Aerodynamic Ground Effect: a case-study of the integration of CFD and experiments

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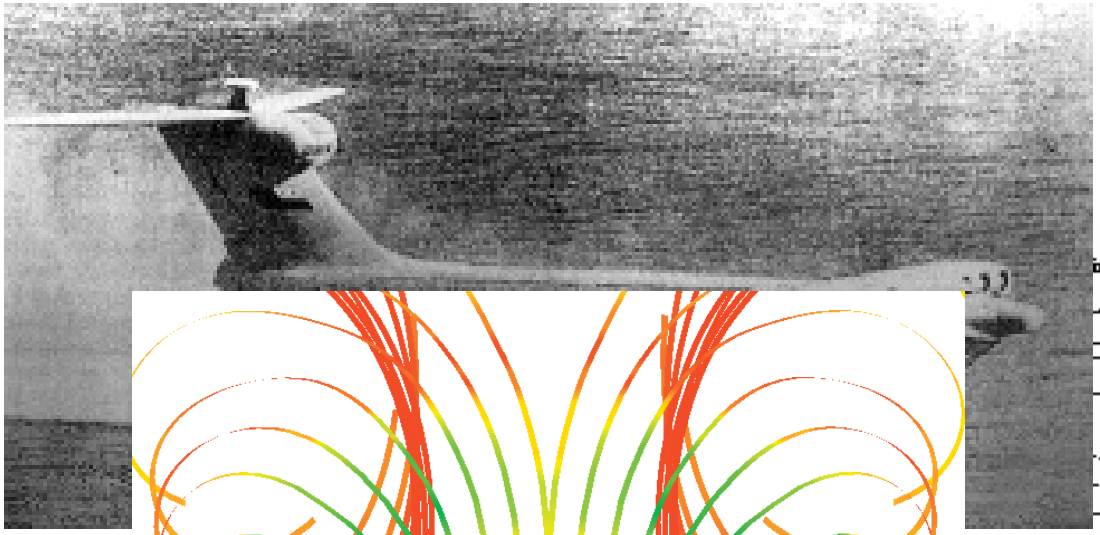
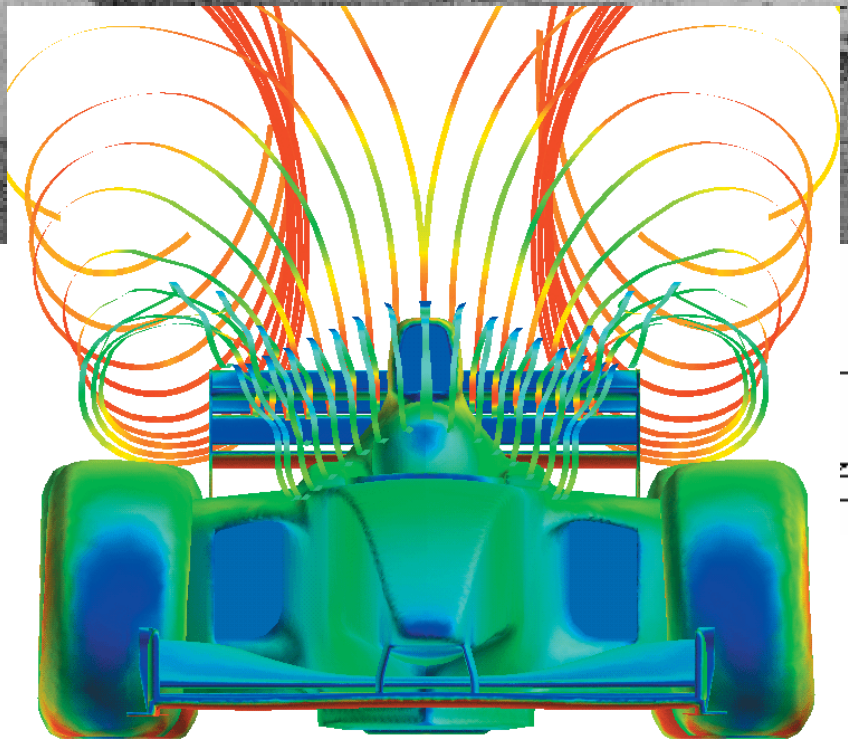
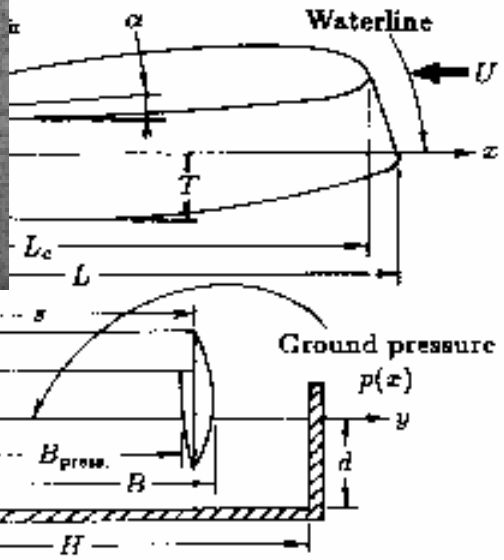
Introduction

- Ground Effect
- Issues causing discrepancies in results
- Boundary Conditions
  - Deformable surface
- Viscous Effects
- Moving Ground design and analysis
- Continuing work

