Electric Propulsion With Beamed MicroWave Power From Earth", 25th Goddard Memorial Symposium, Visions of Tomorrow: A Focus on National Transportation Issues; Volume 69, Science and Technology Series, American Astronautical Society Publication.

Baseline Vehicle/Mission	Revised Vehicle/Mission - I	Revised Vehicle/Mission - II
Total Mass in LEO-(300 KM) 90,000 kg. Propellants 14,000 Ascent 9,900 Return 4,100 Thrusters 10,000 Rectenna 10,000 Structure and PMAD 10,000 Loaded Veh. Wt. (less P/L) 44,000 Kg. Payload (51%) $\boxed{46,000 \text{ Kg.}}$	Total Mass in LEO-(300 KM) 90,000 Kg. Propellants 17,000 Ascent 11,000 Return 6,000 Thrusters 10,000 Rectenna 10,000 Rectenna Structure: (1) 5,000 Structure and PMAD 10,000 Orb. Maneuver. Syst.: (2) Propulsion and tankage 1,000 Propellants 13,000 Loaded Veh. Wt. (less P/L) 66,000 Kg. Payload (27%) $\boxed{24,000 \text{ Kg.}}$	Total Mass in LEO-(300 KM) 90,000 Kg. Propellants 19,000 Ascent 12,000 Return 7,000 Thrusters 10,000 Rectenna 500 Rectenna Structure: (1) 200 Structure and PMAD 10,000 Orb. Maneuver. Syst.: (3) Propulsion and tankage 800 Propellants 2,000 Loaded Veh. Wt. (less P/L) 42,500 Kg. Payload (53%) $\boxed{47,500 \text{ Kg.}}$
Notes; Thrusters; Isp = 4500 sec. Equatorial ascent from 300 Km altitude; Delta V (one way) to GEO - 4600 m/s. Single microwave beam transmission from terrestrial equatorial station. No payload return to LEO. Microwave beam frequency: 2.45 Ghz.	Notes; Thrusters; Isp = 4500 sec. Launch azimuth 28.5 deg. (300 Km); Delta V (one way) to GEO - 6100 m/s. Single microwave beam transmission from terrestrial equatorial station Orbital maneuvering system raises LEO orbit from 300 Km to 1000 Km prior to start of beam power phase. This is required for equatorial power station to "see" vehicle. 25% of maximum payload returned to LEO. Microwave beam frequency: 2.45 Ghz.	Notes; Thrusters; Isp = 4500 sec. Launch azimuth 28.5 deg. (300 Km); Delta V (one way) to GEO - 6100 m/s. Single microwave beam transmission from orbiting power station in 28.5 degree orbit at 300 Km. altitude. 25% of maximium payload returned to LEO. Microwave beam frequency: 100 Ghz.
(1): Rectenna weight of 0.2 Kg/m2 is interpreted as weight only of rectenna blanket. Additional structure is required to ensure adequate separation of rectenna modes and vehicle structural and control modes.	(2): Orbital maneuvering system is required for rendevous at LEO and GEO. Space shuttle system with 800 m/s delta V total capability is assumed; Isp = 313 seconds, Propellants; N204-MMH.	(3): Orbital maneuvering system is required for rendezvous at LEO and GEO. Requirements are less than CASE I since GEO injection point can always be "seen" by orbiting power station. Space shuttle system is also assumed.

BEAM POWER APPLICATIONS: LEO TO GEO AND RETURN TRANSPORT

Reference/Baseline: Brown, Wm. C.,"LEO to GEO Transportation System Combining Electric Propulsion With Beamed MicroWave Power From Earth", 25th Goddard Memorial Symposium, Visions of Tomorrow: A Focus on National Transportation Issues; Volume 69, Science and Technology Series, American Astronautical Society Publication.

