Conceptual Design of Manned Space Transportation Vehicle Using Laser Thruster in Combination with H-II Rocket

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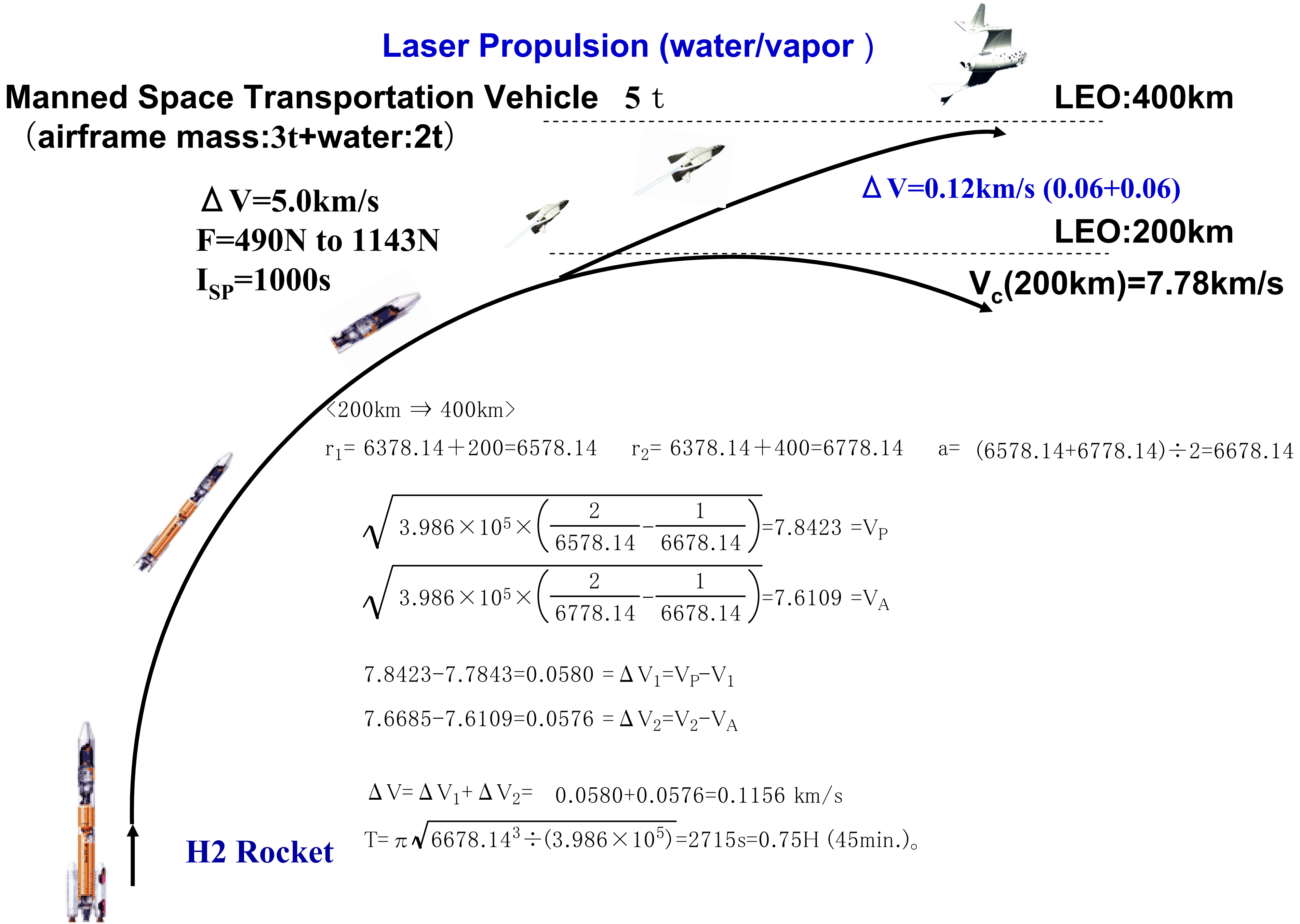
Background and Purpose
-Commercial Manned Space Trip-

- Nowadays, the space trip business in the private sector aiming at weightless experience is becoming a reality in Europe and the United States.

  For example, “Space Ship One” or “Space Ship Two” .
- Three kinds of space trips such as sub-orbital trip, orbital trip and round trip around the moon are prepared for the space trip, which can be purchased through a travel company or an agency.
- Once MSTV with crews boarding achieves circular orbit at an altitude of 200km around the earth (parking orbit) by use of H-II Rocket, MSTV is then put into circular orbit in an altitude of 400 km (ISS orbit) from 200km circular orbit by use of laser thruster.
- We propose the conceptual design of Manned Space Transportation Vehicle (MSTV) using laser thruster in combination with H-II Rocket.