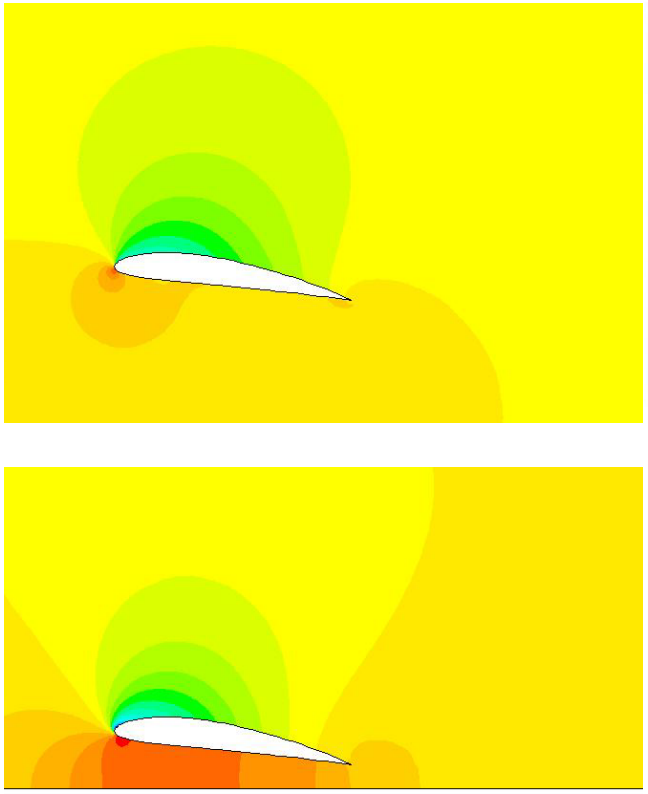
Ground effect - applications

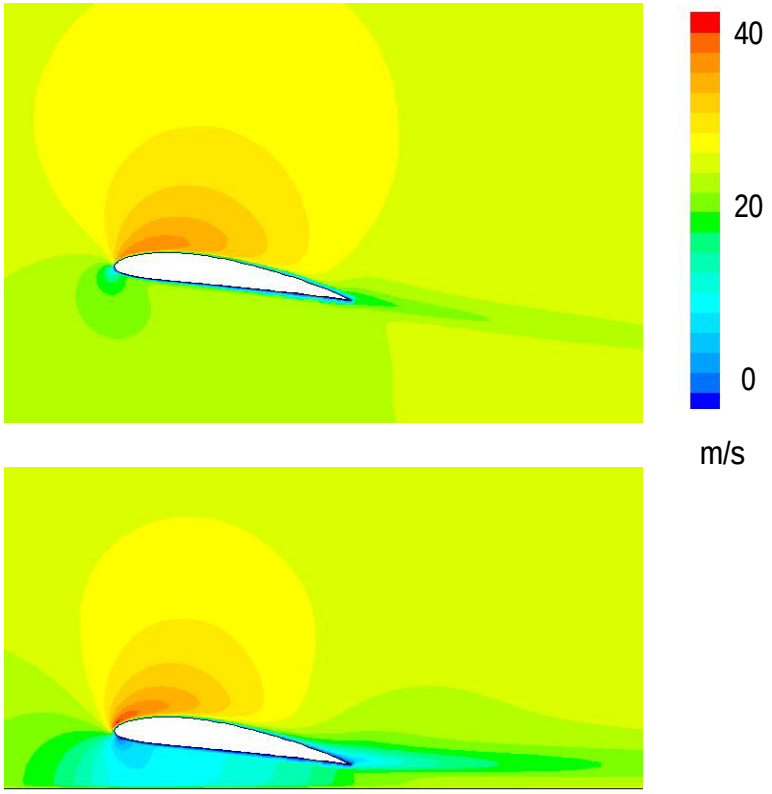






WIG





Pressure

Velocity

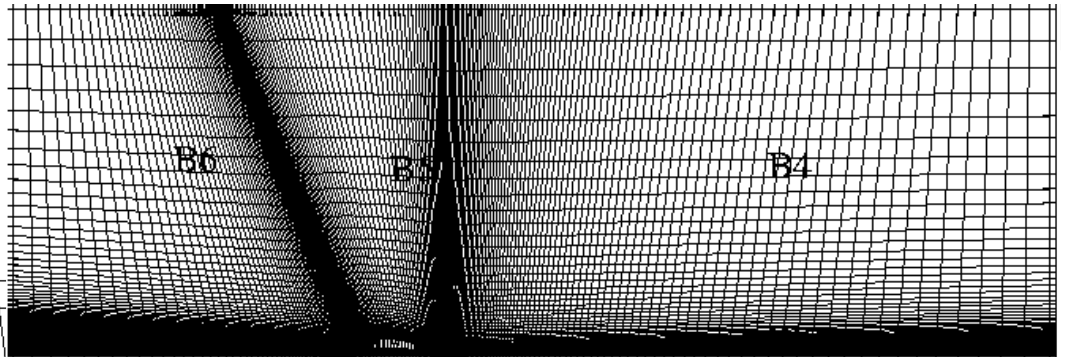
Previous Research

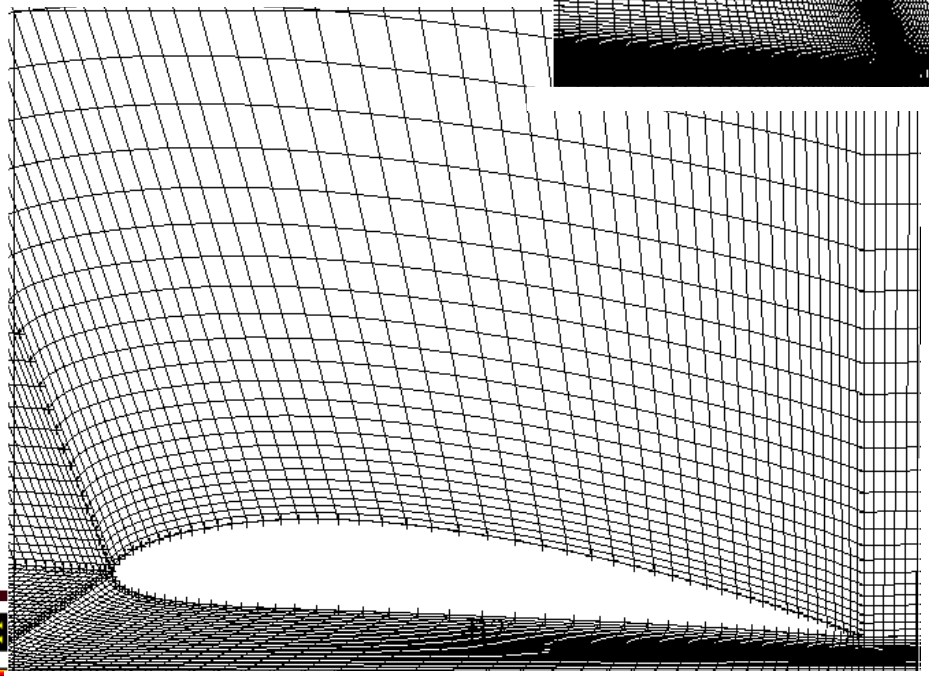
- Inviscid (ie panel methods) used extensively
- Analytical methods also used (many assumptions, limitations)
- Limited viscous CFD results
- Inappropriate boundary conditions often used
- Experimental results scarce / unreliable

Current Work

- Reynolds-Averaged Navier Stokes Equations (CFX & Fluent)
- Higher order discretising schemes
- RNG or Realizable k-ε turbulence model, standard wall functions

Test-cases

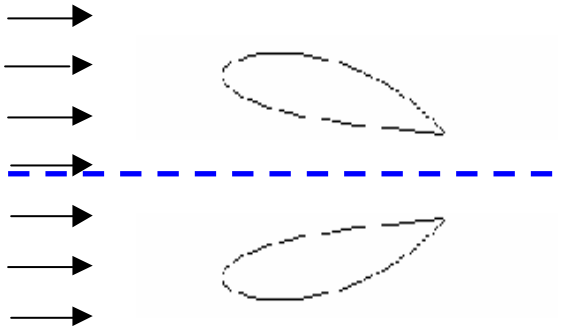




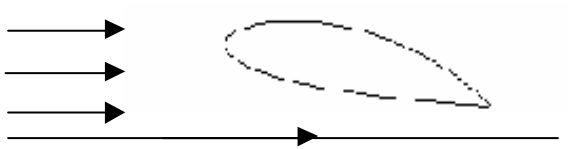
Testcases: (2D)

- NACA 4412 wing
- Angles of attack:
  - 1.2^{O}, 4^{O}, 6.4^{O}, 10^{O}, 12^{O}
- Reynolds Number:
  - 8,200,000
- Clearances (h/c):
  - 0.05, 0.10, 0.50, 1.00, free air

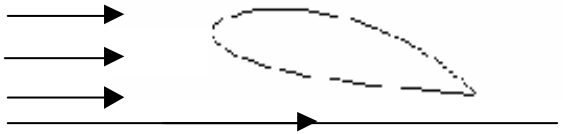
Boundary conditions



IMAGE



SLIP

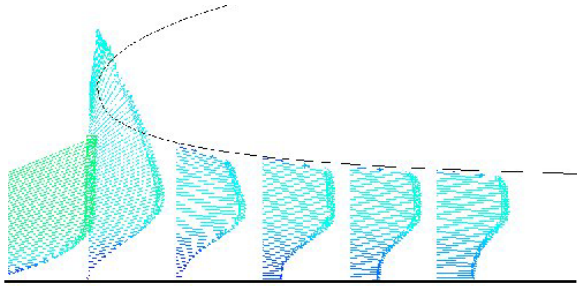


GROUND STATIONARY

GROUND MOVING

Results - velocity vectors

IMAGE



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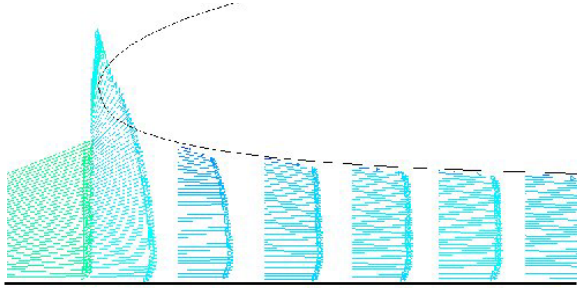
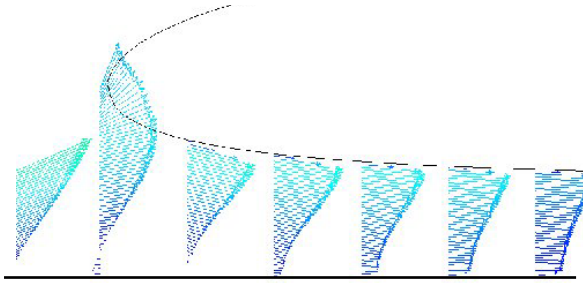
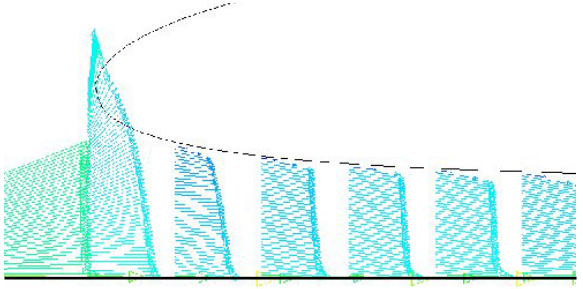


