PAB3D simulations for 3rd AIAA Drag Prediction Workshop

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Presentation Outline

- Introduction
- Governing Equations
- Results and Discussion
- Summary

Introduction

- Case 1 DLR-F6-WB and FX2B configurations
- Code PAB3D structured multi-block
- Grid Boeing grids
  (coarse, medium, medium-fine, & fine)
- Mach = 0.75, Re = 5 million

Methodology
PAB3D CFD Code

- 3-D RANS Upwind Code
- Multi-block structured with general patching
- Parallel computing using MPI
- Mesh sequencing
- Low memory requirement
- Graphical user interface (GUI) capabilities
- Linear two-equation k-ε models
- Suite of algebraic Reynolds stress models
- LES & PANS

Governing Equations

Reynolds (Favre) Averaged Navier-Stokes

RANS

Continuity
$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_i}{\partial x_i} = 0$$

Momentum
$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial (\rho u_i u_j + p\delta_{ij})}{\partial x_j} = \frac{\partial (\tau_{ij} - \rho \overline{u_i u_j})}{\partial x_j}$$

Energy
$$\frac{\partial \rho e_0}{\partial t} + \frac{\partial (\rho e_0 u_i + p u_i)}{\partial x_i} = \frac{\partial (\tau_{ij} u_j - \rho \overline{u_i u_j} u_j)}{\partial x_i}$$
$$- \frac{\partial (q_i - C_P \rho \overline{u_i t})}{\partial x_i} - \frac{\rho \overline{u_i u_j u_j}}{2}$$

Reynolds Stress

Governing Equations

Two Equation K- ε Model

$$\frac{\partial \rho k}{\partial t} + \frac{\partial \rho u_i k}{\partial x_i} = -\overline{\rho u_i u_j}\frac{\partial u_j}{\partial x_i} + \frac{\partial}{\partial x_i}\left[\mu_l + \frac{c_\mu k^2}{\sigma_k \varepsilon}\frac{\partial k}{\partial x_i}\right] - \rho\varepsilon(1. + M_\tau^2)$$

$$\frac{\partial \rho \varepsilon}{\partial t} + \frac{\partial \rho u_i \varepsilon}{\partial x_i} = -C_{\varepsilon 1}\overline{\rho u_i u_j}\frac{\partial u_j}{\partial x_i}\frac{\varepsilon}{k} + \frac{\partial}{\partial x_i}\left[\mu_l + \frac{c_\mu k^2}{\sigma_\varepsilon \varepsilon}\frac{\partial \varepsilon}{\partial x_i}\right] - f_2 \tilde{C}_{\varepsilon 2}\rho\frac{\varepsilon}{k}\left[\varepsilon - \nu_l\left(\frac{\partial \sqrt{k}}{\partial n}\right)^2\right]$$

Reynolds Stress

$$C_\mu = .09,\ C_{\varepsilon 1} = 1.44,\ and\ \tilde{C}_{\varepsilon 2} = C_{\varepsilon 2} = 1.92$$

Turbulent viscosity: $$\upsilon_t^{RANS} = f_\mu \rho\, C_\mu \frac{k^2}{\varepsilon}$$

Governing Equations

Turbulent Stresses

Two Equation K- ε Linear Model
(NASA CR-4702, December 1995)

$$-\overline{u_i u_j} = 2\upsilon_t S_{ij} - \frac{2}{3}\delta_{ij} k$$

Shih, Zhu, & Lumley (SZL) Nonlinear Model
NASA TM-106644, August 1994

$$-\overline{u_i u_j} = 2\upsilon_t S_{ij} - \frac{2}{3}\delta_{ij} k + 2\beta \frac{K^3}{\varepsilon^2}(W_{ik}\bar{S}_{kj} - \bar{S}_{ik}W_{kj})$$