External View of Manned Space Transportation Vehicle (MSTV)



<200km ⇒ 400km>

r_1= 6378.14＋200=6578.14 r_2= 6378.14＋400=6778.14 a= (6578.14+6778.14)÷2=6678.14

$$\sqrt{3.986\times10^5\times\left(\frac{2}{6578.14}-\frac{1}{6678.14}\right)}=7.8423=V_P$$

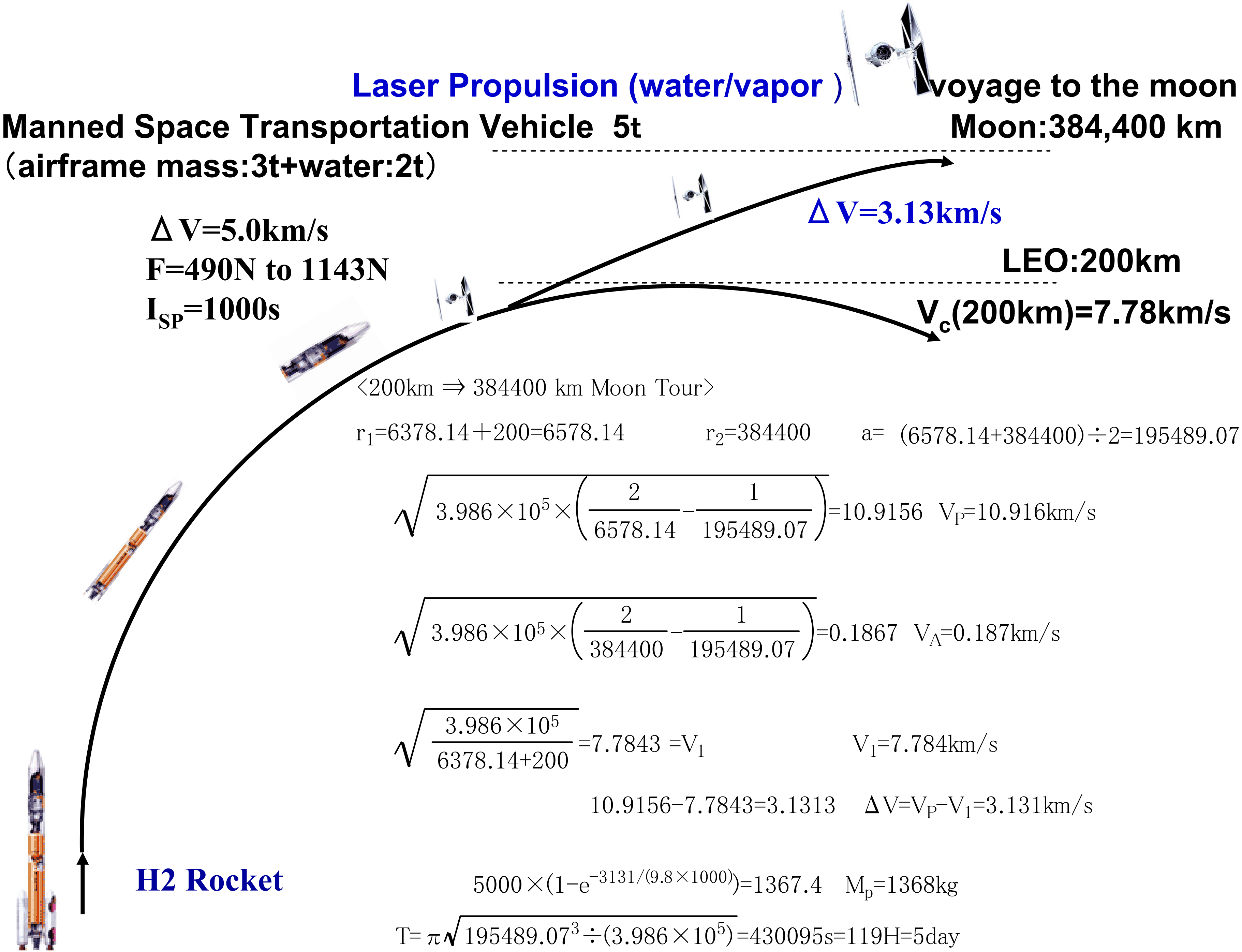
$$\sqrt{3.986\times10^5\times\left(\frac{2}{6778.14}-\frac{1}{6678.14}\right)}=7.6109=V_A$$

$7.8423-7.7843=0.0580=\Delta V_1=V_P-V_1$

$7.6685-7.6109=0.0576=\Delta V_2=V_2-V_A$

$\Delta V=\Delta V_1+\Delta V_2=$ 0.0580+0.0576=0.1156 km/s

$T=\pi\sqrt{6678.14^3\div(3.986\times10^5)}$=2715s=0.75H (45min.)。



〈200km ⇒ 384400 km Moon Tour〉

r_1=6378.14＋200=6578.14 r_2=384400 a= (6578.14+384400)÷2=195489.07

$$\sqrt{3.986\times10^5\times\left(\frac{2}{6578.14}-\frac{1}{195489.07}\right)}=10.9156 \quad V_P=10.916\text{km/s}$$

$$\sqrt{3.986\times10^5\times\left(\frac{2}{384400}-\frac{1}{195489.07}\right)}=0.1867 \quad V_A=0.187\text{km/s}$$