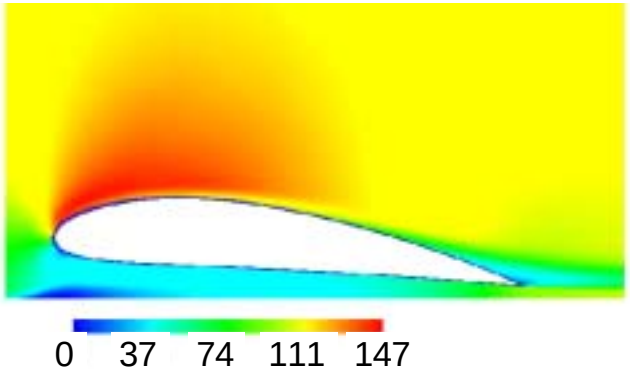
GROUND STATIONARY



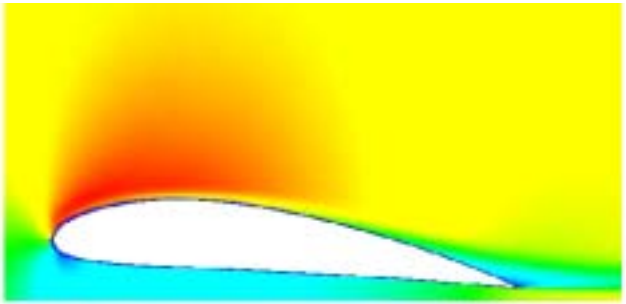
GROUND MOVING



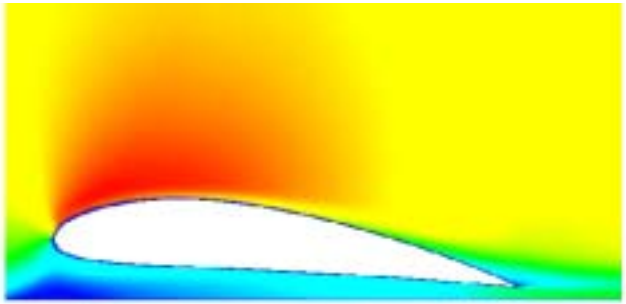
Results - velocity contours



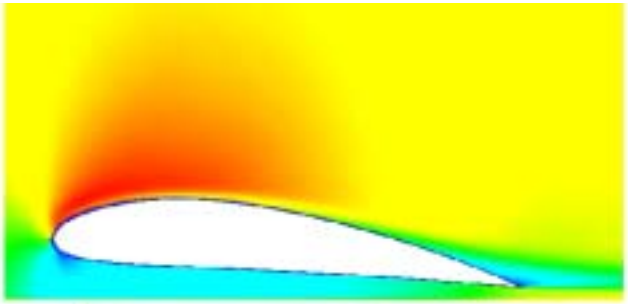
Image



Slip



Ground Stationary

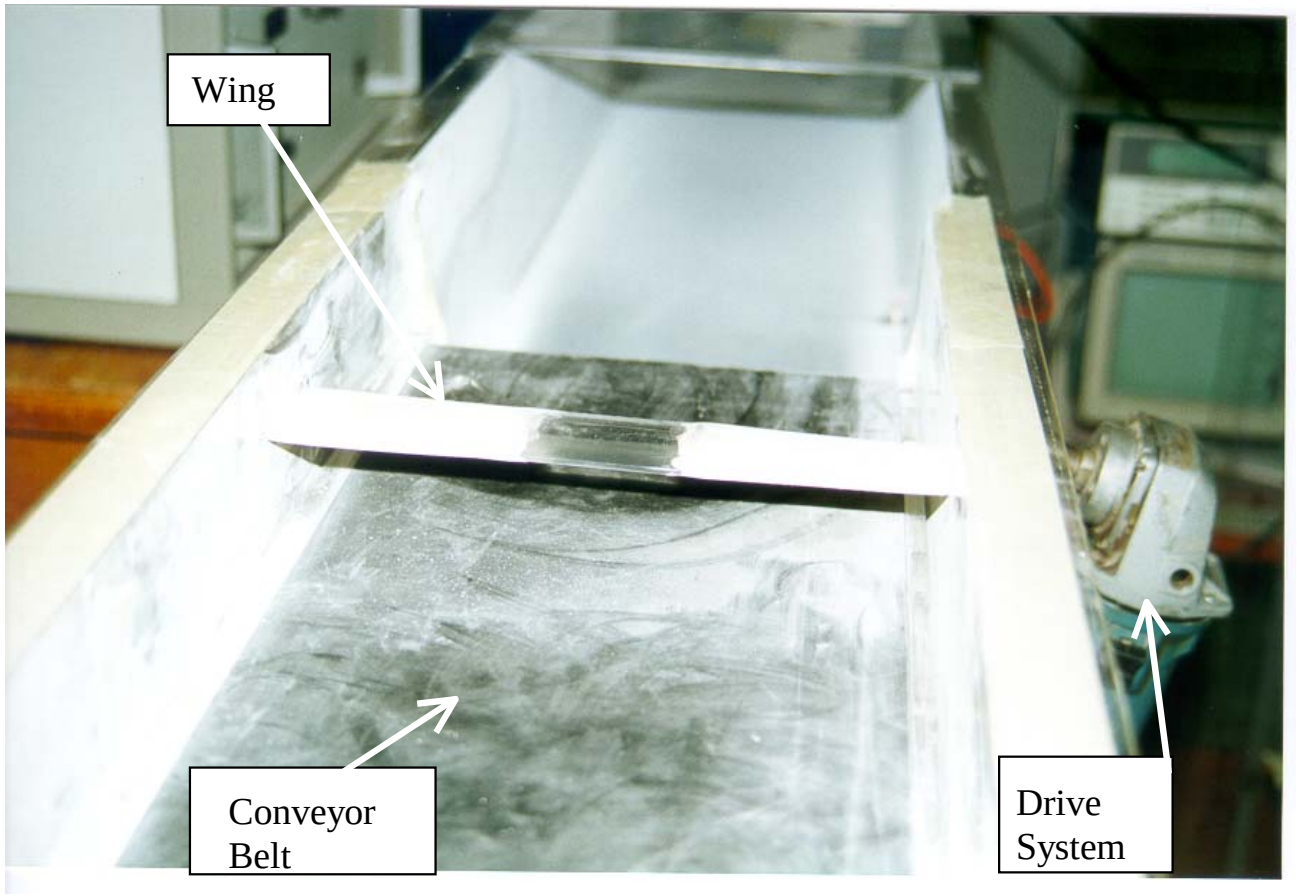


Ground Moving

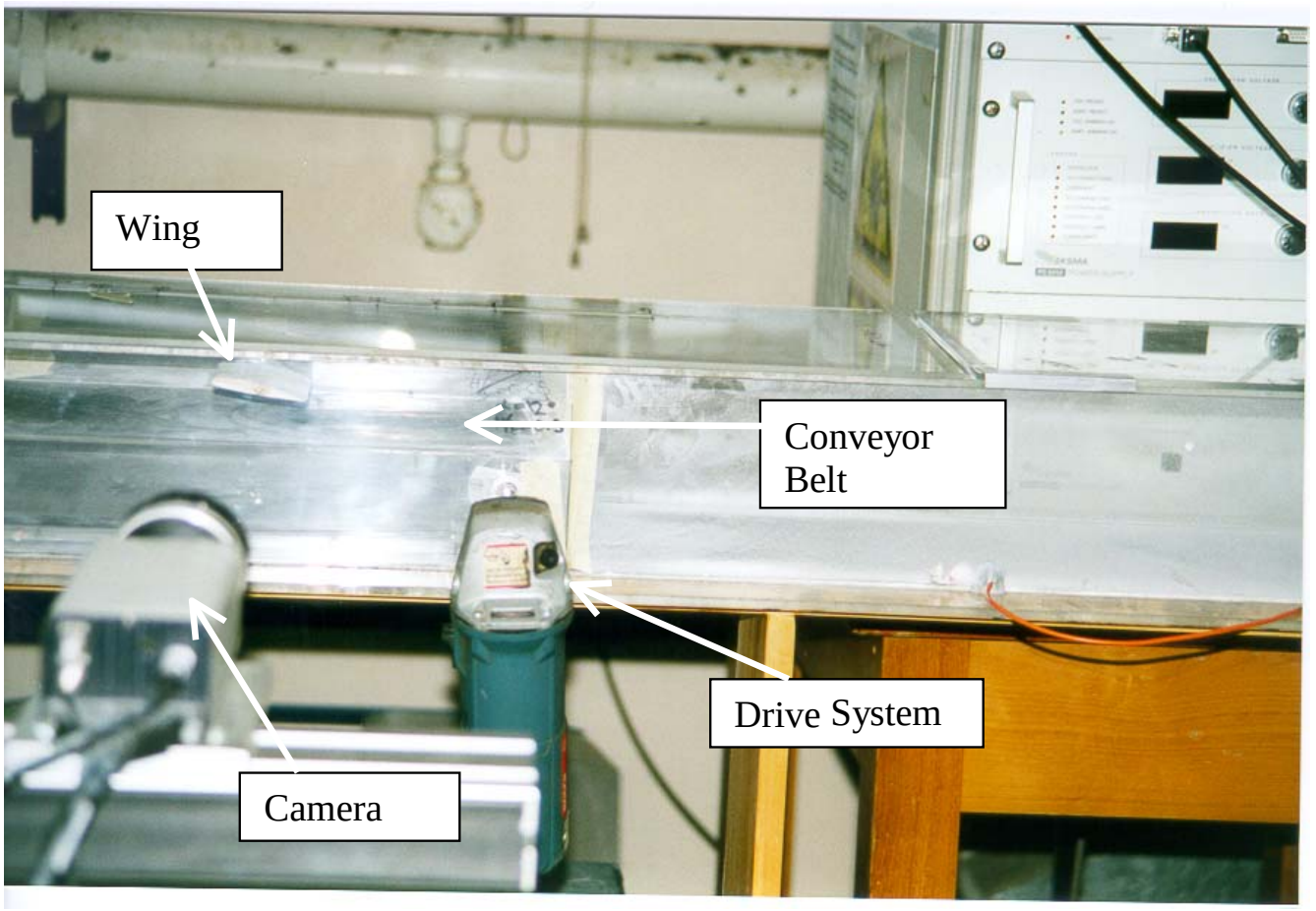
PIV Analysis

- Particle Image Velocimetry
  - Pairs of images allow particle movement to be determined
- Nd-Yag laser, 532 nm, 100mJ/pulse
- Particles of spherical latex (5μm)
- Initial investigation considered effect of moving ground

