Improving Automotive Fuel Efficiency with Deturbulator Tape

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MOTIVATION

Investigate Applicability of DETURBULATOR wing drag reduction device to bluff bodies to Develop a SIMPLE, EFFECTIVE, and PRACTICAL Method of increasing Automobile and Truck Efficiency Through Aerodynamic Drag Reduction
BACKGROUND

The Deturbulator
ATTENUATING TURBULENT MIXING: 
SINHA - FLEXIBLE COMPOSITE SURFACE DETURBULATOR (FCSD)

Boundary Layer Flow

Fundamental Flexural Vibration Mode of Membrane
Shown (Amplitude < 0.1 µm)

High Strips or Ridges

Flexible Membrane ~ 6µm thick

Membrane Tension

Wing or other aerodynamic body

Low Strips as needed to fix flexural damping and higher modes

Substrate Base glued to aerodynamic surface

10-50µm thick Air-Gap (Membrane Substrate)

50-100µm
CLOSE UP OF DETURBULATOR

Flexible Membrane across Ridged Substrate

Substrate Cavity Vents
How Deturbulator Reduces Turbulence

Large Vortex Rolling

Freestream Flow

Boundary Layer

Small Vortices created from small-wavelength deflection

Small Vortices Drain Large Vortex

Flexible Skin of Deturbulator

RED: Large Wavelength deflection
BLUE: Small Wavelength Deflection

Ridges on Deturbulator

ANALOGY: Perturbation of large vortex creates small vortices similar to a tire rolling over rumble strips on a highway to warn approaching stop.

LARGE VORTICES PRODUCE TURBULENCE FROM MEAN FLOW
DETURBULATOR BREAKS UP LARGE VORTICES

Small vortices quickly dissipated by viscosity
FLOW-FCSD INTERACTION

Free stream
$\frac{\partial U}{\partial t} \approx v \left( \frac{\partial u}{\partial y} \right)_{y=0}$

Flow of pressure fluctuations

$\frac{\partial p}{\partial x} < 0$

$\frac{\partial p}{\partial x} \approx 0$

$\frac{\partial p}{\partial x} > 0$

SINHA-FCS
(Membrane Oscillation velocity $v$)

Separation point

Separated Shear Layer
(Oscillates due to fluctuations)

BEST INTERACTION where $\frac{\partial p}{\partial x} = 0$

• FCSD passes oscillation without damping at the Interaction Frequency:

$$f = \frac{U}{s}$$

Attenuates other frequencies

• This stabilizes the shear layer and mitigates turbulent dissipation
INTEGRATION OF DETURBULATOR WITH AIRFOIL TO INCREASE LIFT AND REDUCE DRAG

Laminar Boundary Layer
Low Skin Friction

Base Airfoil

Transition to Turbulent flow

Turbulent Boundary Layer
High Skin Friction

Marginally Separated Boundary Layer Alters “Virtual” Shape of Airfoil; Increases Lift Coefficient

Airfoil with Deturbulator

Thickness of Deturbulator Tape encourages Marginal Separation

Dynamic Flow-Flexible-Surface interaction on Deturbulator maintains nearly stagnant regions of marginal separation

Deturbulator attenuates Turbulent Mixing
Keeps separated regions nearly stagnant
Almost Zero Skin Friction (Lower than in Laminar Flow)
Effect of Deturbulator on Separation bubble

- BASE FLOW STRONG LAMINAR SEPARATION BUBBLE w TRANSITION
- DETURBULATED FLOW: NO TRANSITION EXTENDED BUBBLE
Smeared Oil: Slip Layer
Full-Span Deturbulator (Tested by Richard Johnson)
Evaluations by Dick Johnson (Dec 2006)
Supported by Dallas Gliding Association

Std. Cirrus Flight Test Measured L/D Values

N2866 SN 60  W/S = 6.58 psf

Consistent L/D Peak At 48 kts

With Deturbulators
Test Flights 1, 5, & 6

Without Deturbulators
Test Flights 8, 9, & 10

Glide Ratio

Calibrated Airspeed - kts
Automotive Fuel Efficiency Enhancement

Reducing Drag in Fully Separated Wakes
DETURBULATOR DRAG REDUCTION ON A VEHICLE

FLOW WITHOUT TREATMENT

FLOW WITH TREATMENT

Deturbulator

Turbulent Eddies

Vehicle or Bluff Body

Stagnant Wake For Virtual Streamlining
1/24 Scale SUV in Sinhatech Wind Tunnel
Measured Coefficient of Drag on Model Car
(Re = 0.4 million)

Test Number

Coefficient of Drag (CD)

- De-turbulator Rear Top
- Tape Top Front De-turbulator Top Rear
- Tape Top Front
- Clean Car
Deturbulator on 2000 Honda Odyssey
2000 Honda Odyssey Overall (Highway plus City) Gas Mileage

Overall Average

Control

Experiment

Miles per Gallon

2000 Honda Odyssey Average Highway Gas Mileage

Control

Experiment

Miles Per Gallon
Average Gas Mileages for 1997 Dodge Dakota

Miles/Gallon or % mpg increase

% increase

clean

experimental

Miles per Hour
Class-8 Tractor-Trailer Truck Fuel/Emissions Reduction

Drag Reduction on Connected Bluff Bodies
Measured Drag of Truck Model: Effect of FCSD (Deturbulator Treatment)

<table>
<thead>
<tr>
<th>Treatment Type</th>
<th>Coefficient of Drag (Cd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEAN</td>
<td>0.45</td>
</tr>
<tr>
<td>FCSD-1</td>
<td>0.4</td>
</tr>
<tr>
<td>FCSD-2</td>
<td>0.35</td>
</tr>
<tr>
<td>FCSD-3</td>
<td>0.32</td>
</tr>
<tr>
<td>FCSD-4</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Fuel Mileage for Freightliner Freight Truck with Trailer

- Control Overall mpg: 5.8
- Deturbulator Overall mpg: 5.9
- Control Highway mpg: 6.0
- Deturbulator Highway mpg: 6.1
- Control Overall mpg: 6.2
- Deturbulator Overall mpg: 6.3
- Control Highway mpg: 6.4
- Deturbulator Highway mpg: 6.5

Bar chart showing fuel mileage comparisons for control and deturbulator conditions on overall and highway mpg.
Operational Class-8 Truck Road Test

<table>
<thead>
<tr>
<th>Condition</th>
<th>Overall Miles/Gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>5.8</td>
</tr>
<tr>
<td>Deturb Cab sides top Trailer top</td>
<td>5.9</td>
</tr>
<tr>
<td>Deturb Cab sides top Trailer top, sides, top, bottom</td>
<td>6.1</td>
</tr>
</tbody>
</table>
Concluding Remarks
DETURBULATOR: Separation without Turbulent Mixing makes Wake more Stagnant (Tractor Cab Wake)

MEAN VELOCITIES 1/3-Height BEHIND CAB MODEL
Mean x-y plane Velocities h/2 Behind Model Tractor-Trailer
Truck of height h = 70 mm

Mean Velocities (u/u-upstream)
Distance From Road Surface (h/h-trailer)

- Vmean treated Cab+Trail
- Vmean UnTreated
Deturbulator Vs. Other Drag Reduction Methods

% Drag Reduction

- Deturb Class-8 truck
- Deturb Class-8 truck
- Under Chasis Blow
- Trailer Strakes Truck Drag
- Tailcone Truck Drag
- 2006 Honda Odyssey
- Deturb 2000 Odyssey
- Deturb Dodge Dakota

% Drag Reduction
ACKNOWLEDGEMENTS

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QUESTIONS?