Revised Vehicle/Mission - III		
Total Mass in LEO-(300 Km)		90,000 Kg.
Propellants		12,000
Ascent	12,000	
Return	-----	
Thrusters		10,000
Rectenna		500
Rectenna Structure: (1)		400
Structure and PMAD		10,000
Orb. Maneuver. Syst.: (2)		
Propulsion and tankage		1,000
Propellants		3,200
Heat shield		1,000
Loaded Veh. Wt. (less P/L)		37,100 Kg.
Payload (59%)		$\boxed{52,900\ Kg.}$

Notes:
Thrusters; Isp = 4500 sec.
Launch azimuth 28.5 deg. (300 Km);
Delta V (one way) to GEO - 6100 m/s.
Single microwave beam transmission from orbiting power station in 28.5 degree orbit at 300 Km. altitude.
Aerobraking reentry on return to 300 Km. LEO rendezvous.
25% of maximum payload returned to LEO.
Microwave beam frequency: 100 Ghz.

Chemically Propelled Vehicle		
Total Mass in LEO-(300 Km)		90,000 Kg.
Propellants		70,000
Ascent	52,000	
Return	17,500	
Orb. Man.	500	
Structure and OMS		10,000
Loaded Veh. Wt. (less P/L)		80,000 Kg.
Payload (11%)		$\boxed{10,000}$

Notes:
Launch azimuth 28.5 deg. (300) Km.
Hohmann transfer ellipse.
Delta V (one way) 4.2 Km/sec. with plane change at apogee.
Advanced H2-O2 propulsion system.
Isp = 500 seconds.
25% of maimum payload returned to LEO.

(1): Additional structure is required to protect rectenna during aerobraking reentry and LEO rendezvous.

(2): Orbital maneuvering system will inject into Hohmann transfer ellipse for LEO reentry and LEO rendezvous.

LEO TO GEO AND RETURN TRANSPORT

FIGURE OF MERIT COMPARISION OF MISSION VERSIONS

- FIGURE-OF-MERIT:

  PAYLOAD MASS/SUPPORT MASS DELIVERED TO LEO

- SUPPORT MASS DELIVERED TO LEO
  - PROPELLANTS FOR LEO TO GEO AND RETURN
  - PROPELLANTS FOR ORBITAL MANEUVERING SYSTEM
  - SPECIAL TRANSFER VEHICLE REFURBISHMENT HARDWARE
  - TRANSFER VEHICLE REPAIR AND MAINTENANCE HARDWARE
  - PRORATED (150 MISSIONS - 30 YR LIFE) POWER STATION MASS
  - PRORATED OPERATIONS SUPPORT MASS IN LEO

- THIS IS NOT A TRUE "COST" FIGURE-OF-MERIT: THESE ENTITIES HAVE A VARYING "COST OF DELIVERY" TO LEO.
  - CAPTIAL COST OF SUPPORT ENTITIES/FUNCTIONS IS NOT ACCOUNTED FOR.

LEO TO GEO AND RETURN TRANSPORT

ORBITING POWER STATION - MISSION SUPPORT ASSUMPTIONS

- 50,000 kW REQUIRED: (20% END TO END EFFICIENCY)
- 100 W/kg FOR NUCLEAR POWER SYSTEM (UNMANNED STATION)
- STATION IS MULTIPLE USE - PROVIDES OTHER FUNCTIONS
  - 250,000 kg CHARGEABLE TO ORBIT RAISING FUNCTION
- 30 YR LIFETIME: 5 LAUNCHES/YR, - 150 TOTAL LAUNCHES

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POWER SYSTEM MASS:	500,000 kg
STATION MASS - CHARGEABLE	250,000
OPERATIONS & MAINT. (30 YRS)	300,000
TOTAL MASS OF ORBITING STATION CHARGEABLE TO ORBIT RAISING FUNCTION	1,050,00 kg
STATION CHARGEABLE MASS/MISSION	7,000 kg

BEAM POWER APPLICATIONS: LEO TO GEO AND RETURN TRANSPORT

MISSION VERSION COMPARISIONS: Support mass/payload delivered to LEO to support a mission.

