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LEO TO GEO AND RETURN TRANSPORT

MICROWAVE BEAM POWER

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LEO TO GEO AND RETURN TRANSPORT

CHARACTERISTICS OF LOW THRUST PROPULSION

- ORBIT RAISING:

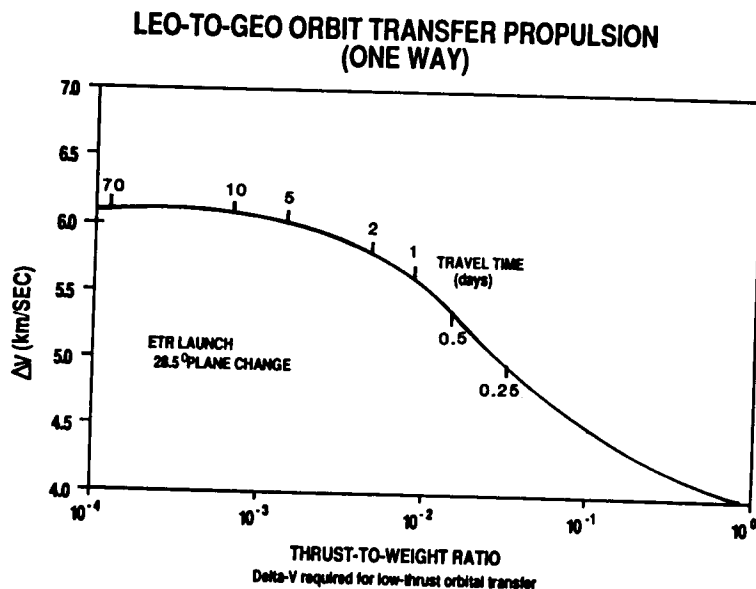
- REQUIRES INCREASED " ΔV " OVER IMPULSIVE HOHMANN TRANSFER BECAUSE OF THRUSTING THROUGH PLANETARY "POTENTIAL WELL".

- PLANE CHANGE MANEUVERS DURING 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



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 59, 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.	Total Mass in LEO-(300 KM)	90,000 Kg.	Total Mass in LEO-(300 KM)	90,000 Kg.
Propellants	14,000	Propellants	17,000	Propellants	19,000
Ascent	9,900	Ascent	11,000	Ascent	12,000
Return	4,100	Return	6,000	Return	7,000
Thrusters	10,000	Thrusters	10,000	Thrusters	10,000
Rectenna	10,000	Rectenna	10,000	Rectenna	500
Structure and PMAD	10,000	Rectenna Structure: (1)	5,000	Rectenna Structure: (1)	200
Loaded Veh. Wt. (less P/L)	44,000 Kg.	Structure and PMAD	10,000	Structure and PMAD	10,000
Payload (51%)	46,000 Kg.	Orb. Maneuver. Syst.: (2)	1,000	Orb. Maneuver. Syst.: (3)	800
		Propulsion and tankage	13,000	Propulsion and tankage	2,000
		Propellants		Propellants	
		Loaded Veh. Wt. (less P/L)	66,000 Kg.	Loaded Veh. Wt. (less P/L)	42,800 Kg.
		Payload (27%)	24,000 Kg.	Payload (53%)	47,900 Kg.
Notes:		Notes:		Notes:	
Thrusters: Isp = 4500 sec.		Thrusters: Isp = 4500 sec.		Thrusters: Isp = 4500 sec.	
Equatorial ascent from 300 Km altitude;		Launch azimuth 28.5 deg. (300 Km);		Launch azimuth 28.5 deg. (300 Km);	
Delta V (one way) to GEO - 4600 m/s.		Delta V (one way) to GEO - 6100 m/s.		Delta V (one way) to GEO - 6100 m/s.	
Single microwave beam transmission from		Single microwave beam transmission		Single microwave beam transmission	
terrestrial equatorial station.		from terrestrial equatorial station		from orbiting power station in 28.5	
No payload return to LEO.		Orbital maneuvering system raises		degree orbit at 300 Km. altitude.	
Microwave beam frequency: 2.45 Ghz.		LEO orbit from 300 Km to 1000 Km		25% of maximum payload returned to	
		prior to start of beam power phase.		LEO.	
		This is required for equatorial		Microwave beam frequency: 100 Ghz.	
		power station to "see" vehicle.			
		25% of maximum payload returned to			
		LEO.			
		Microwave beam frequency: 2.45 Ghz.			
(1): Rectenna weight of 0.2 Kg/m ²		(2): Orbital maneuvering system is		(3): Orbital maneuvering system is	
is interpreted as weight only of		required for rendezvous at		required for rendezvous at LEO	
rectenna blanket. Additional		LEO and GEO.		and GEO. Requirements are less	
structure is required to ensure		Space shuttle system with		than CASE I since GEO injection	
adequate separation of rectenna		800 m/s delta V total		point can always be "seen" by	
nodes and vehicle structural and		capability is assumed;		orbiting power station.	
control nodes.		Isp = 313 seconds;		Space shuttle system is also	
		Propellants: N2O4-MMH.		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", 28th 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		Chemically Propelled Vehicle	
Total Mass in LEO-(300 Km)	90,000 Kg.	Total Mass in LEO-(300 Km)	90,000 Kg.
Propellants	12,000	Propellants	70,000
Ascent	12,000	Ascent	52,000
Return	-----	Return	17,500
Thrusters	10,000	Orb. Man.	500
Rectenna	500	Structure and OMS	<u>10,000</u>
Rectenna Structure: (1)	400	Loaded Veh. Wt. (less P/L)	80,000 Kg.
Structure and PMAD	10,000	Payload (11%)	<u>10,000</u>
Orb. Maneuver. Syst.: (2)	1,000	-----	-----
Propulsion and tankage	1,000	Notes:	Launch azimuth 28.5 deg. (300) Km.
Propellants	3,200		Hohmann transfer ellipse.
Heat shield	<u>1,000</u>		Delta V (one way) 4.2 Km/sec. with
Loaded Veh. Wt. (less P/L)	37,100 Kg.		plane change at apogee.
Payload (59%)	<u>52,900 Kg.</u>		Advanced H2-O2 propulsion system.
Notes:			Isp = 500 seconds.
Thrusters; Isp = 4500 sec.			25% of maximum payload returned to LEO.
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.			

