Design of the Inlet for an Open Circuit Wind Tunnel for Testing Full Scale Class Eight Trucks

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# Overview

- Open circuit design
- Boundary layer analysis
- CFD analysis
- Conclusions



# **Design Strategy**

#### Objectives

- Guarantee no separation
- Obtain uniform velocity profile upstream of vehicle under test

#### Boundary layer analysis

- Run CFD model with slip BC on walls
- Use Thwaites' method to find  $c_f(x)$  and  $\theta(x)$
- Goal:  $c_f(x) > 0$  for all x

#### CFD Analysis

- Three dimensional, quarter model.
- Goal: maximum velocity deviation < 1% outside the boundary layer
- Look for secondary flow in corners

# **Inlet Geometry**



# **Inlet Geometry**



$$\frac{y - y_1}{H_s - H_t} = -3\xi^5 + \frac{15}{2}\xi^4 - \xi^3 \qquad \qquad \xi = \frac{x - x_1}{L_c}$$

 $\frac{z - z_1}{W_s - W_t} = -3\xi^5 + \frac{15}{2}\xi^4 - \xi^3$ 

# **Design Parameters**

# Fixed

Dimensions of cross section:  $H_s$ ,  $W_s$ ,  $H_t$ ,  $W_t$ Air speed in test section

Variable Length of settling chamber,  $L_s$ Length of contraction,  $L_c$ Length of test section inlet,  $L_t$ Number, location, and porosity of screens

# Boundary Layer Analysis

- Preliminary CFD work found no separation
- Bell and Mehta showed that Thwaites' method predicted successful designs of low speed wind tunnels
- Run CFD model with slip BC on walls.
  Velocity along the wall from slip solution is external velocity for Thwaites' method.
- Thwaites' method used to check that boundary layer does not separate. Detailed CFD analysis is still useful.

Given  $u_e(s)$ , the variation of free stream velocity outside the boundary layer, numerically integrate the momentum equation to get  $\theta(s)$ ,  $\delta(s)$ , and  $c_f(s)$ 



$$\theta^{2} = \theta_{0}^{2} + \frac{0.45v}{u_{e}^{6}} \int_{s_{0}}^{s} u_{e}^{5}(\zeta) d\zeta$$

# **Thwaites Method – External Pressure Gradient**



#### Thwaites Method – Wall shear vs. $L_{sv}$



# **CFD Model**

- Quarter model
- 1.6 × 10<sup>6</sup> cells
- Highly graded mesh
- MARS convection scheme



• Low Reynolds number k- $\varepsilon$  turbulence model

# 100×100 Mesh in Cross Section



### **Screen Models**

Local pressure drop

$$\Delta p = \frac{1}{2} K_m \rho v_n^2$$

### Idelchik model

$$K_m = K_{\text{mesh}} K_{\text{Rn}} (1 - f) + \frac{(1 - f)^2}{f^2}$$

Star-CD model

$$\Delta p = \rho \left( \alpha |\upsilon_n| + \beta \right) \upsilon_n$$
$$\alpha = \frac{K_m}{2} - \frac{\beta}{\upsilon_n} \qquad \beta = 0.01$$

# Velocity Profiles development in test section



# Single screen in settling chamber



## Two screens in settling chamber







$$x_t/L_t = 0$$

$$|V_{\rm max}| = 0.042 U_t$$



$$x_t/L_t = 0.5$$

$$|V_{\rm max}| = 0.022 U_t$$

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$$x_t/L_t = 1$$

 $|V_{\rm max}| = 0.014 U_t$ 

# Conclusions

- Boundary layer and CFD analysis are complementary
- No separation predicted for  $d/L_s < 0.35$  and  $L_c/D_{\rm hs} = 0.81$
- Weak secondary flow in corners
- Wind tunnel is operating



## The Team





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## Extra

# 100×100 Mesh in cross section

