Drag Reduction by Trailing Edge Tabs on a Square Based Bluff Body with a Stationary Ground Plane

Scott Sawyer
Faculty Advisor: Dr. Jin Tso
Overview

• Project Goals
• Bluff Body
  – Background
• Ground Effect
  – Background
  – Testing
• Previous Work
• Experimental Apparatus
• Testing Results
Project Goals

• To investigate drag reduction via trailing edge tabular devices on a square based bluff body in ground effect

• Compare base pressures in a bounded flow to previous work performed in unbounded flow

• Compare results of drag reduction devices in and out of bounded flow
Bluff Body Basics

• A bluff body contains a large base region perpendicular to the airflow
  • Resulting separation of flow generates vortices, creating a low pressure region behind the vehicle and increasing overall aerodynamic drag
• Drag force is dominated by pressure drag in comparison to viscous drag
Vortex Creation

- The trailing edge creates an instantaneous separation of flow, resulting in the formation of an unstable shear layer.
- This shear layer will roll into a vortex on both the top and bottom surfaces, forming a Karmen vortex sheet.
Applications

- Real world application include aircraft, submarines and automobiles
  - This effect can most commonly be seen on large transport automobiles, buses, and tractor trailers
Bluff Body Drag Reduction

• For a large tractor trailer, as much as 70% of fuel consumption can be attributed to aerodynamic drag, depending on speed
  • A major cause of this is the bluff shape of the trailer
• Passive drag devices can be used to control and minimize this drag, which results in lower fuel consumption, and greater profits for the company
Bounded vs. Unbounded

- In aircraft aerodynamics, the majority of the airflow can be considered “unbounded”
  - However, in a bounded case, the boundary creates an alteration of the flow field by preventing the expansion of the streamlines
  - For aircraft, this can lead to an increase in lift and a decrease in drag
Ground Effect

- Aircraft experience ground effect most often during takeoff and landing
- For automobiles, the ground is constantly having an effect on the overall aerodynamics of the vehicle
  - High performance racing vehicles (Formula 1, Indy) have tried to utilize this effect to increase downforce
  - Wing in Ground Effect Vehicles (WIGS) have been built and tested
Modeling Ground Effects

- Presence of ground plays an important role in flow characteristics.
- Depending on height above the ground, flow circulation is created in bounded airflow.
- In a wind tunnel, because the air is moving in relation to the object, a boundary layer is formed that does not depict the real situation.
Modeling Ground Effect

- Mimicking real world bounded flow phenomena in a wind tunnel presents difficult challenges
  - Money, complexity, and space
- Lifted model is the easiest test setup and provides realistic results for larger ground clearances
- Moving belt is most accurate, but is complex and costly
Previous Work at Cal Poly

• Jarred Pinn found a large drag reduction by adding tabs to each side of the model

• Reported a 36% increase in base pressure with the addition of tabs
  –Attributed the attenuation of vortex shedding to this large drag decrease
Previous Work Cont.

- Ethan Erlhoff investigated active drag reduction for 3D bluff bodies via distributed forcing
- Baseline model pressures contradicted Pinn
- Concluded that while drag was decreased with forcing, it was not efficient energy wise
Previous Work Cont.

• Barker reported drag increase of a 3D bluff body with tabs for vortex attenuation, over the untabbed version

• Trailing edge tabs were ineffective at decreasing base pressure drag, and larger tabs created lower base pressures
Experimental Apparatus

• 3’ X 3.5’ aluminum ground plane installed from wind tunnel ceiling
• 6” flap at the trailing edge
  – Controls stagnation point
• Full adjustability allows for testing at all ground clearance heights
• Structural support was added as a result of initial testing
• Rounded leading edge to prevent separation
Ground Plane Installation

- Ground plane lowered from wind tunnel ceiling
  - No interference with sting balance or strut
Ground Plane Validation

- Laminar boundary layer was present at 5 and 10 m/s
- Turbulent at higher test velocities

<table>
<thead>
<tr>
<th>Speed [m/s]</th>
<th>BL Thickness (Laminar) [mm]</th>
<th>BL Thk (Turb) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>9.07E+00</td>
<td>3.11E+01</td>
</tr>
<tr>
<td>10</td>
<td>6.41E+00</td>
<td>2.71E+01</td>
</tr>
<tr>
<td>20</td>
<td>4.53E+00</td>
<td>2.36E+01</td>
</tr>
<tr>
<td>30</td>
<td>3.70E+00</td>
<td>2.17E+01</td>
</tr>
</tbody>
</table>
Bluff Body Model

• Same model that Barker used in testing
  • Allows for direct comparisons of results
• Square base with 44 tapped pressure ports
• Utilized one row of ports on both the spanwise and normal directions
  • Limited by spacing in sting balance strut for tubing
Testing Results

Normal Base Pressures

- No Ground Plane
- Ground Clearance: H/h=0.5
- Ground Clearance: H/h=0.25

Spanwise Base Pressures

- No Ground Plane
- Ground Clearance: H/h=0.5
- Ground Clearance: H/h=0.25

• Ground plane alters the flow field at the base of the model
  • Unbounded flow side experiences a large drop in $C_p$
Testing Results

- Average base pressure coefficients drop with decreasing ground clearance
- Much greater decrease at the lowest ground clearance
- Turbulent boundary layer effects
• Sting balance data indicates the addition of trailing edge tabular devices actually increases overall drag force
• Drag decreases with decreasing ground clearance, up to a critical gap height
Questions?