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Flow Separation Control and Lift-to-Drag Ratio Improvement Using Repetitive Laser Pulses

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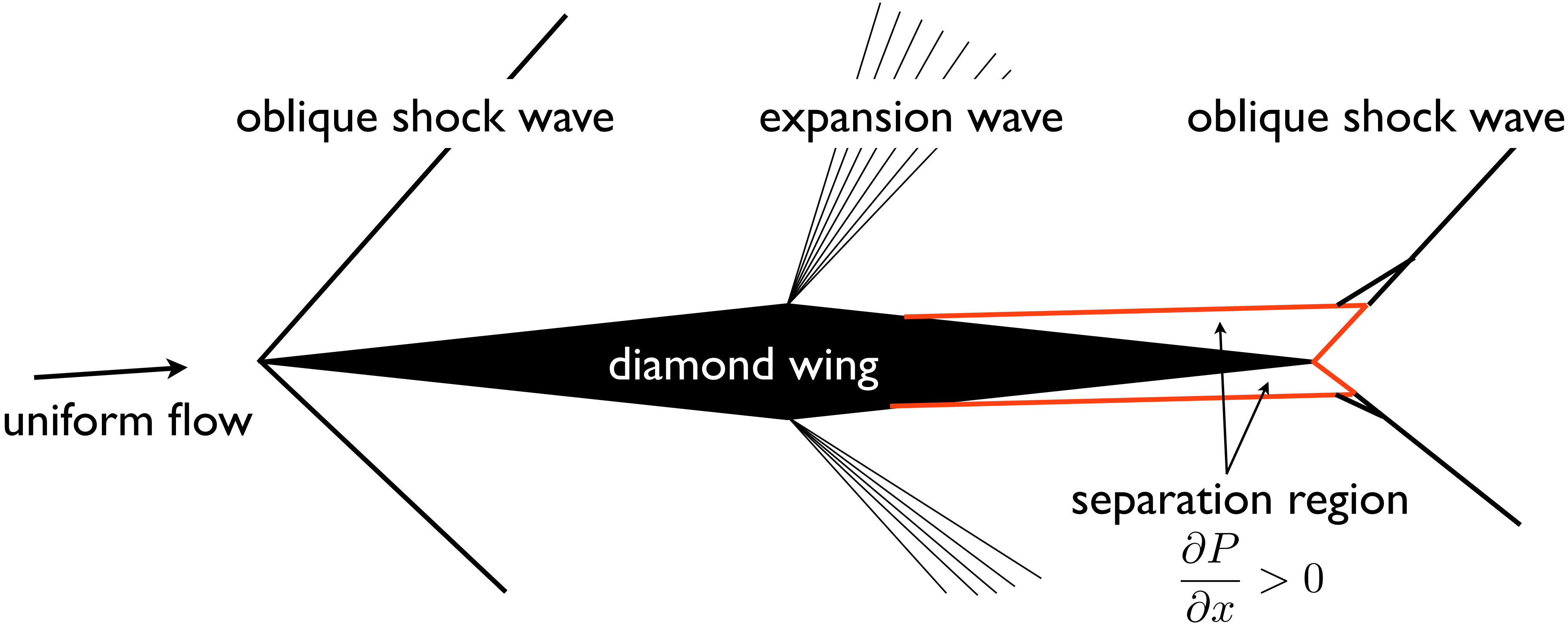
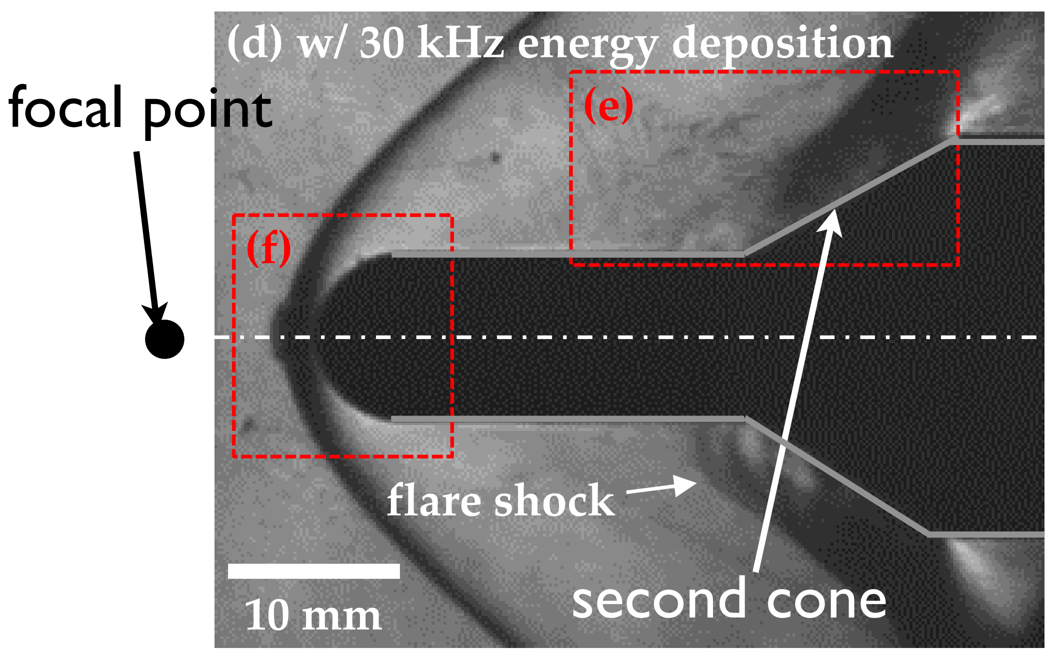
Flow Separation During Supersonic Flight