Girimaji Nonlinear Model
ICASE 95-82, December 1995

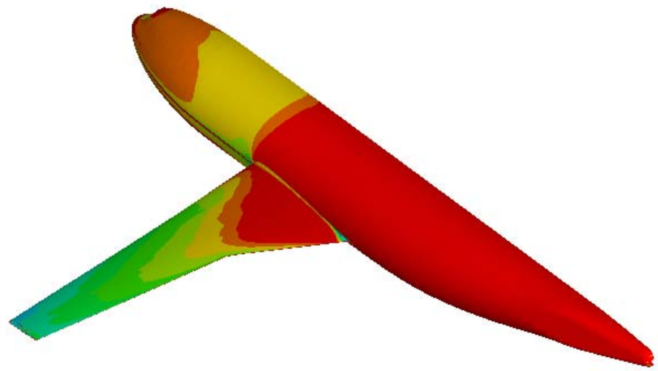
$$-\overline{u_i u_j} = 2\upsilon_t S_{ij} - \frac{2}{3}\delta_{ij} k + 2C_\mu^* \frac{K^3}{\varepsilon^2}[-G_2(W_{ik}S_{kj} - S_{ik}W_{kj}) + G_3(S_{ik}S_{kj} - \frac{1}{3}S_{mn}S_{mn}\delta_{ij})]$$

where

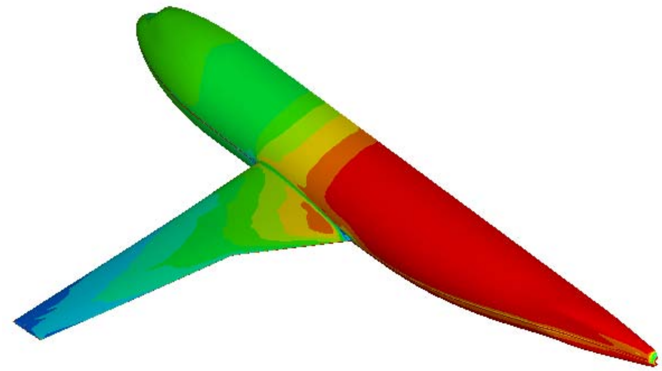
$$W_{ij} = \frac{1}{2}(\frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i}) \ \& \ \bar{S}_{ij} = S_{ij} - \frac{1}{3}S_{kk}\delta_{ij}$$

Computational Grids, Y+

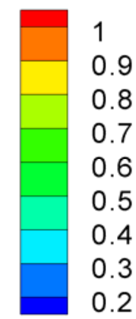
BOEING H-Grids generated by : T.J. Kao and N. J. Yu for Ed. Tinoco