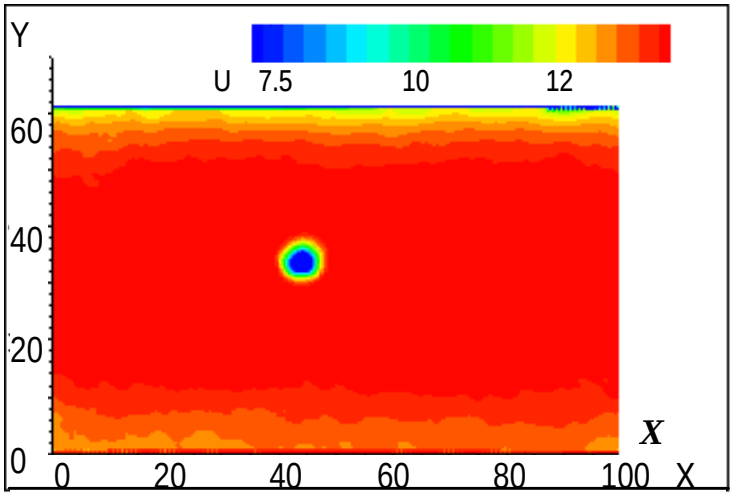
Moving Ground

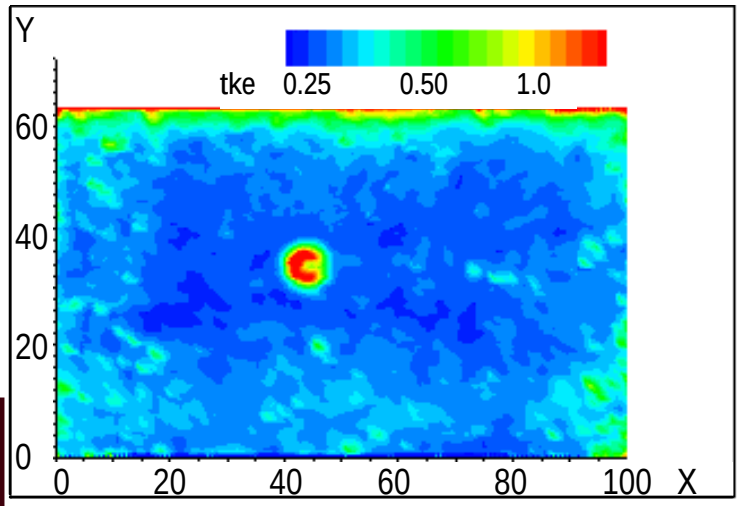


Moving Ground

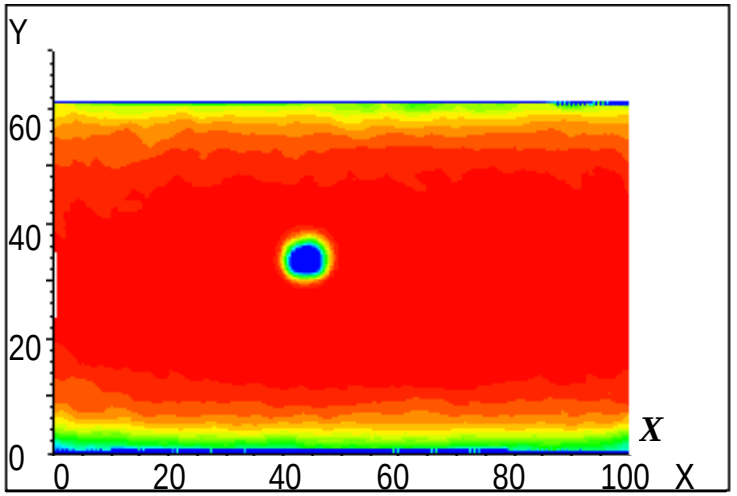


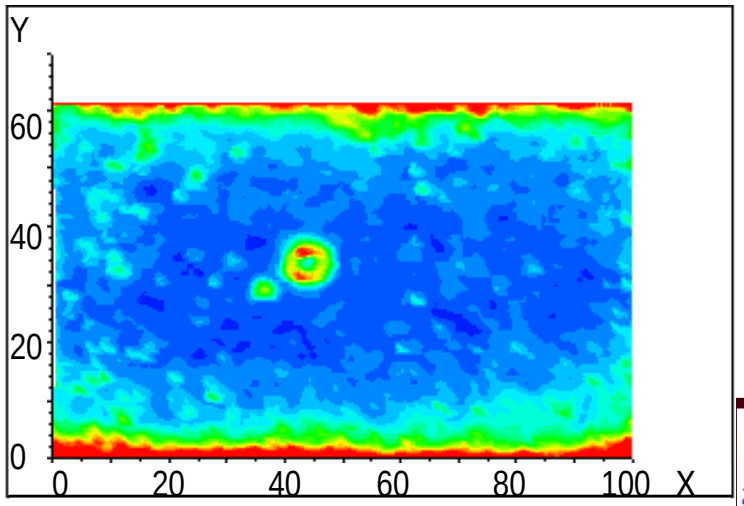
Moving Ground





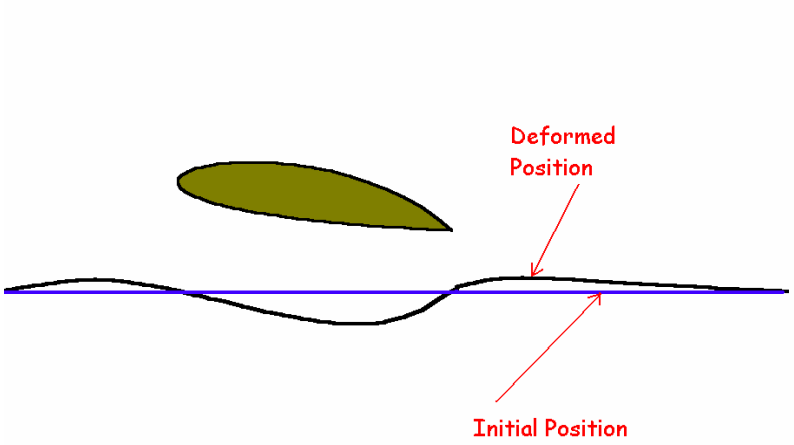
Stationary Ground





Free Surface Effects

- Most WIG craft operate over water
- Lifting bodies produce a high pressure on their lower surface
- "Does this pressure change the surface shape, and does this affect the aerodynamic characteristics of the body?"



