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STUDY TO DETERMINE THE EFFECTIVENESS AND COST OF A LASER-PROPELLED "LIGHTCRAFT" VEHICLE SYSTEM – RESULTS TO GUIDE FUTURE DEVELOPMENTS

Second International Symposium on Beamed Energy Propulsion
Sendai, Japan
20 – 23 Oct 2003

By Froning, Pike, McKinney, Mead, & Larson
Work Performed by Flight Unlimited, Flagstaff, AZ
Under the Direction of the Propulsion Directorate
Air Force Research Laboratory, Edwards AFB, CA

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Lightcraft Vehicle Concept

Shroud (Cowl): within which Laser Heating of Airflow and Propellant Occurs

Forebody: for Lift and Compression of Airflow during Atmospheric Flight

Axi-Symmetric Body

Afterbody: with Mirrored Surface for Focusing Laser Energy into the Shroud (Cowl)

Laser Airbreathing Flight from Zero Velocity to Hypersonic Speed

Laser Beam

Laser Rocket Flight from Hypersonic to Orbital Speed
Lightcraft Earth-to-Orbit Trajectory and Associated Pointing Direction of Laser Beam

(Not to Scale)
**Laser Beam Power Loss Mechanisms**

Diffraction:
Reduces Vacuum Propagation Intensity of Power P and wavelength $\lambda$, through an aperture of diameter $D$ at a range of $R$ to: $PD^2/R^2\lambda^2$

Thermal Blooming:
Laser Heating of Air Distorts Far Field Beam:
- Aggravated by low wind, low slew rate, high absorption, high power density

Turbulence:
Fluctuates Day-to-Day & Seasonally:
- Aggravated by low altitude targets, short wavelength, large diameter beams

Extinction:
Varies Seasonally, Daily if Fog/Rain, & by Detailed Laser Wavelength(s):
- Aggravated by higher temperature, long ranges, rain
- Devastated by fog, clouds
Optimization Considerations
Balancing Loss Mechanisms

Optical Turbulence

Scattering

Diffraction

Shorter ← Wavelength → Longer

Absorption (Thermal Blooming)

Extinction

Selecting the Appropriate wavelength is a Delicate Balancing Act
Influence of Lightcraft Range and Laser Pointing Angle on Laser Power Captured by Lightcraft

Given Laser Wavelength/Aperture and Lightcraft Diameter

Fraction of Radiated Power Captured by Lightcraft

Vertical Beam-Pointing Angle

Final Beam-Pointing Angle

No Adaptive Optics

Lightcraft Slant Range/Lightcraft Maximum Range
Influence on Laser Wavelength on Lightcraft Power Capture

Earth-to-Orbit Trajectory

Fraction of Radiated Power Captured by Lightcraft

End of Laser Airbreathing Propulsion

Best Wavelength Investigated

Worst Wavelength Investigated

Lightcraft Achievement of Orbital Speed

Lightcraft Slant Range/Lightcraft Maximum Range
Influence of Wavelength on Lightcraft Power Captured

Fraction of Radiated Power Captured by Lightcraft

Laser Wavelength/Optimum Laser Wavelength

Earth-to-Orbit Trajectory

End of Laser Airbreathing Propulsion

End of Laser Airbreathing and Rocket Propulsion
Influence of Wavelength on Lightcraft Power Captured

Fraction of Radiated Power Captured by Lightcraft

Laser Wavelength/Optimum Laser Wavelength

Earth-to-Orbit Trajectory
End of Laser Airbreathing and Rocket Propulsion

Beam Power Attenuation due to Diffraction
Beam Power Attenuation due to Diffraction and Atmospheric Effects
Influence of Wavelength on Orbited Mass

Same Radiated Power and Aperture for Each Ground Based Laser Candidate

Ground-Based Laser Candidate

1  2  3  4  5  6

Assumption: Orbited Mass is Directly Proportional to Collected Laser Power

Shorter Wavelength ← Best Wavelength → Longer Wavelength
Summary and Conclusions

- Laser-powered lightcraft systems that deliver microsatellites to low-earth-orbit (LEO) have been studied for the Air Force Research Laboratory.
- The many iterations needed for design of such an earth-to-orbit (ETO) system requires a multi-disciplinary optimization (MDO) for definition of the ground-based laser and lightcraft vehicle elements.
- An example is the influence of laser wavelength on the energy and power lost during laser beam propagation through Earth's atmosphere and space, and the resulting effect on mass delivered by lightcraft to orbit.
- Here, energy and power losses in the laser beam are very significant for ETO missions, and losses are highly dependent on laser wavelength.
- Thus, wavelength (together with other laser technical, operational, and cost issues) is an important consideration in laser selection for lightcraft.