- Oblique shock wave at the trailing edge forms an inverse pressure gradient on the wing surface because positive pressure of the oblique shock wave propagates toward the upstream in the inside of the subsonic boundary layer
- Flow separation is induced even if AoA is small because of the oblique shock wave, which decreases a lift-to-drag ratio (L/D) of the airfoil

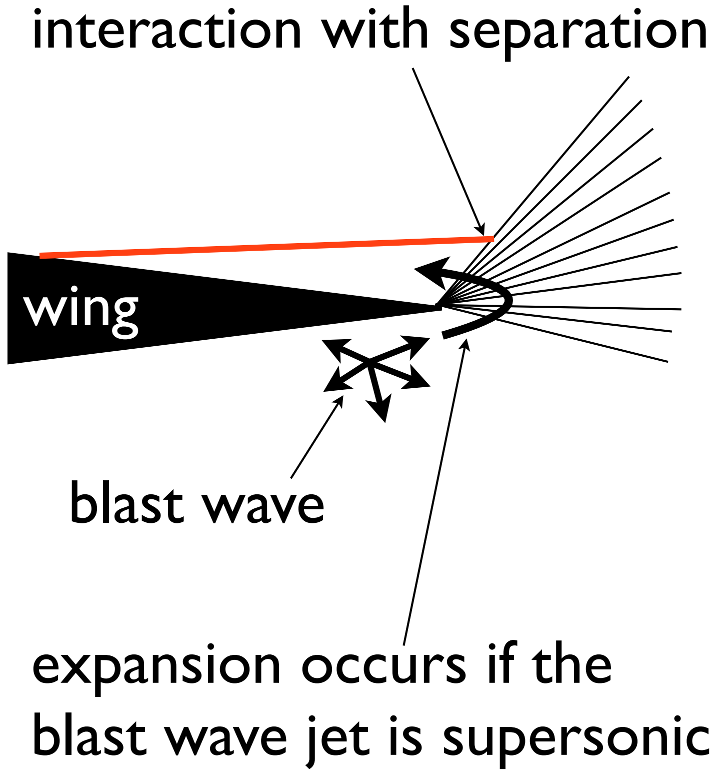
Conventional Techniques Based on Perturbation Generation