Free Surface Effects

- Froude number

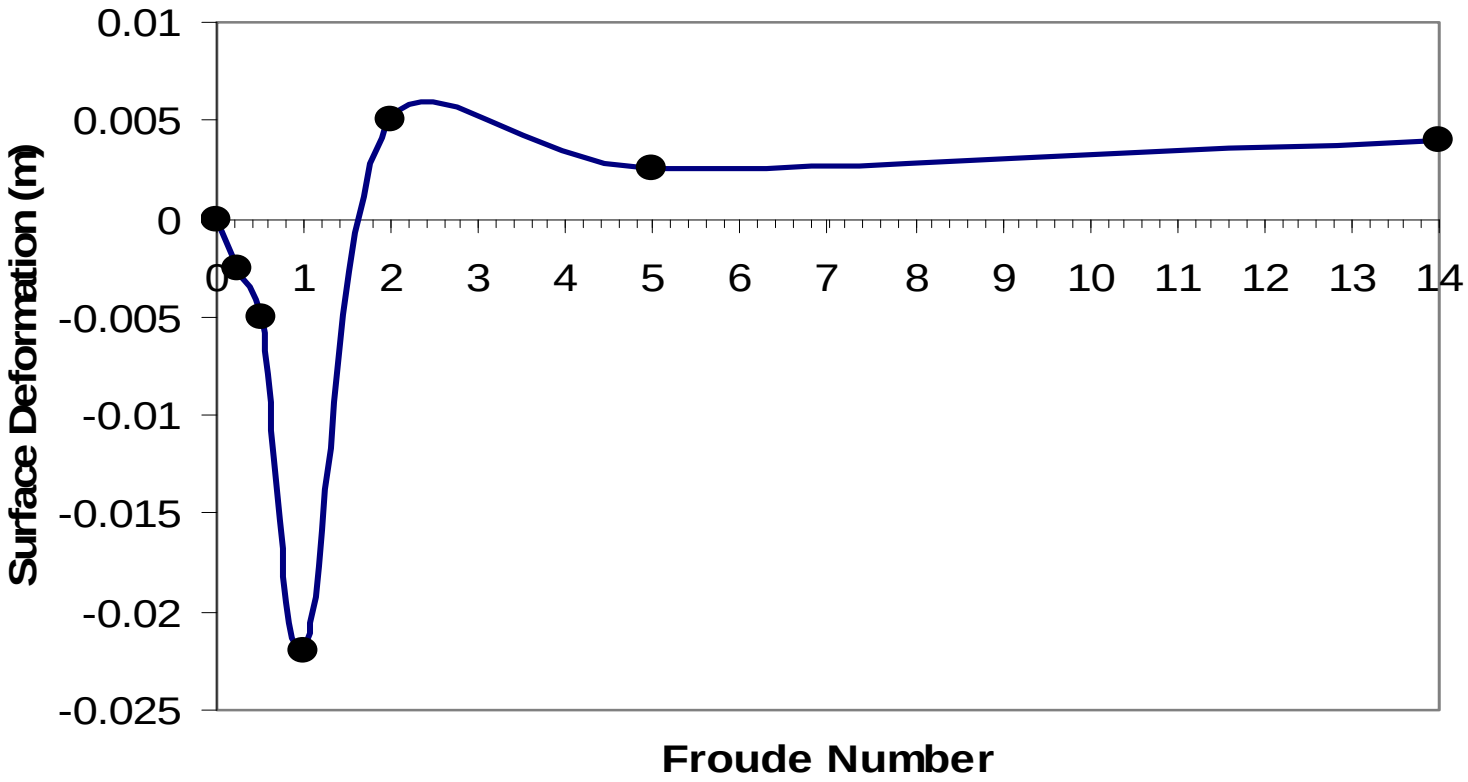
$$Fr = \frac{U}{\sqrt{gL}}$$

- Reynolds number:

$$\mathrm{Re} = \frac{\rho U c}{\mu}$$

- CFD model (VOF) overcomes this issue

Max Surface Deformation Beneath Airfoil vs Froude Number



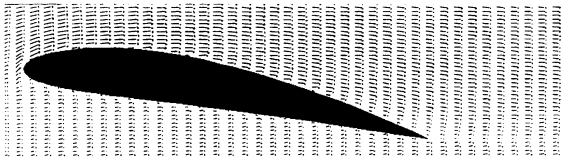
Importance of Viscous Effects

- Panel methods (inviscid) frequently used for ground effect
- Real flow situations – will viscous effects greatly affect results?

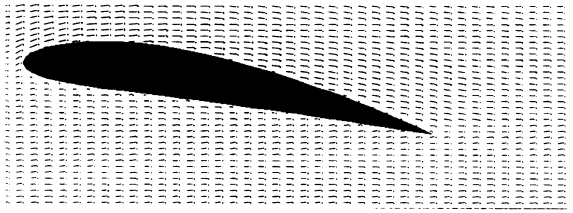
Results: Three-Dimensional

- NACA 4412 wing, AR=6
- Angles of attack:
  - 1.2^{O}, 4^{O}, 6.4^{O}, 10^{O}
- Reynolds Number:
  - 8,200,000
- Clearances (h/c):
  - 0.05, 0.10, 0.50, 1.00, free air

