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Wave drag reduction of blunt bodies using laser sustained energy deposition in argon atmosphere

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Laser-induced energy deposition has been proposed for an effective flow control concept in super- and hypersonic transportation. Especially for blunt bodies the strength of the normal shock waves can be significantly mitigated by a modification of the gas temperature commonly generated by spark-discharge or repetitive laser-induced gas breakdown. The paper presents experimental and computational results of a laser-induced, non-repetitive gas heating concept in supersonic argon flow. Ignited by the gas breakdown of a Q-switched Nd:YAG laser a focused continuous wave CO_2 laser sustains a plasma. The pressure distribution of a miniature hemisphere is measured by four static pressure taps and determines a drag reduction of up to 55 % for the Mach number 2.1 and of up to 60 % for the Mach number 2.7 using an average pulse power of up to 5.4 kW for a typical duration of 700 μs.

Nomenclature

A_k, A_i	Transition probability
d_f, d_0, d	Focal spot size, incident laser beam diameter, diameter of the test body
ΔD	Drag reduction, $\Delta D = 1 - D_{P_L}/D_0$
ED	Energy deposition
E_k, E_i	Energy level
$f, f_\#$	Focal length, lens number, $f_\# = d_0/f$,
g_k, g_i	Statistic weight
I, I_{d_f}	Intensity, focal intensity
k	Boltzmann constant
κ_s	Absorption coefficient
l	Distance between energy source and test body
λ	Wavelength
M	Mach number
n_e, n_{Ar}	Electron density, neutral particle density
ΔP_{th}	Reduced thrust, $\Delta P_{th} = \Delta D \cdot u_\infty$
$\overline{P}_L, P_s, P_{s,\kappa}$	Average laser pulse power, enthalpy source, absorpted source power
$\dot{P}_s$	Power flux density
p_∞, p_s	Static pressure, static source pressure
ρ_∞, ρ_{ED}	Free jet density, rarefied gas density
T_0, T_e	Total temperature, electron temperature
Re_d	Reynolds number, related to diameter
u_∞	Free jet velocity
η	Power efficiency ratio, $\eta = \Delta P_{th}/\overline{P}_L$
y_R	Rayleigh length

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