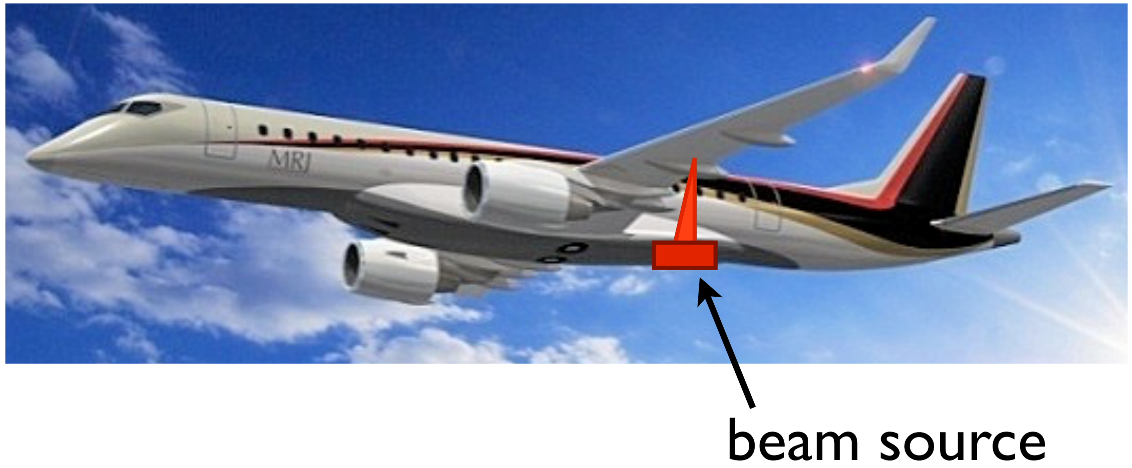


A. Iwakawa et al. (2016)

- Dielectric-barrier-discharge plasma actuator (PA) was proposed for flow control, but a flow control force was insufficient for supersonic flow
- Interaction duration between flowfield and perturbation generated by PA or laser was too short when speed of the main stream is fast
- It is necessary to propose new concept to control high-speed flow

New Flow Control Concept Proposed by Us





https://response.jp/imgs/zoom1/921821.jpg

- Expansion wave is induced from the trailing edge when the blast wave propagates to the upper surface, which interacted with the separation
- A source of the repetitive pulses is equipped on the aircraft
- After a computational fluid dynamics (CFD) simulation, we show the experimental results using the repetitive pulses in this presentation

Objective of Our Study

Establishing new flow control concept based on propagation of the blast wave

- Phase 1: Checking feasibility of our flow control concept using CFD
- Phase 2: Proving our concept by conducting a wind-tunnel experiment
- Phase 3: Conducting actual flight test by equipping the repetitive pulses

Governing Equation and Numerical Methods

• Governing equation	2D compressible Navier-Stokes equation

$$\frac{\partial \mathbf{Q}}{\partial t} + \frac{\partial(\mathbf{E} - \tilde{\mathbf{E}})}{\partial x} + \frac{\partial(\mathbf{F} - \tilde{\mathbf{F}})}{\partial y} = \mathbf{S}$$

• Spatial discritization	cell-centered finite volume method
• Numerical flux	AUSM-DV with 2nd-order MUSCL method
• Viscous flux	2nd-order central difference method
• Time integration	1st-order Euler explicit method
• Turbulence model	N/A to examine pure shock wave dynamics
• Chemical reaction	N/A to examine pure shock wave dynamics