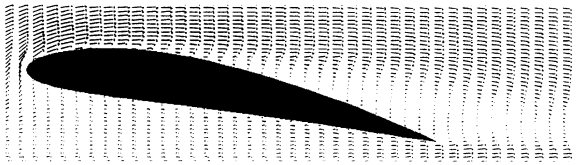
Effect of Ground on Separation



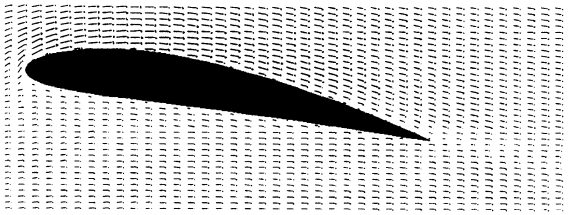
Wingtip Plane



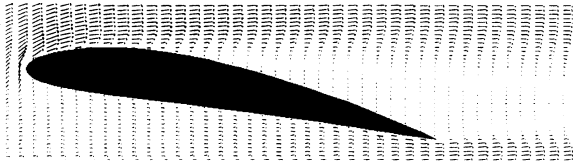
Wingtip Plane



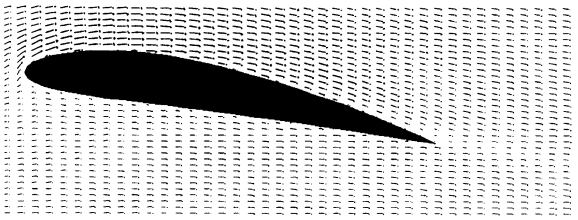
Mid-Semispan Plane



Mid-Semispan Plane



Symmetry Plane

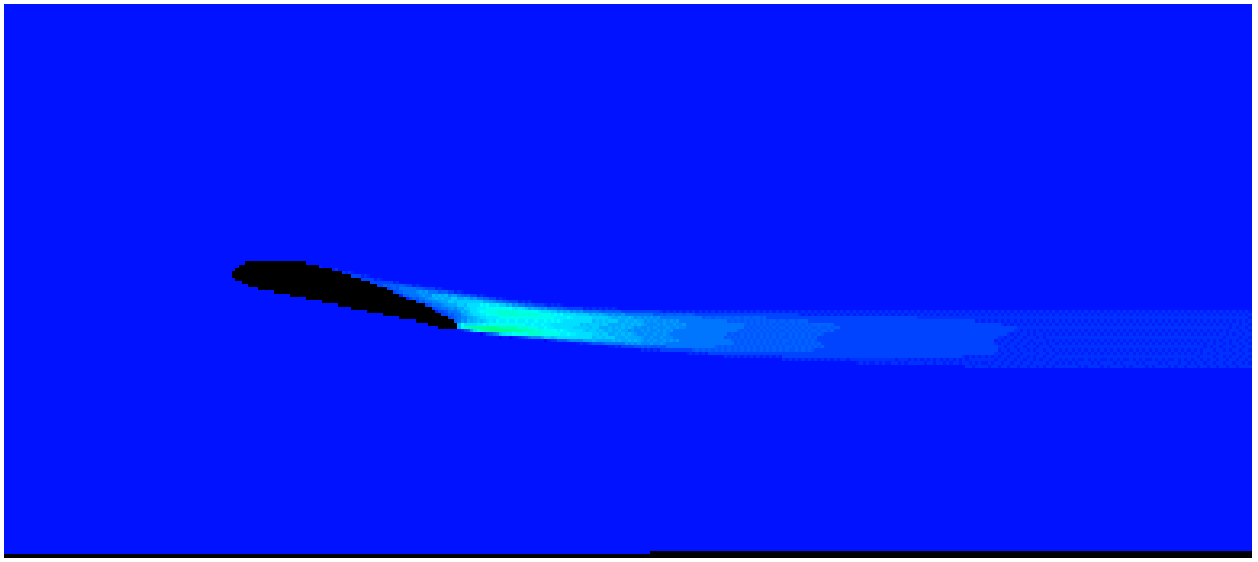


Symmetry Plane

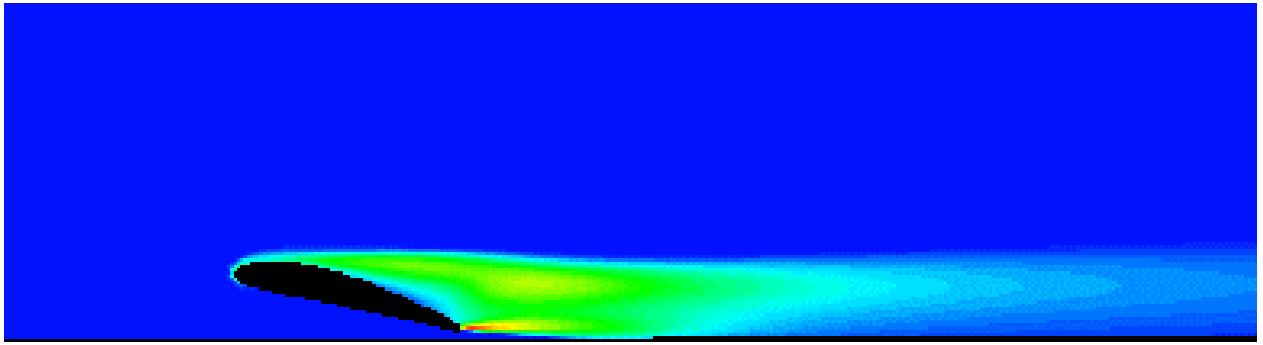
h/c=0.05

h/c=free air

Effect of Ground on Wake

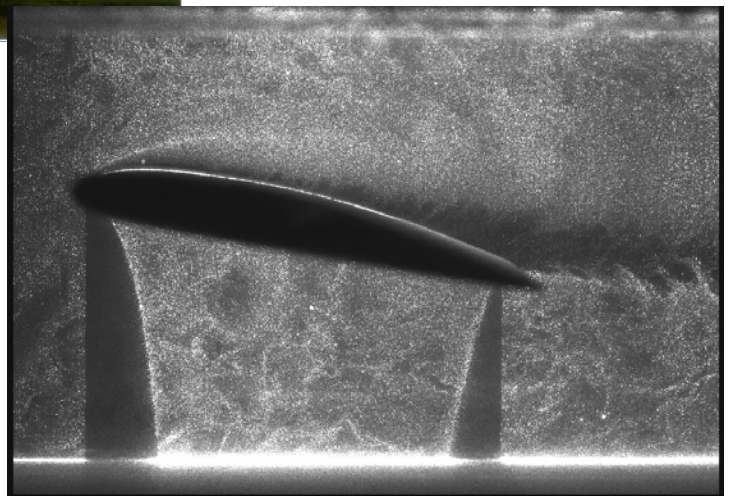


h/c=1.00

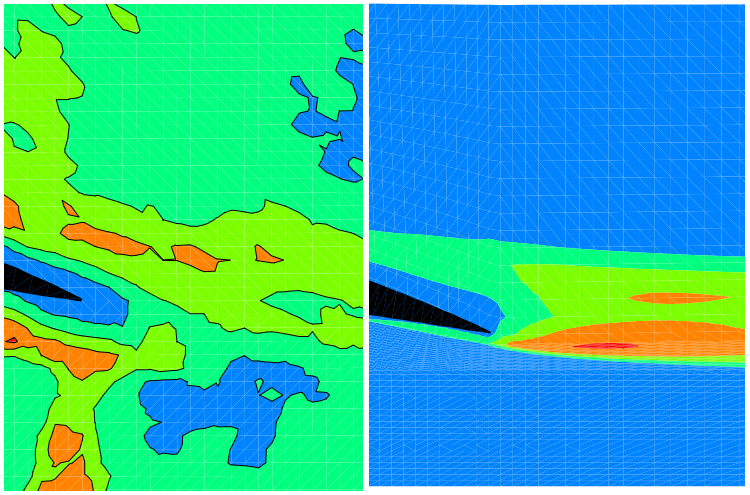


h/c=0.05