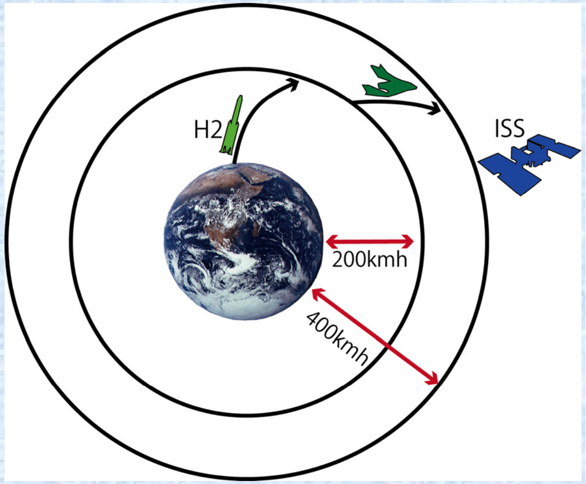
$$\sqrt{\frac{3.986\times10^5}{6378.14+200}}=7.7843=V_1 \qquad V_1=7.784\text{km/s}$$

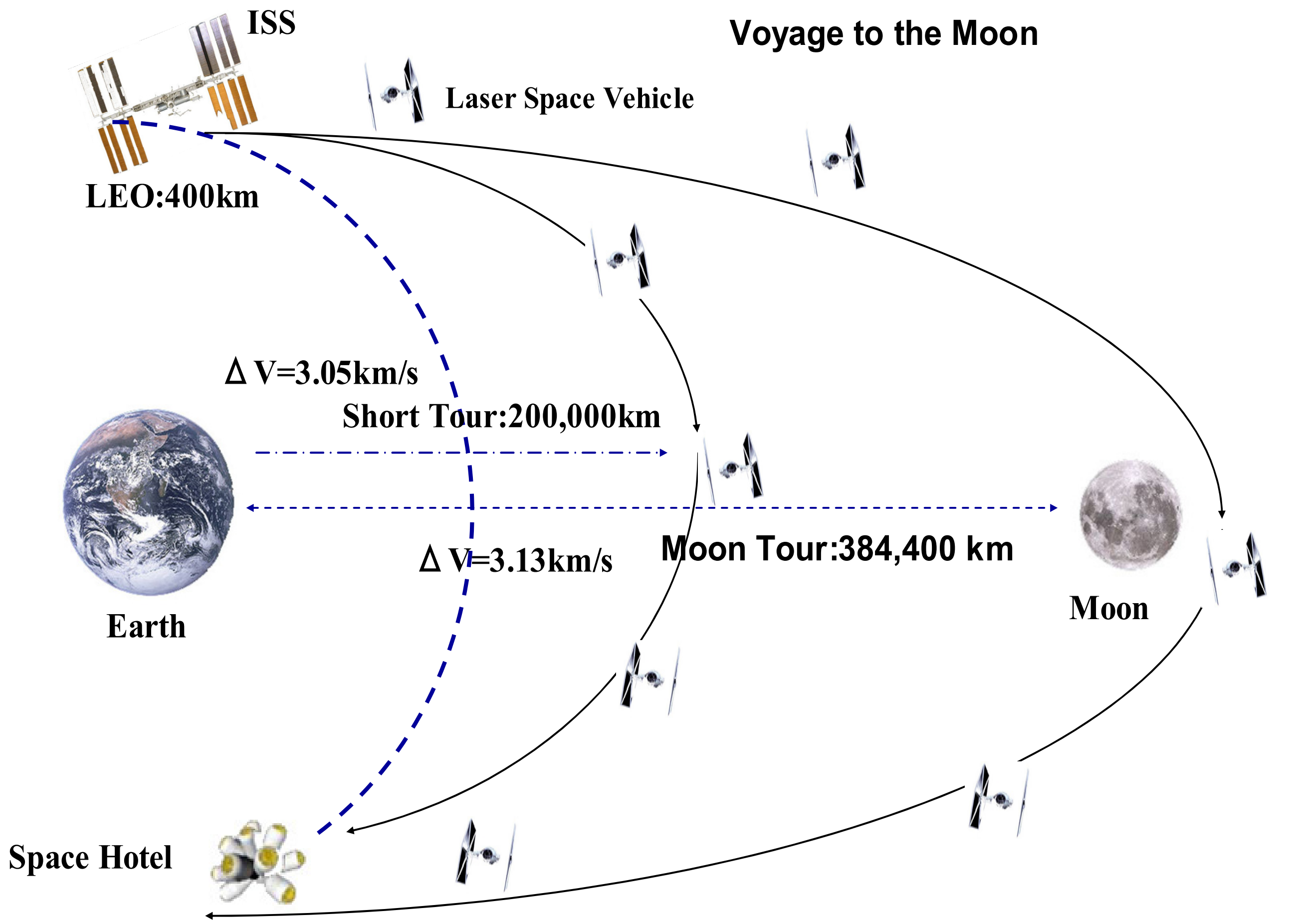
$$10.9156-7.7843=3.1313 \quad \Delta V=V_P-V_1=3.131\text{km/s}$$

$$5000\times(1-e^{-3131/(9.8\times1000)})=1367.4 \quad M_p=1368\text{kg}$$

$$T=\pi\sqrt{195489.07^3\div(3.986\times10^5)}=430095\text{s}=119\text{H}=5\text{day}$$