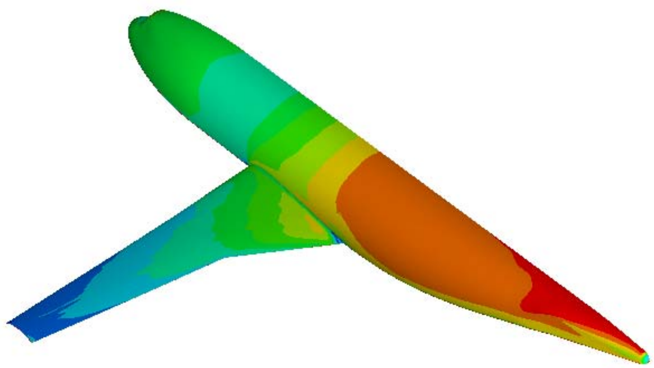


Coarse Grid
26 Blocks & 2298880 Cells

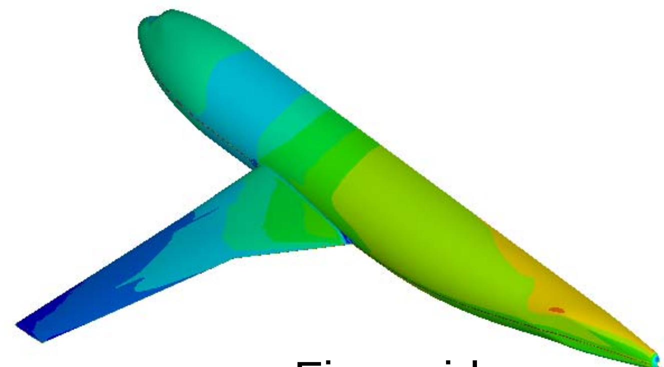


Medium grid
38 Blocks & 8080896 Cells





Medium-fine grid
26 Blocks & 15856320 Cells

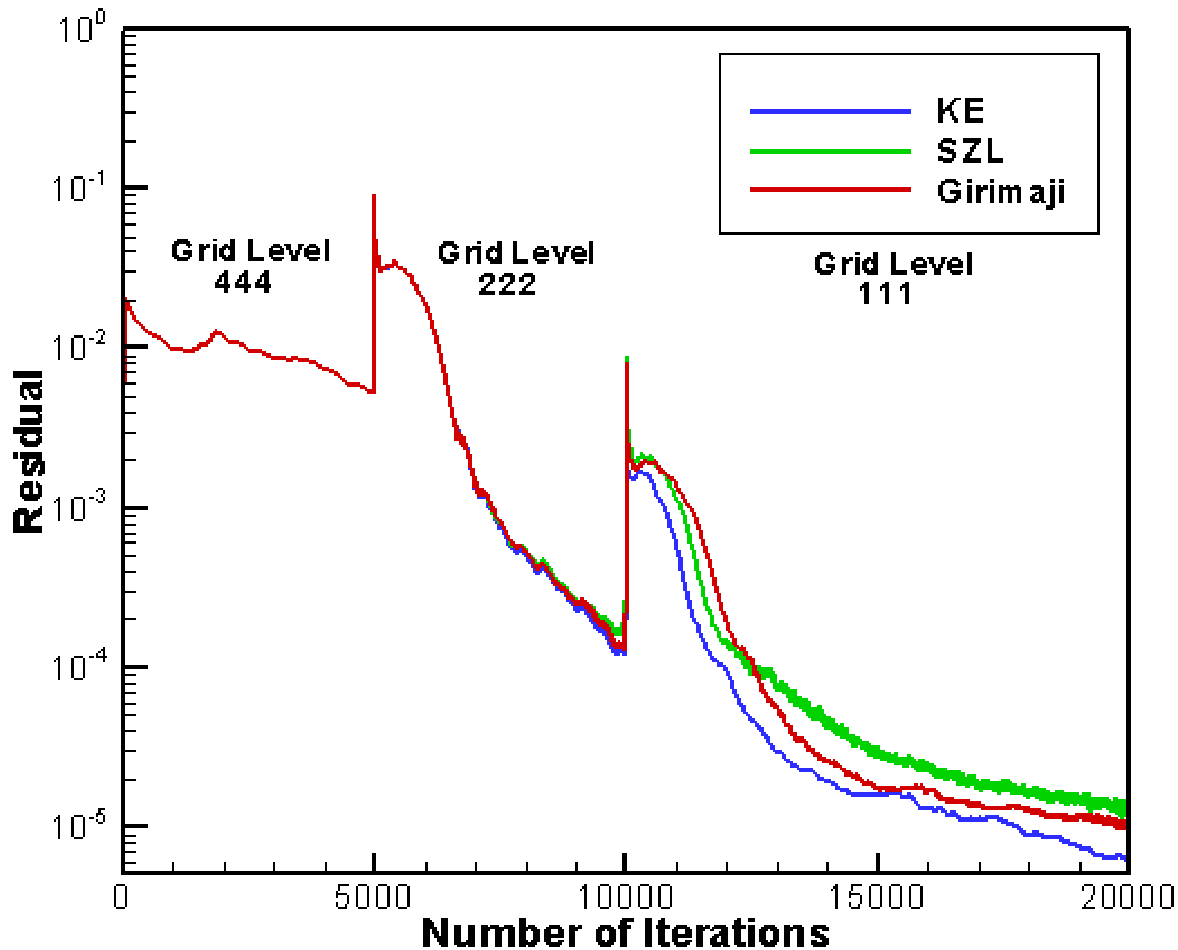


Fine grid
57 Blocks & 27185664 Cells

Case1, F6-WB & FX2B
Mach 0.75, $Re=5*10^6$

Turbulence Model/ Grid	Coarse	Medium	Medium fine	Fine
k ε	X	X	X	X
SZL	X	X	X	X
Girimaji	X	X	X	X

Convergence History



Typical CPU Timings

Grid	Blocks	# of Cell * 10^6	Processors	Wall Time	Wall Time /grid point 10^{-6} sec
Coarse	26	2.3 *10^6	24	02:02	0.4196472
Medium	38	8.0	38	5.42	0.3032175
Medium fine	49	15.8	46	8:33	0.2713972
Fine	58	27.2	56	17:45	0.2537843

Grid Convergence, Girimaji

Mach =0.75, Re=5*10^6, AOA=0.0

Grid	CL	CD	CM_TOT
Coarse	0.496	0.03224	-0.1227
Medium	0.487	0.02833	-0.1362
Medium fine	0.485	0.02743	-0.1377
Fine	0.485	0.02728	-0.1378