Moving Ground - wing

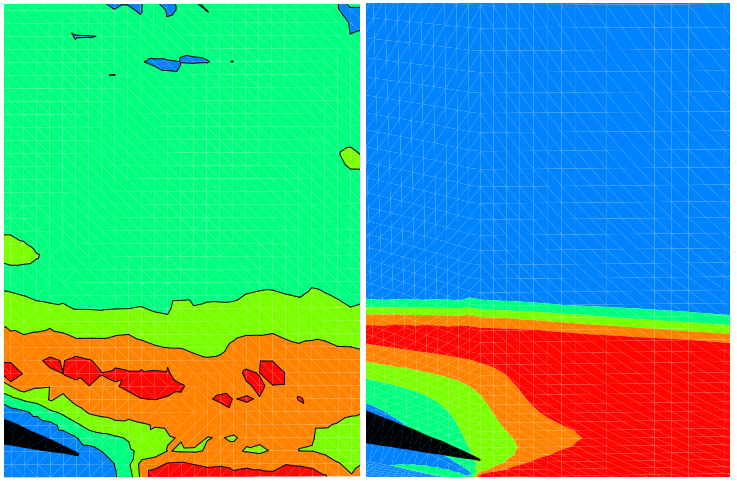


PIV Results – Flow separation



PIV tke CFD tke

NACA 4412 wing at 12º, h/c=0.45, trailing edge region



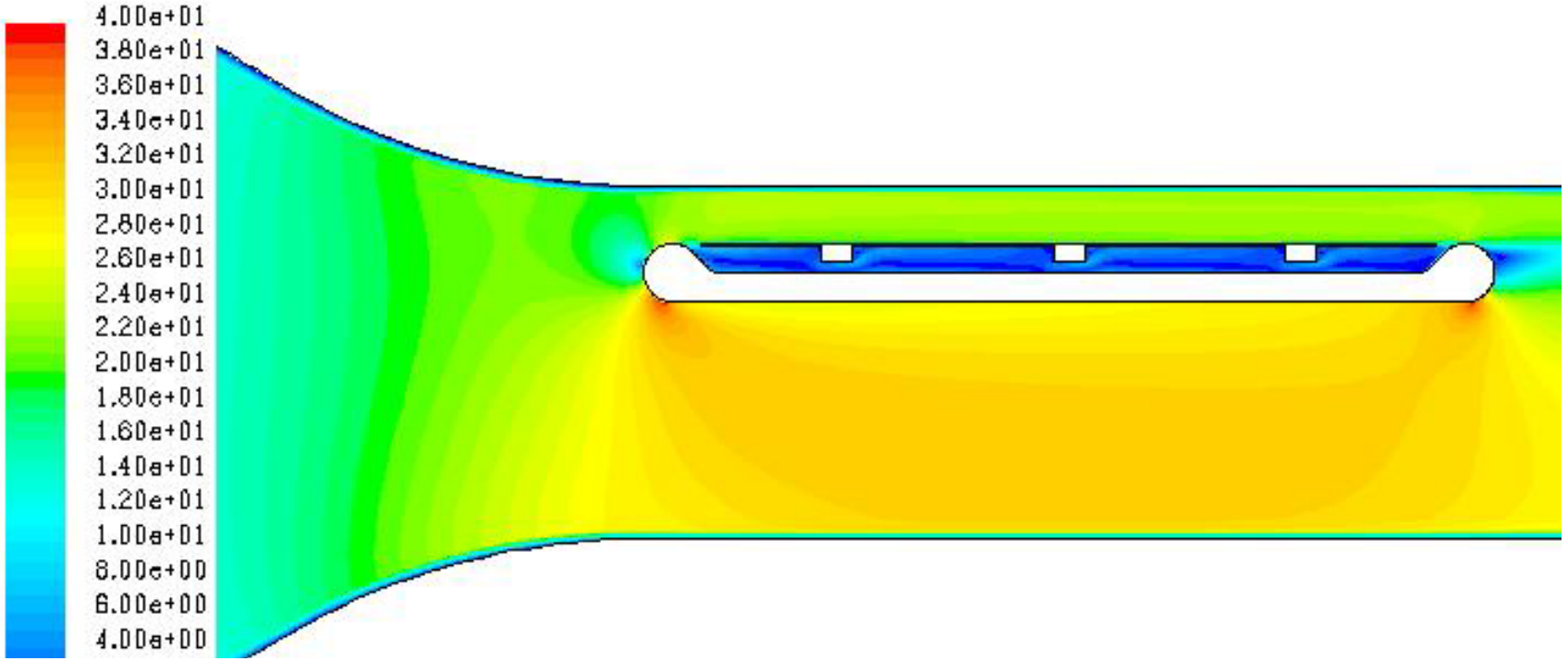
PIV tke CFD tke

NACA 4412 wing at 12º, h/c=0.05, trailing edge region

Moving Ground

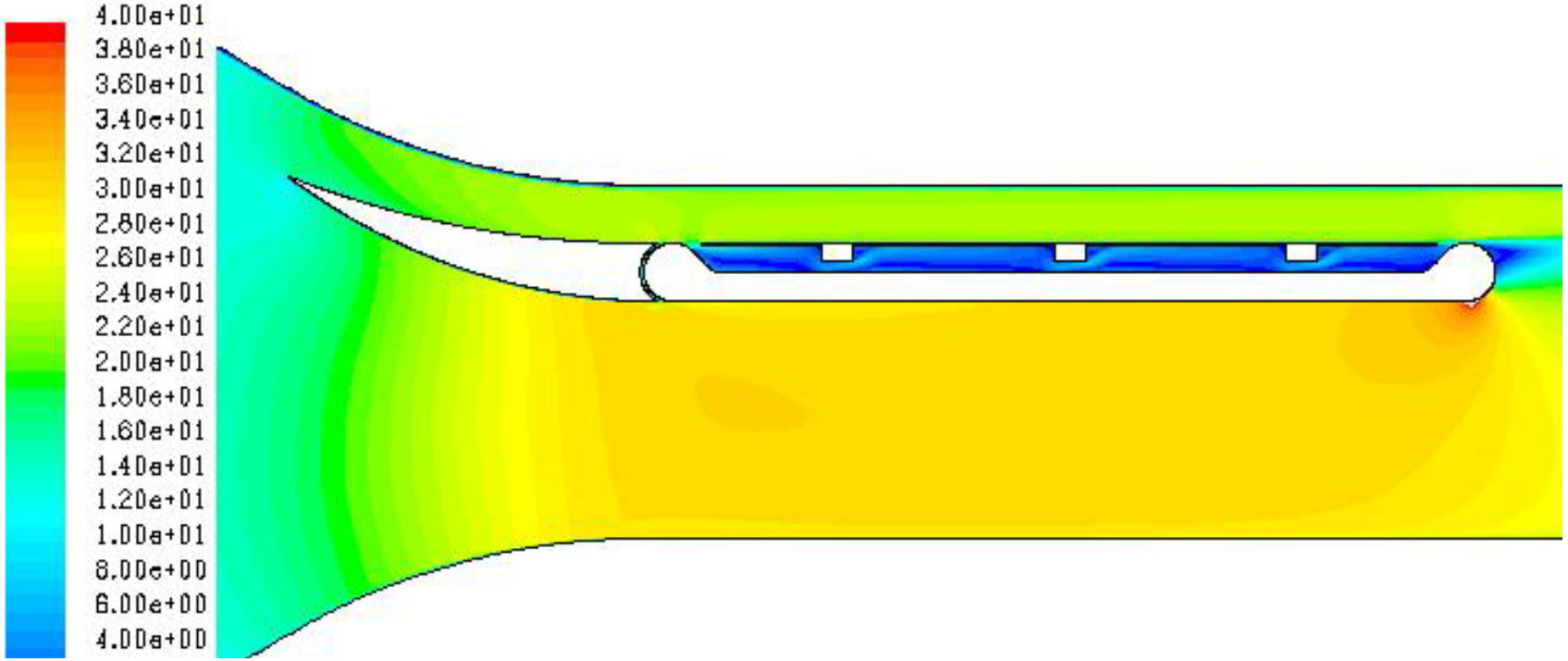
- Implementation of moving ground into 3ft x 4ft wind tunnel
  - Belt speed of 60m/s
  - Extensive CFD analysis to determine best configuration
  - Uniform velocity profile
  - Uniform turbulence profile