Launch to ISS by H-II Rocket and Moon Tour from ISS or Space Hotel





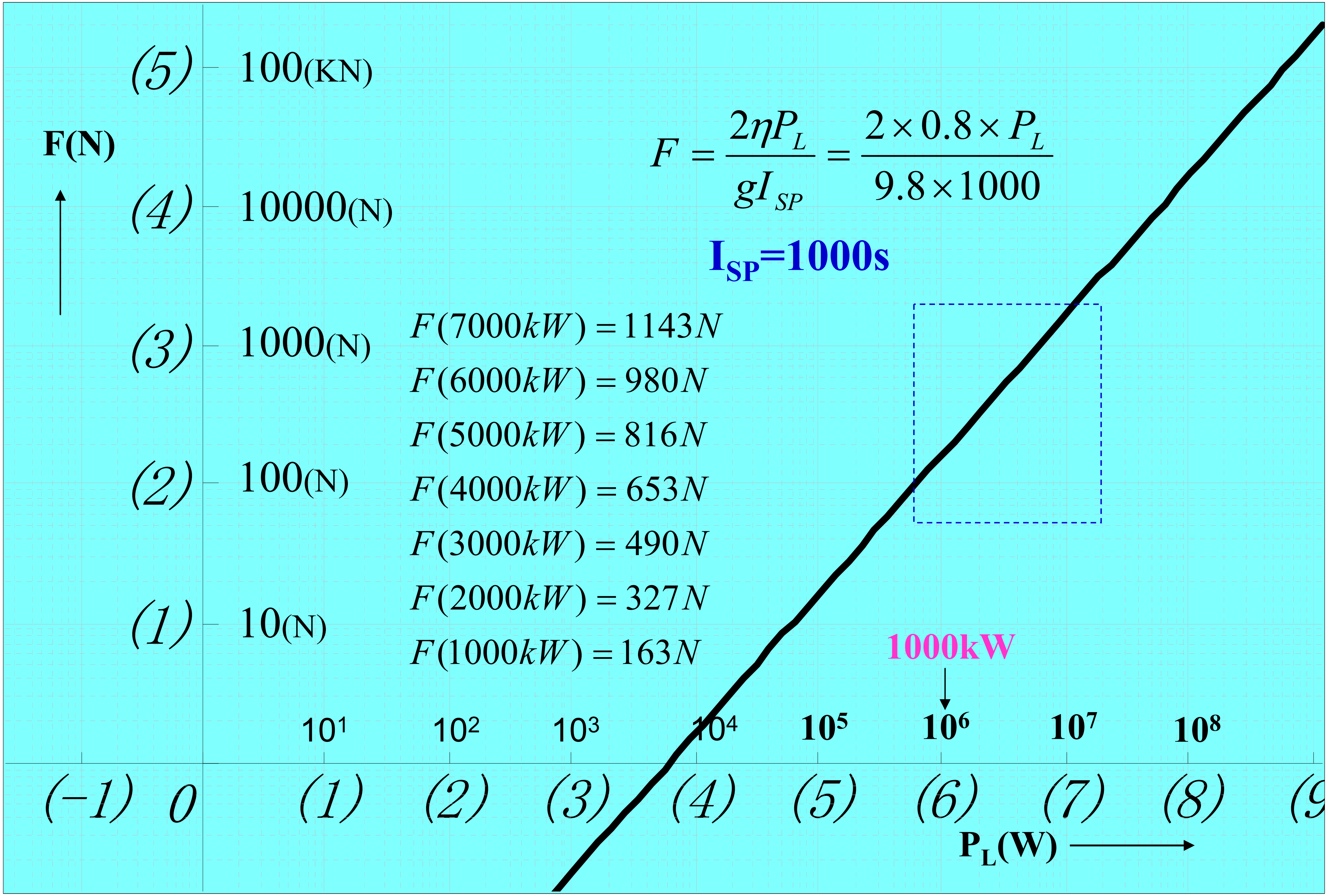
Laser Thruster (Laser Propulsion)

- The basic principle of laser propulsion is the same as for a rocket except that acceleration of propellant is done by ablation using the laser irradiation.
- Any materials melt and evaporate when the irradiated by a high power laser radiation. Reaction thrust is generated due to vapor molecular or ions are ejected in the direction of pressure gradient formed on the material surface.
- This corresponds to the jet of the rocket, and is a propulsion principle by the same momentum thrust as the rocket.
- Laser propulsion system became possible by the recent development of high-power semiconductor laser technology and miniaturization technology of power supply.
- Laser diode (LD) which has made remarkable technical progress in terms of high power generation is supposed to be a suitable choice for an on-board power source.
- LD can perform at their best when used in a CW mode and is suitable for generating low I_{SP} thruster and on the other hand a pulsed laser mode generating high peak power is suitable for high I_{SP} thruster.
- It has been clarified that ablation velocities from 100 m/s (I_{SP}=10 s) to 40 km/s (I_{SP}=4000 s) are possible by selecting a proper combination of ablating materials and laser conditions, mainly intensity.
- It has been improved sharply and the electric light conversion efficiency of LD has attained 75%.

