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主　論　文　の　要　旨

論文題目　**Experimental Study of Impulse Generation and Stabilization Performance of a Doughnut-Spherical Laser Launch System**
(ドーナツ型レーザーを用いた打ち上げシステムのインパルスと安定性に関する研究)

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論　文　内　容　の　要　旨

Since ancient times, humans have dreamed to explore the universe. However, space exploration was started and explored in the latter half of the 20th century. The powerful chemical rockets were manufactured to overcome the force of gravity that opened the door to space exploration. As a result, many satellites, people, and even experimental laboratories have been launched to the orbit by the chemical rocket systems. However, because of the high costs of launching, many innovation plans such as space adventure tourism have been delayed. Furthermore, the chemical rocket shows a low efficiency with a low payload ratio. By applying the advance of technology, the new propulsion systems that can be mentioned as electrodynamic tethers, high-power electronic propulsion, and laser propulsion have been developed for cost reduction and operation at a higher efficiency.

In the laser propulsion concept, a vehicle can be put into orbit by absorbing radiation from a remote powerful laser station on the ground. The vehicle carries just a simple propulsion system, for which the mass and production cost are quite low, leading to an increase in the payload ratio. Moreover, the propellant (propellant onboard or air in the nearby) can be heated to a quite high temperature using a laser beam so that the

resultant specific impulse can be much higher than that of the conventional chemical rocket propulsion. Hence, the concept is expected to decrease the launch cost drastically as compared to a conventional launch system. To accelerate a vehicle using the laser propulsion, a passive technique of keeping the vehicle irradiated by the laser beam, known as the beam-riding technique, plays an important role. In actual flight conditions, aerodynamic forces cause the vehicle trajectory to deviate from the laser beam. Restoring force is necessary to recede the offsets, keeping the vehicle accelerated along the laser beam. However, the studies of the technique have been limited.

In this study, the feasibility of the new approach, called doughnut-spherical laser launch system, was first investigated experimentally. According to this concept, a spherical vehicle could be accelerated stably along a doughnut beam from the ground to a low Earth orbit (50 km ~ 100km from the ground) where the ambient pressure is in the order of several Pa. Once lateral offset between the axis of the laser beam and the center of the sphere exists, lateral force is generated to recede the offset, while a thrust is always generated to propel the vehicle in the vertical direction.

The first part of this study is focused on clarifying the physical phenomena occurring during the interaction between the laser beam and propellants such as ablation jet, shock wave propagation, plasma formation, and impulse. A spherical aluminum target is irradiated by a nanosecond 1 um wavelength pulse laser at the wide range of ambient pressure from 10 Pa to 100 kPa. The beam pattern is in a circular profile. Shock waves resulting from the expansion of the laser ablation plume are visualized by a Schlieren system for the first time. The shock wave expands quickly and anisotropically at low ambient pressure, $p_a < 10$ kPa, while it becomes a sphere at higher p_a due to the confinement of the ablation plume by the ambient air. The impulse is found to be generated by the sum of the ablation jet and the blast wave. The distribution of the ablation jet to the impulse decreases with increasing p_a, while the blast wave dominates the impulse generation at higher p_a.

In the second part, the impulse and stability generated on a sphere irradiated by a doughnut profile are investigated. Schlieren visualization gives a better understanding of the impulse generation. As a result, the ratio of the doughnut beam radius, R_{dn}, to the target radius, R_{sp}, is found to have a major impact on the impulse. For a relatively small value of R_{dn}/R_{sp} at 0.56, at atmospheric pressure, the impulse is enhanced due to the focusing of the toroidal blast wave, whereas the shock focusing effect is negligible for a larger value of R_{dn}/R_{sp} at 0.86. On the other hand, R_{dn}/R_{sp} must be larger than 0.83 to generate the restoring lateral force.

The resultant data in this study are useful for a feasibility study of the spherical-doughnut launch system. The impulse force is improved at high p_a > 10 kPa, and it is generated even at low p_a ~ 10 Pa. using laser ablation, resulting in high specific impulse for laser propulsion. Besides, the stability of the system is improved by the generation of the restoring force regardless of the impact of environmental effects such as the wind.