Mission Version	I.	II.	III.	IV.
Propellants/Mission	30,000 kg.	21,000 kg.	15,200 kg.	70,000 kg.
Special Maint. Items/Miss.	---	---	1,000	---
Total Mission Support; Mass delivered to LEO For Direct Miss. Support.	30,000 kg.	21,000 kg.	16,200 kg.	70,000 kg.
Prorated Op's Support: Mass/Mission.	5,000	10,000	10,000	5,000
PAYLOAD	24,000 kg.	47,500 kg.	52,900 kg.	10,000 kg.
PL/Dir.Sup. Mass, (kg/kg)	.686 kg/kg	1.532 kg/kg	1.941 kg/kg	.1334 kg/kg
Pow. Stat. Sup. Mass/Miss.	?	7,000 kg.	7,000 kg.	7,000 kg.
Veh. Repair & Maint. Sup.	1,000 kg.	1,000 kg.	1,000 kg.	1,000 kg.
$\frac{\text{DELIVERED PAYLOAD MASS. kg}}{\text{TOTAL SUPPORT MASS kg}}$	$\boxed{.667\ kg/kg}$	$\boxed{1.21\ kg/kg}$	$\boxed{1.50\ kg/kg}$	$\boxed{.120\ kg/kg}$

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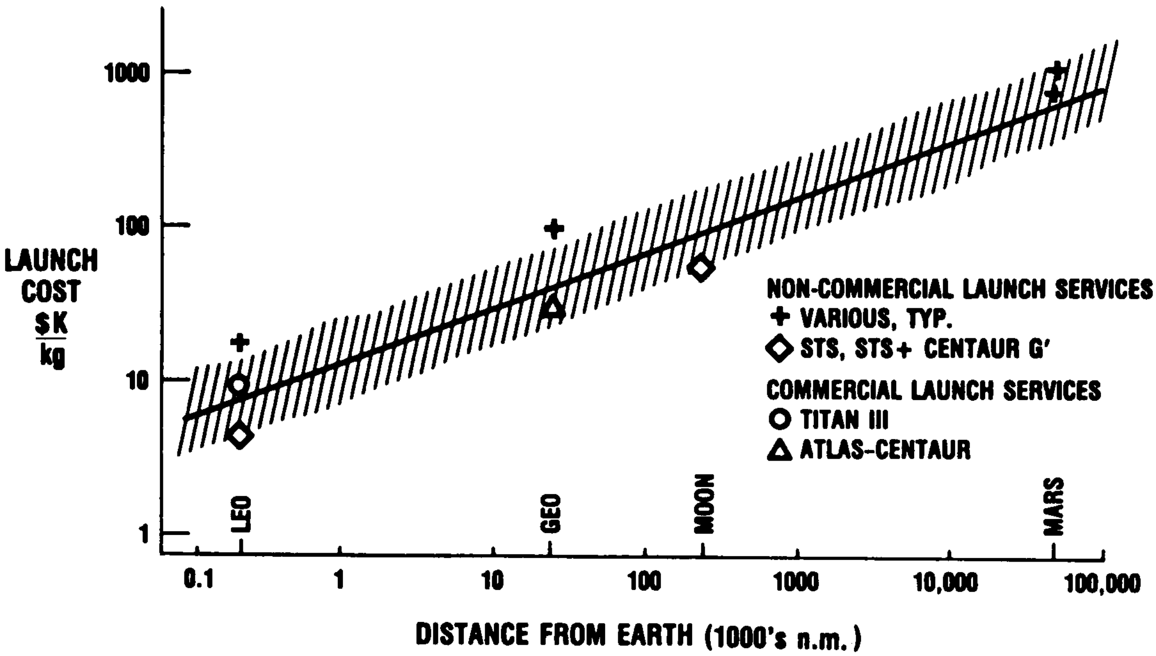
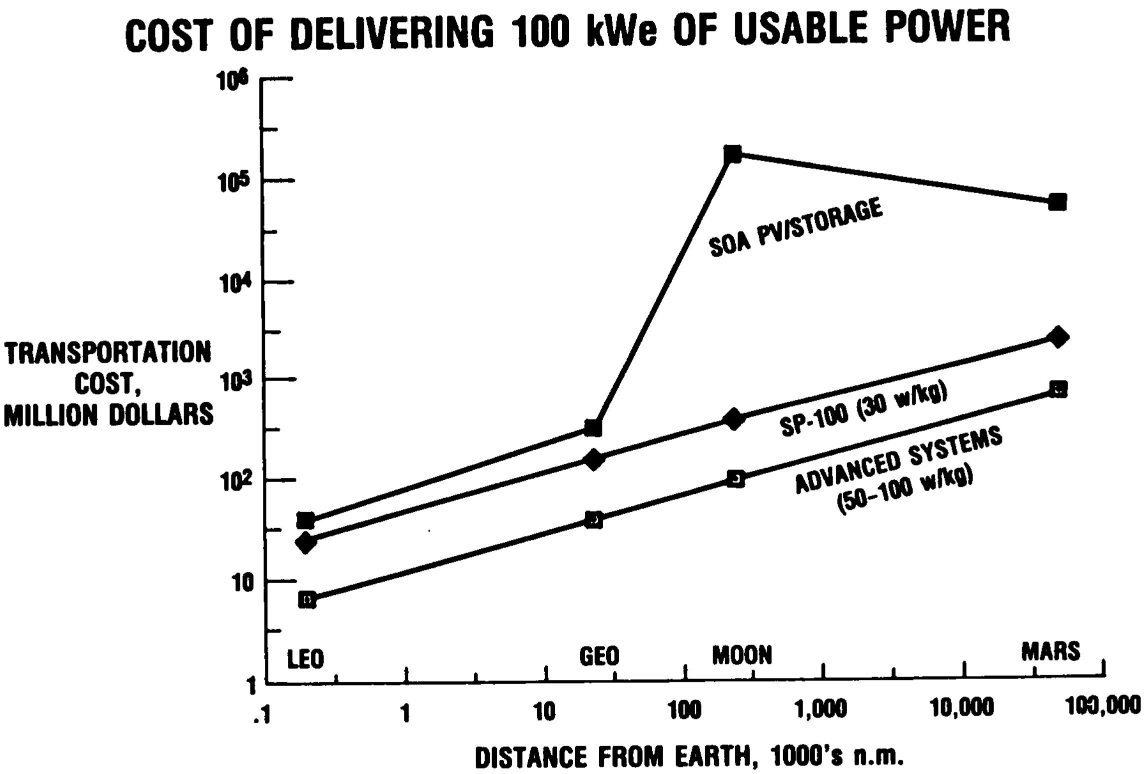
SUMMARY