(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 COMPARISON 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

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 COMPARISONS: Support mass/payload delivered to LEO to support a mission.

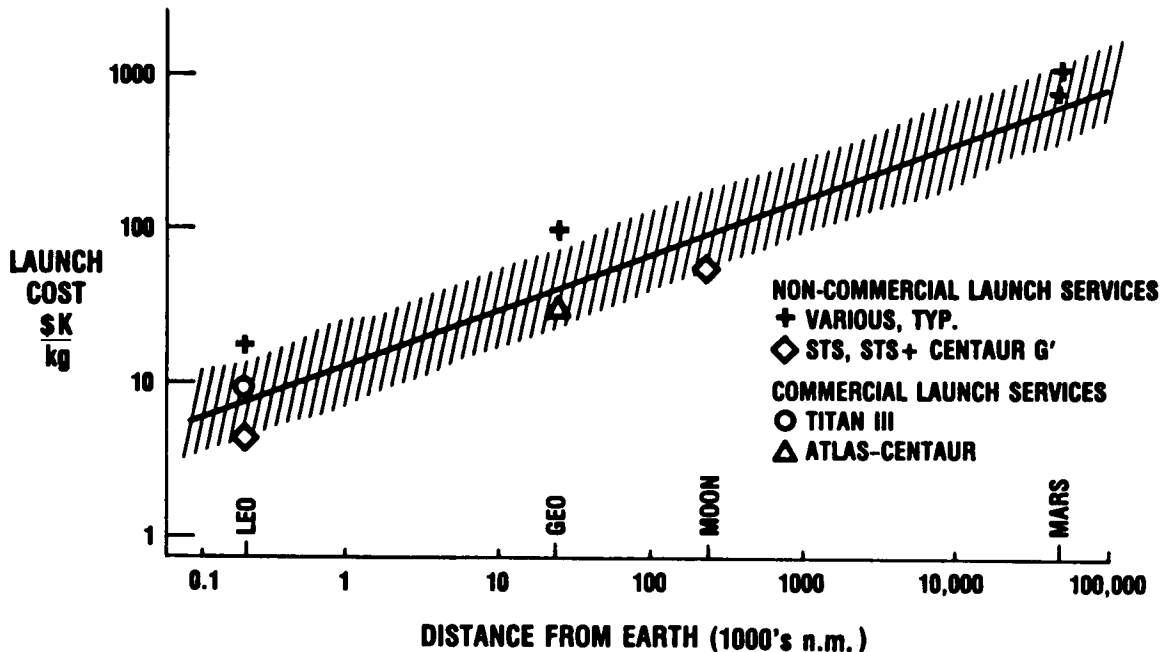
Mission Version	I.	II.	III.	IV.
Propellants/Mission	30,000 kg.	21,000 kg.	15,200 kg.	70,000 kg.
Special Maint. Items/Miss.	---	---	1,000	---
Total Mission Support: Mass delivered to LEO For Direct Miss. Support.	30,000 kg.	21,000 kg.	16,200 kg.	70,000 kg.
Prorated Op's Support: Mass/Mission.	5,000	10,000	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.
DELIVERED PAYLOAD MASS. kg TOTAL SUPPORT MASS kg	.667 kg/kg	1.21 kg/kg	1.50 kg/kg	.120 kg/kg