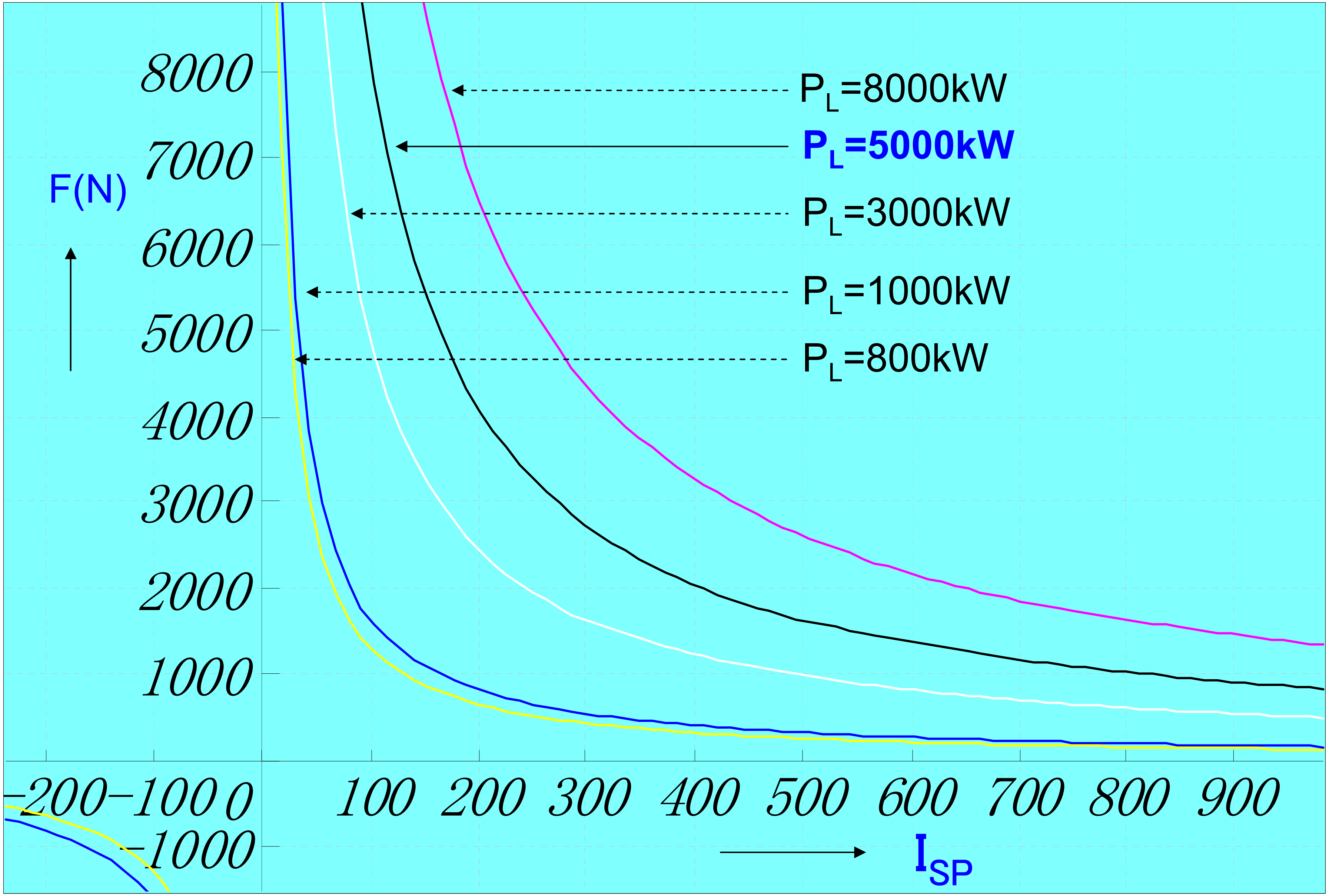
Why Laser Thruster for MSTV?

- The feature of laser propulsion is that both thrust and specific impulse (I_{SP}) can be arbitrarily controlled with laser power density (W/cm^2).
- Since the exhaust velocity and fluid conditions of a propellant can be controlled by means of the combinations of laser parameters such as intensity, wavelength and propellants, the selection between high thrust system and high specific impulse (I_{SP}) system can be easily implemented.
- Control of laser power intensity is performed by position control of a condenser (i.e. control of laser spot size) which adjusts thrust and specific impulse.
- The high-precision velocity of MSTV can then be precisely controlled by laser power density.
- Additionally, since MSTV does not use liquid hydrogen or liquid oxygen but the water as propellant, it is a promising highly safe technology.