Moving Ground - suspended



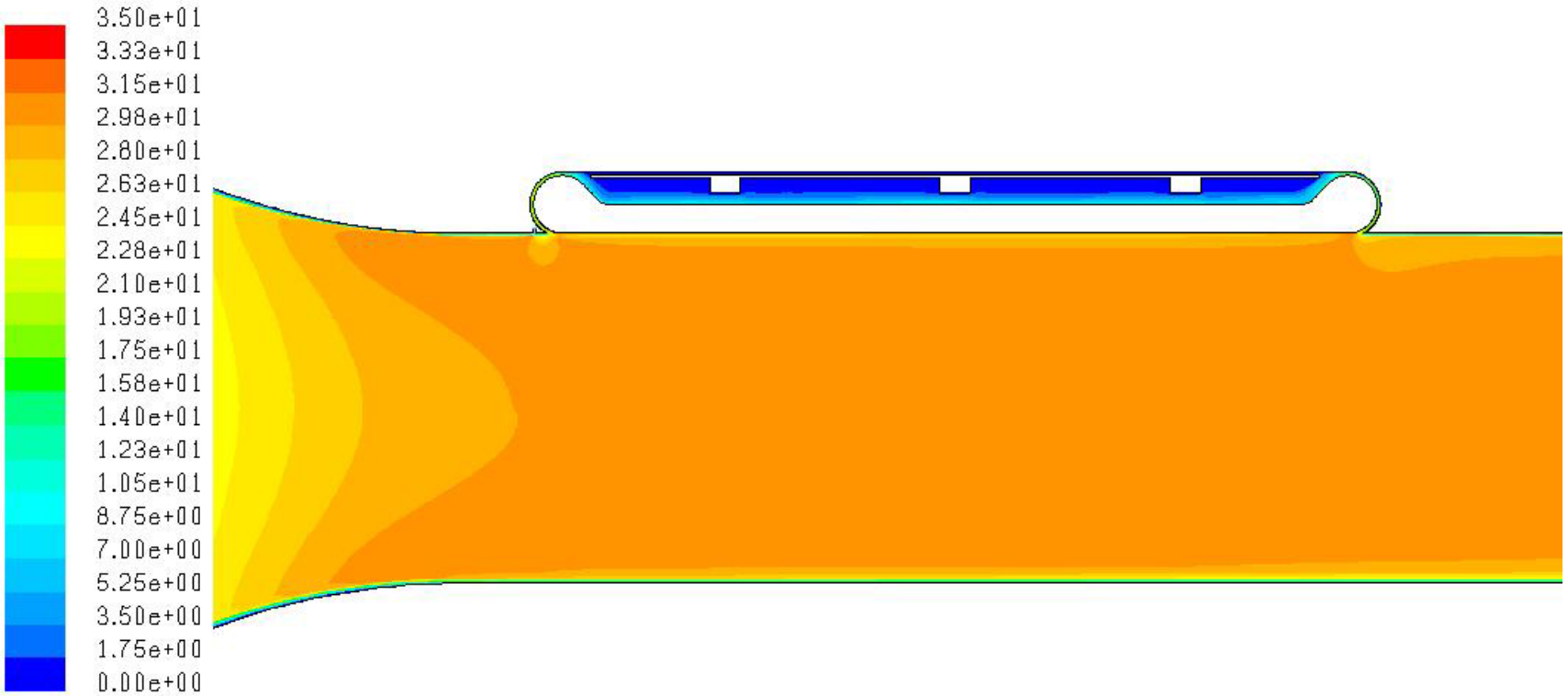
Velocity Contours

Moving Ground – suspended, leadup



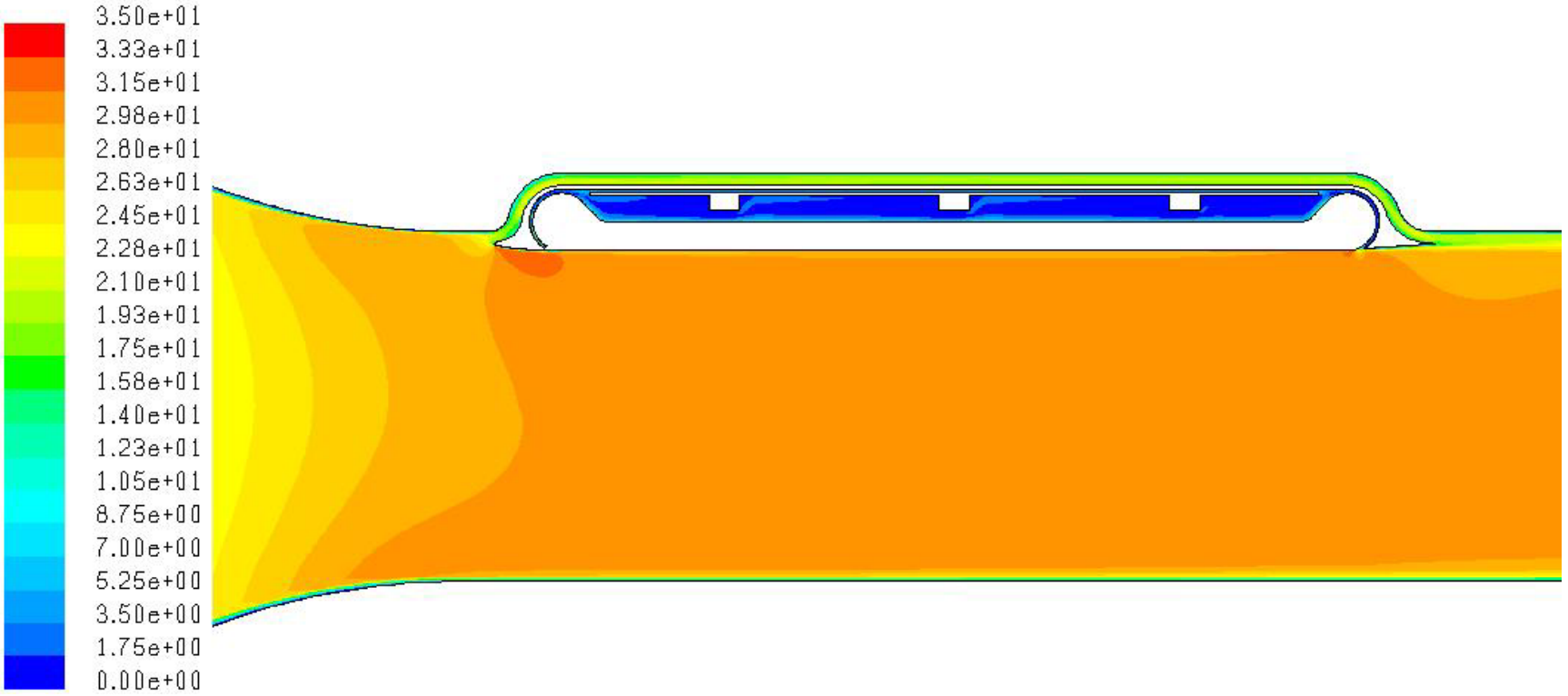
Velocity Contours

Moving Ground, in line



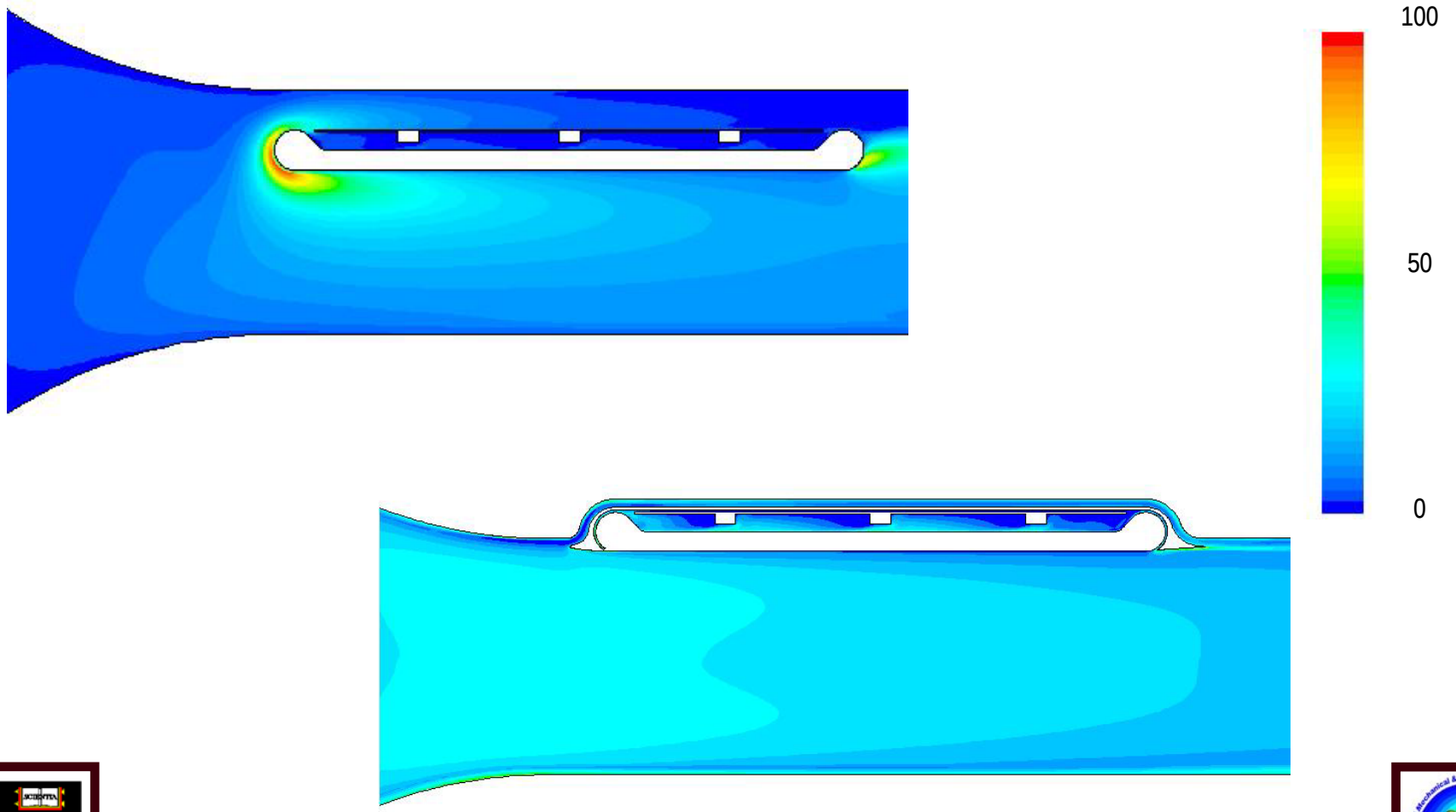
Velocity Contours

Moving Ground, offset, leadup, suction

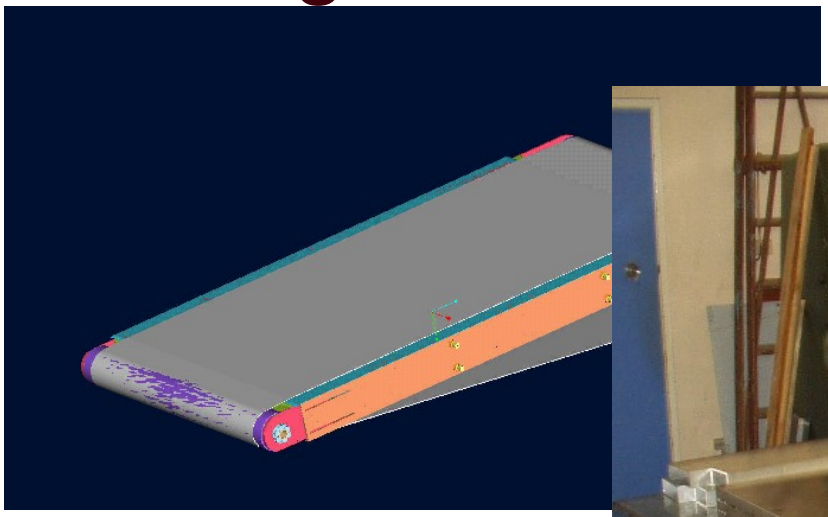


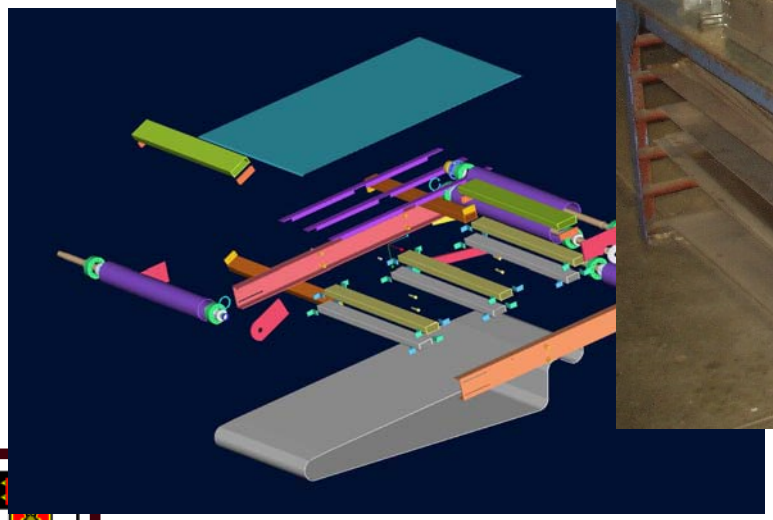
Velocity Contours

Moving Ground - turbulence



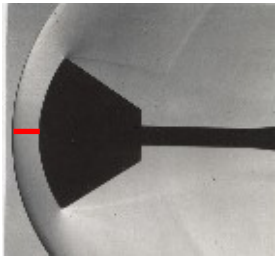
Moving Ground – design & construction

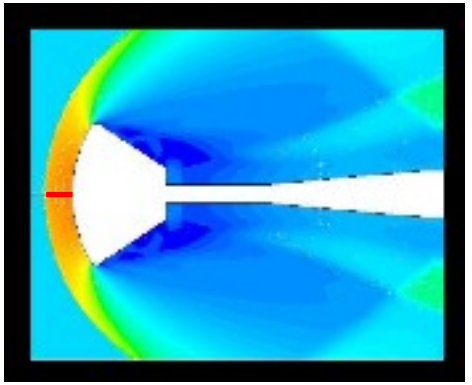




Supersonic Ground Effect

Shock Wave
Validation Cases





Stationary Ground
Supersonic Ground Effect
(Experimental)

Stationary Ground
Supersonic Ground Effect
(CFD)

Moving Ground
Supersonic Ground Effect
(CFD)

Integration of CFD & Experiments