LEO TO GEO AND RETURN TRANSPORT

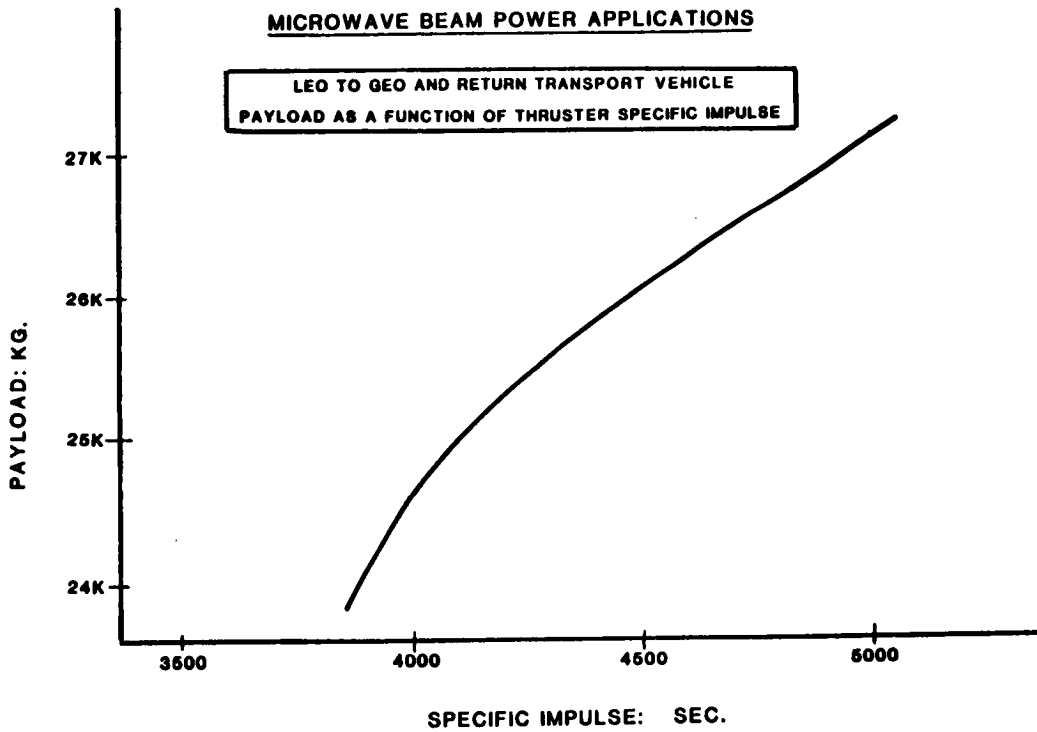
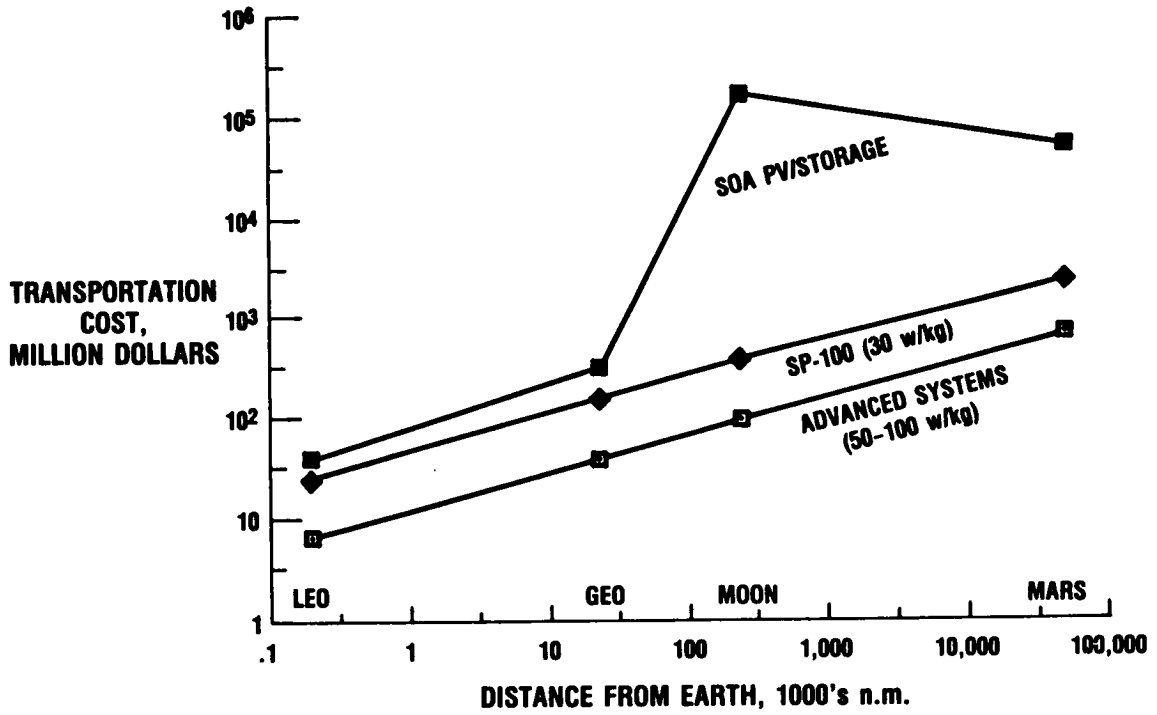
SUMMARY

- 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



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.

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