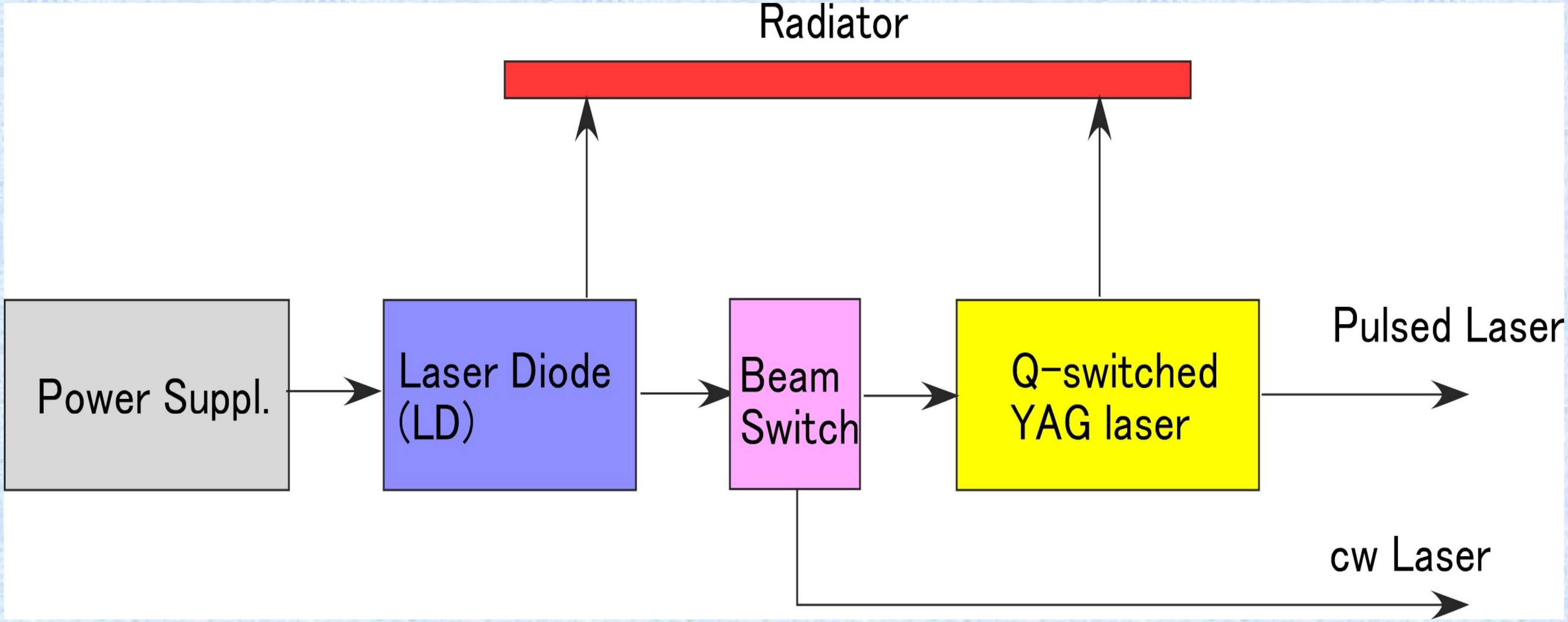
Thrust／Laser Power



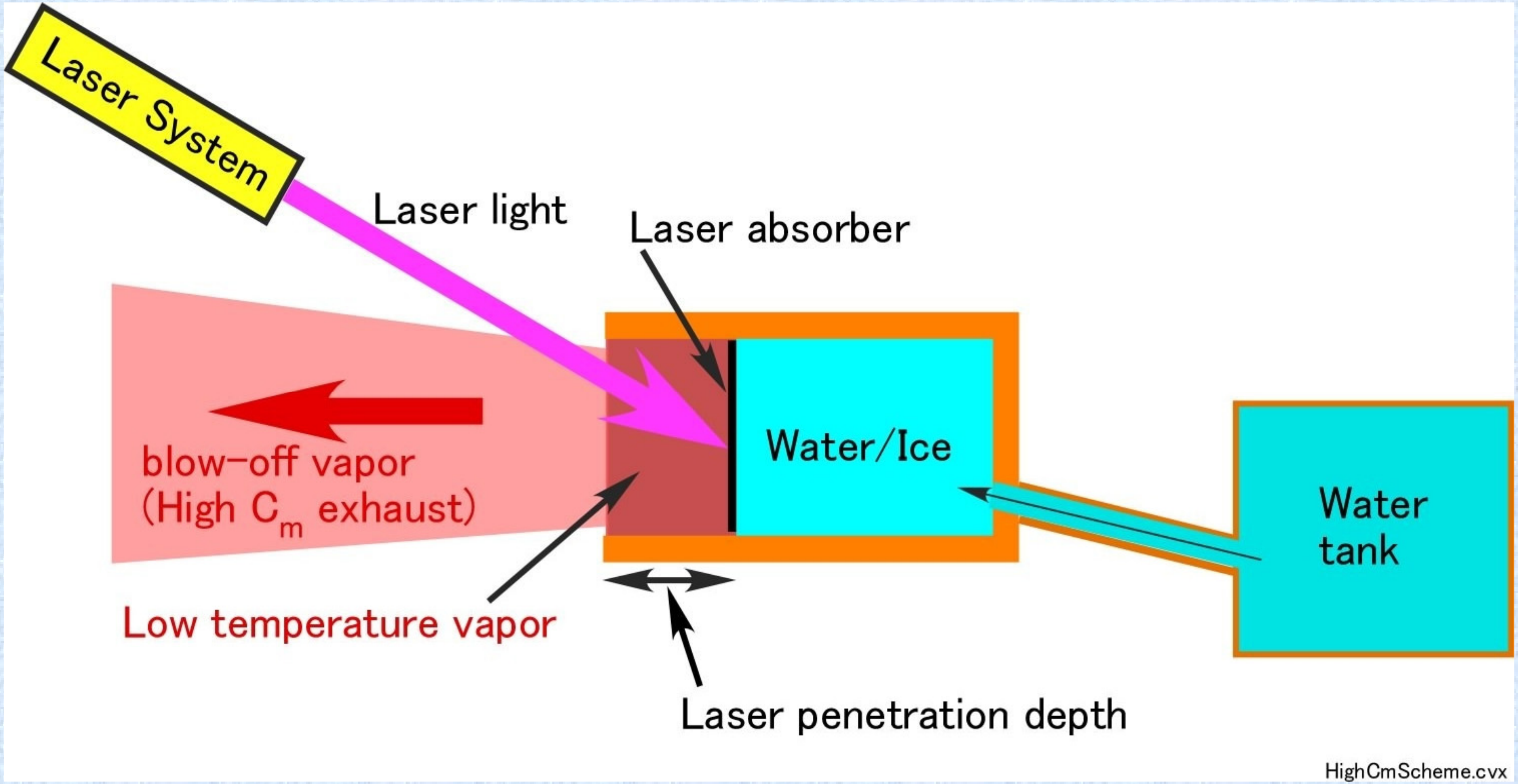
Thrust／I_{SP} : P_L = Constant



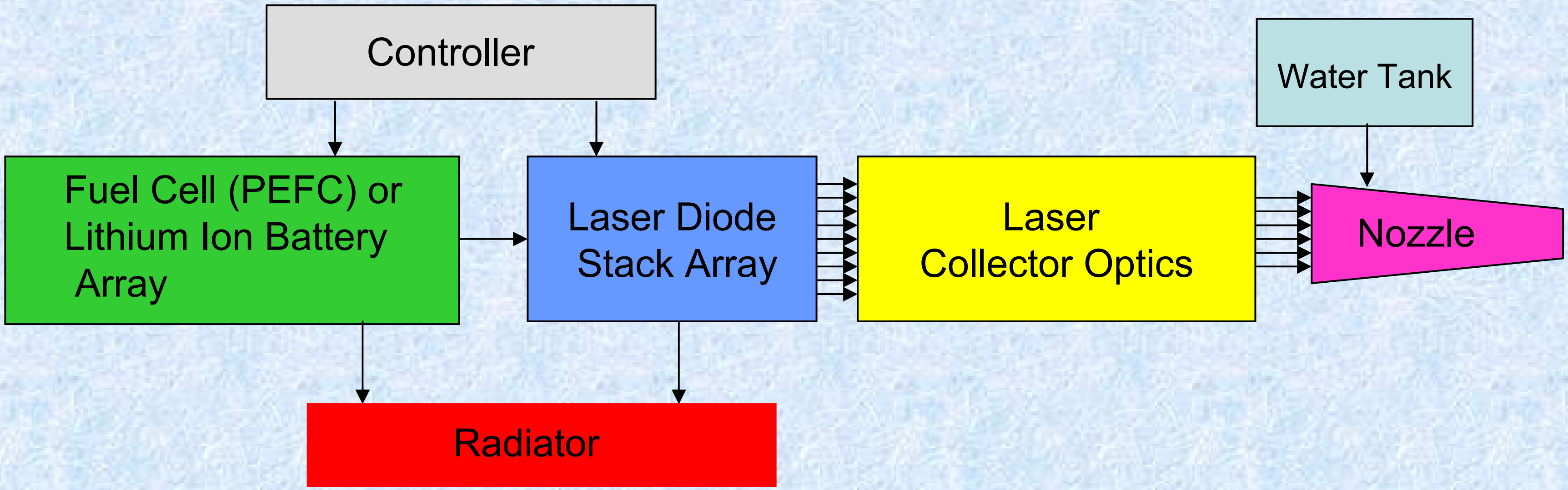
Laser System Block Diagram



Laser Thruster Using Water as Propellant



MSTV System Block（High Thrust Mode）



Major Specifications of MSTV（target）

- **Laser**：High Power Laser Diode (CW/Pulse change-over system)
- **Propellant**：Water
- **Laser Power Source**：Polymer Electrolyte Fuel Cell (PEFC) or laminate type lithium ion battery
- **Laser Power**：5000kW
- **Thrust**：800N (variable)
- **Specific Impulse (I_{SP}):**1000s (variable)
- **Mass**： 5ton - 10ton
- **Winged Vehicle**：5m（Length）×5m（Wing span）×2.5 m（Height）
- **Crew**：1-3 persons (TBD)