Simulation Conditions

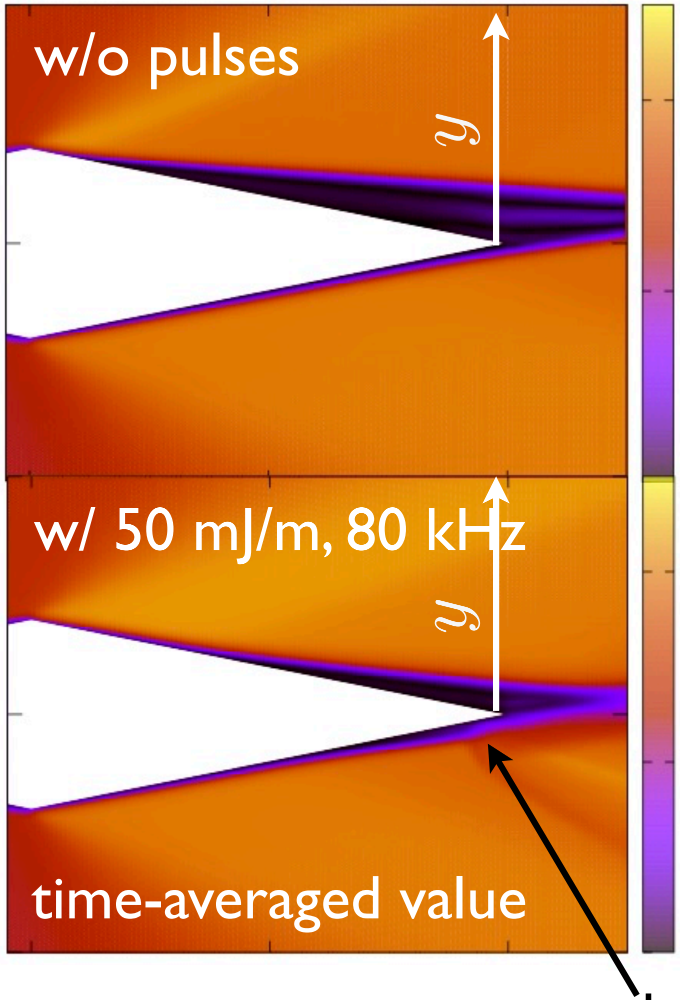
<u>Flow condition (D. Maruyama et al. (2007))</u>

- Flow Mach number 1.7
- Ambient gas 20 km param. of air
- Angle of attack 2 degree
- Reynolds number 1.26×10^5
- Airfoil diamond wing (*t*/*c*=0.2)
- Minimal grid size $1/25 \cdot (5L_{\text{ref}})/\sqrt{Re}$

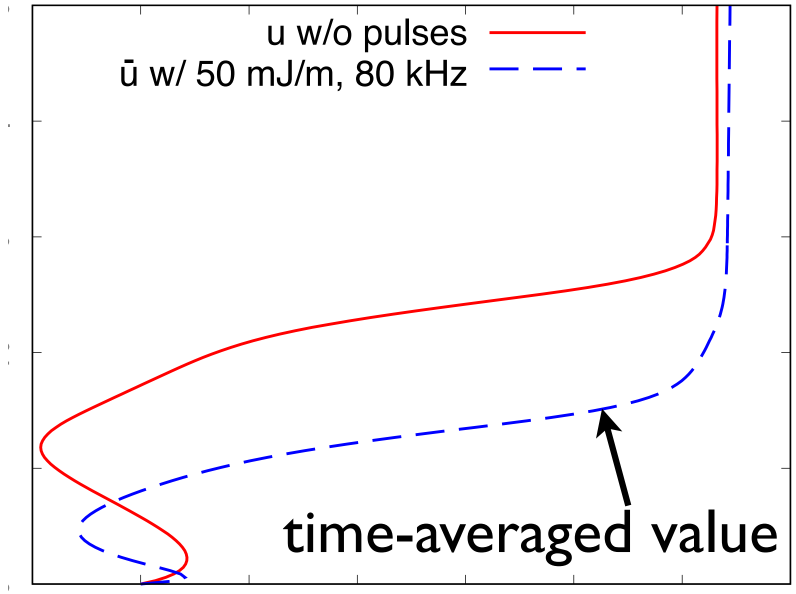
<u>Pulse laser condition (A. Iwakawa et al. (2016))</u>