- BEAM POWER SHOWS ADVANTAGES IN REDUCED MASS DELIVERED TO LEO TO SUPPORT MISSION
  - ARE TECHNOLOGY ASSUMPTIONS VALID?
  - FURTHER WORK NEEDS TO TRANSLATE MISSION COMPARISONS TO "TRUE DOLLARS" PER kg OF PAYLOAD
- IF ASSUMPTIONS HAVE "ANY" VALIDITY-BEAM POWER ORBIT RAISING FOR LEO-TO-GEO AND RETURN TRANSPORT HAS SIGNIFICANT POTENTIAL

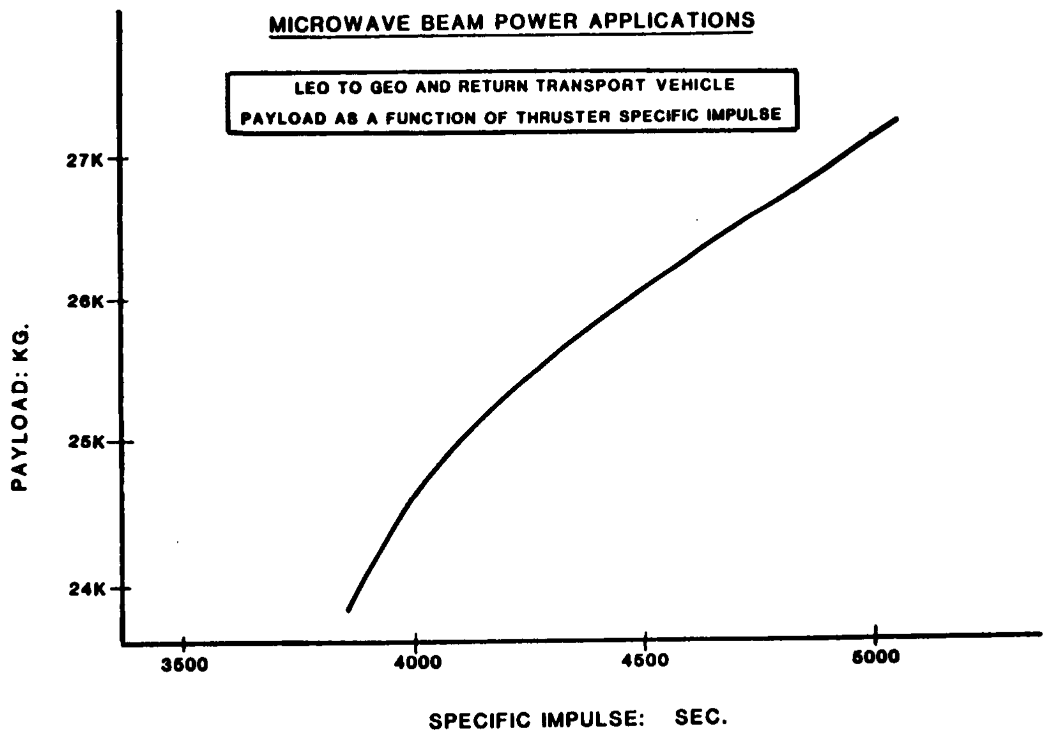
1988 COST OF DELIVERING 1 kg PAYLOAD TO ORBIT

(ADVANCED LAUNCH SYSTEM NOT INCLUDED)





COST OF DELIVERING 100 kWe OF USABLE POWER
TRANSPORTATION COST, MILLION DOLLARS
10^6
10^5
10^4
10^3
10^2
10
1
SOA PV/STORAGE
SP-100 (30 w/kg)
ADVANCED SYSTEMS (50-100 w/kg)
LEO
GEO
MOON
MARS
.1
1
10
100
1,000
10,000
100,000
DISTANCE FROM EARTH, 1000's n.m.



MICROWAVE BEAM POWER APPLICATIONS
LEO TO GEO AND RETURN TRANSPORT VEHICLE
PAYLOAD AS A FUNCTION OF THRUSTER SPECIFIC IMPULSE
PAYLOAD: KG.
27K
26K
25K
24K
3500
4000
4500
5000
SPECIFIC IMPULSE: SEC.

SPACE PROPULSION APPLICATIONS--DISCUSSION SUMMARY

by Ja H. Lee

This miniworkshop dealt with both microwave LEO → GEO propulsion and laser LEO → low lunar orbit propulsion. Laser propulsion was compared with chemical and nuclear reference propulsion missions already established by the Pathfinder program. A difficulty encountered immediately was that the reference missions had two separate scenarios: chemical propulsion for transportation of men and nuclear propulsion for freight-only missions to lunar base and then to Mars.

The laser propulsion option did not closely follow these two separate missions but took an intermediate size to accomplish the lunar mission by a series of repetitive trips to the moon. However, this approach left the comparison indirect; therefore, the conclusions that were favorable for the laser option were criticized for being ambiguous, at best, by the session chairperson.

The microwave option presented was for LEO-to-GEO propulsion only. The GEO to the moon base was not addressed, and a study of different schemes of propulsion for such long distance beyond GEO has to be made. Perhaps the microwave option is entirely out of the question for a distance >5,000 Km, and its application may be limited to near-Earth missions due to the large receiver size.

Placing the nuclear reactor in near-Earth orbit below GEO is obviously a sensitive issue related to the radiation safety of the earth. Therefore, the solar-driven laser propulsion then becomes a more desirable option. However, this issue is not confined to technical issues but depends upon the national and international policies on space nuclear power. Future studies may find suitable multi-missions that the space laser station can accommodate for its cost-effective operation. The duty cycle of the laser station for LEO-LLO propulsion is extremely low, and the high capital invested in the laser station cannot be justified by a single laser propulsion mission.