Trade-off for Laser Power Source

- Fuel Cell: PEFC (Polymer Electrolyte Fuel Cell)

  Gemini Spacecraft: PEFC (1kW, 31kg) ×2

  Space shuttle: AFC (Alkaline Fuel Cell)[10kW, 127kg) ×3

  Motor car (Japan): PEFC (100kW, 67kg)
- Lithium Ion Battery: HEV (Hybrid Electric Vehicle) 15kW, 14kg;

  EV (Electric Vehicle) 90kW, 730kg,24kWh
- Metal/Air Battery (Metal Fuel Cell)
- At present, PEFC used by car is desirable

OTHERS

- Laser Thruster: Laser Diode (CW mode only), ON-OFF switching for Pulse mode
- Thermal Protection System weight for Re-entry: 300kg-600kg (Re-entry speed 7.6km/s is low as compared to Apollo Spacecraft 10.9km/s)
  - Apollo Spacecraft: 848kg/(total weight 5806kg)
  - Gemini Spacecraft: 144kg/(total weight 1983kg)
- Thermal Control System (Radiator): Liquid Droplet Radiator is now developed for space use and promising

Laser Propulsion (water/vapor)

Manned Space Transportation Vehicle 10t
（airframe mass:9t+water:1t）

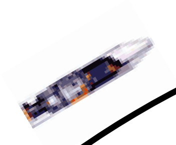
LEO:400km

$$\Delta V = 9.8\times1000\times\ln(10/9) = 1.03 km/s$$

Required ΔV=0.12km/s (0.06+0.06)

LEO:200km

ΔV=1.03km/s
F=490N to 1143N
I_{SP}=1000s



V_c(200km)=7.78km/s

<200km ⇒ 400km>

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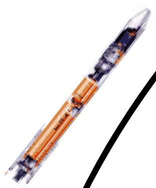

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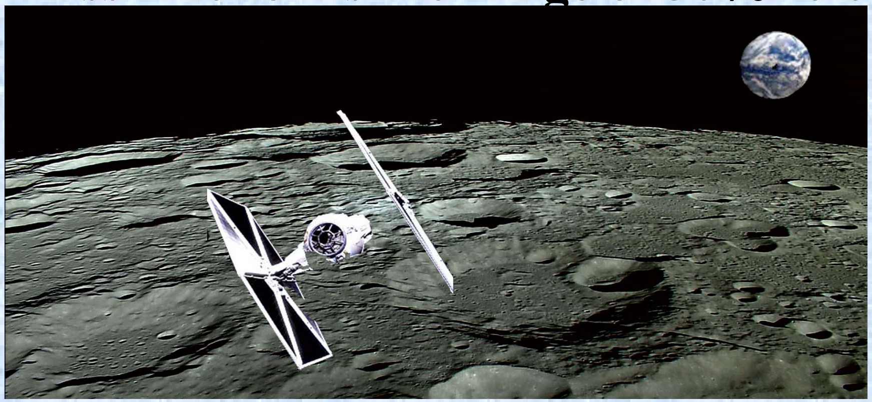
H2 Rocket

$\Delta V=\Delta V_1+\Delta V_2=$ 0.0580+0.0576=0.1156 km/s

$T=\pi\sqrt{6678.14^3\div(3.986\times10^5)}$=2715s=0.75H (45min.)。

Required Performance of MSTV Launched from Surface of the Moon

- To fly in the circular orbital altitude of 100km from the surface of the Moon: Orbital velocity of 1600 m/s is necessary
- Supposing the initial mass of MSTV is 1ton:
  - **Laser power must be at least 5000kW**
  - **Specific impulse (I_{SP}) ranging from 200s to 300s are preferable**
  - **Propellant mass fraction is the range of 50% to 60%**



Final velocity (v_f) of MSTV lifted off vertically from the surface of the moon is given by

$$v_f = -I_{sp} g_0 \ln(1-\alpha) - g_m \alpha \frac{m_0}{\dot{m}}$$

$\dot{m}$ (kg/s), m_0(kg), α are flowing quantity of the propellant, initial mass of OTV, installing ratio of propellant respectively.

CONCLUSION

- The possibility of Manned Space Transportation Vehicle (MSTV) using laser thruster that carries laser source and power supply is investigated.
- Due to the latest developments of high power laser diode (LD) and fuel cell, a laser space vehicle that carries both laser device and power supply on board is found to be feasible.
- Propellant for laser thruster is water : no space environmental pollution and safe & easy handling for thruster.
- MSTV equipped with laser engine system will fly from the space platform, ISS and the space hotel on the earth orbit to the moon.
- Future work is needed to establish the design of laser thruster including nozzle by experiment.

The End of Presentation

If you have any questions on this presentation, please ask Mr.Minami whose e-mail address is shown as follows;

E-mail: y-minami@mtj.biglobe.ne.jp