- Pulse energy 50 mJ/m
- Pulse frequency 80 kHz
- Focal point lower surface

Separation Flow Control by Repetitive Pulses

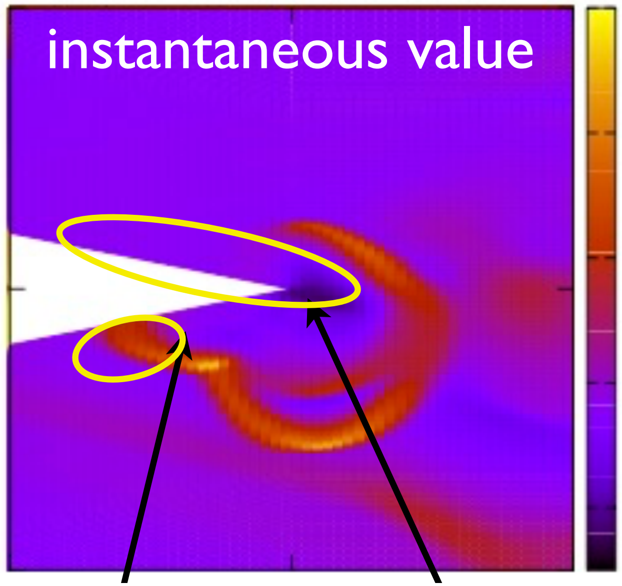


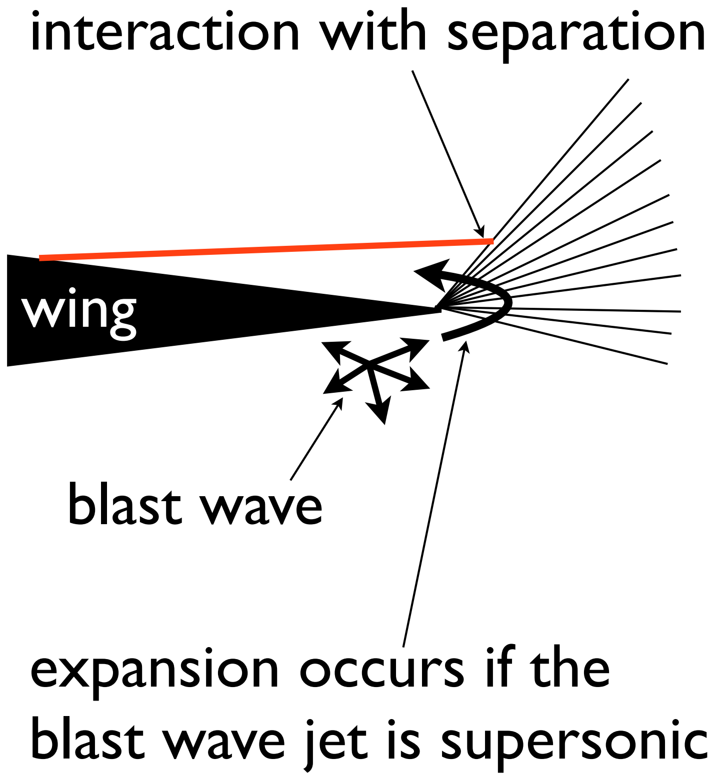
beam's focus point



- Separation region on the upper surface became smaller when the repetitive pulses were irradiated to the lower surface

Mechanism of Separation Control Using Repetitive Pulses





- Prantdle-Mayer expansion occurred at the trailing edge when the blast wave with supersonic speed propagated from the lower to upper surface
- The inverse pressure gradient on the upper surface was relaxed when the expansion wave at the trailing edge interacted with the separation region

Summary

- CFD simulation was conducted to check a feasibility of flow control method using the repetitive laser pulses
- An adverse pressure gradient was relaxed on the upper surface because an expansion wave induced from the trailing edge when the blast wave propagated from the lower to upper surfaces
- L/D performance was improved by combining the pressure decrease on the upper surface and pressure increase on the lower surface
- The lift increment was experimentally captured when the repetitive pulses were irradiated on the lower surface
- The lift becomes higher with an increase in the laser power