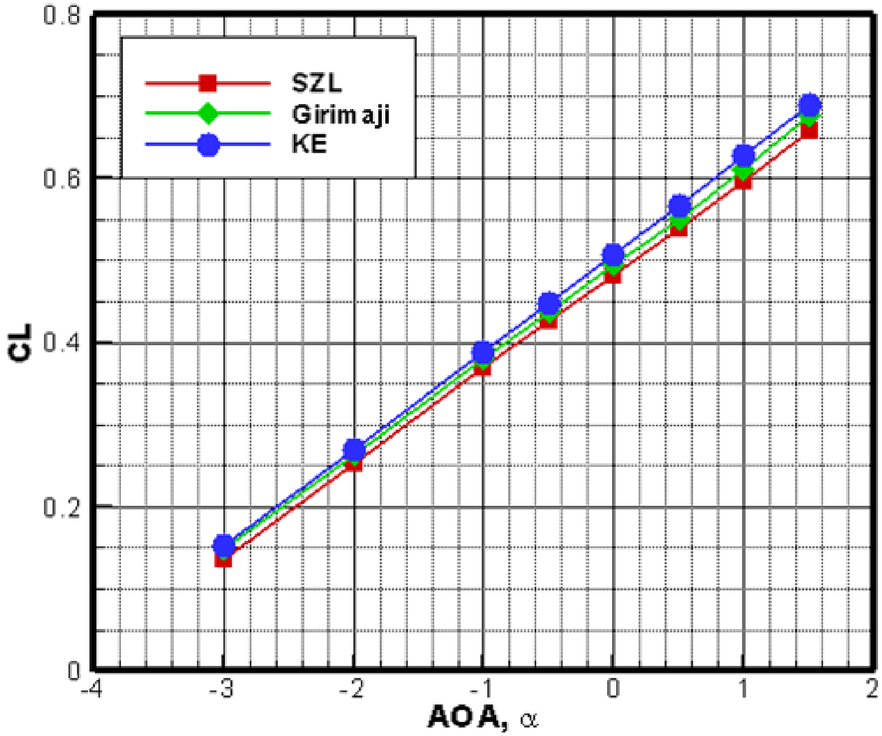
Turbulence Model Effect

Mach =0.75, Re=5*10^6, AOA=0.0

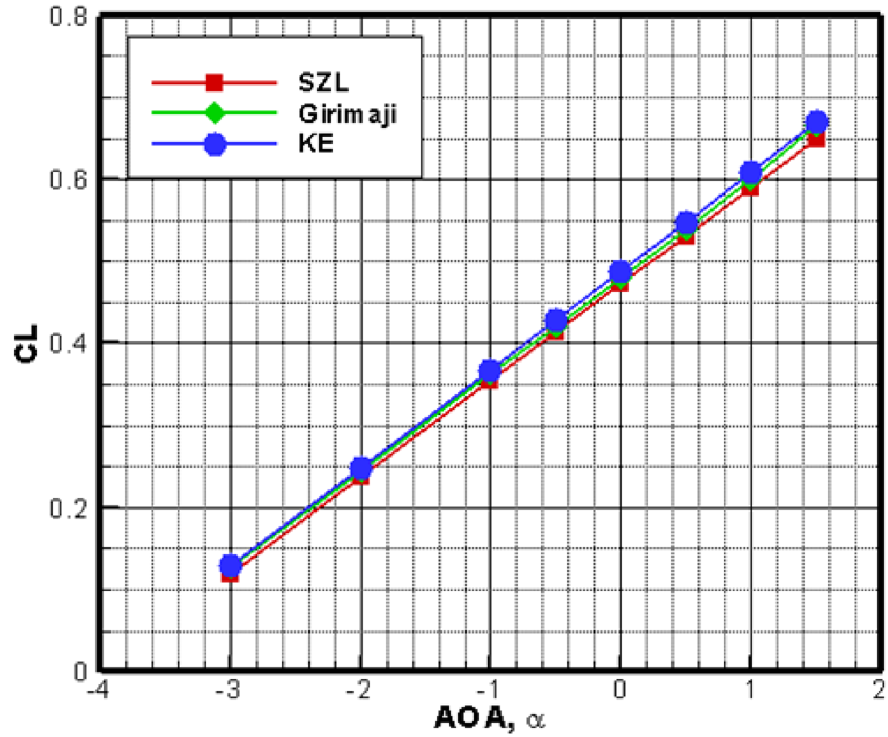
Grid	CL	CD	CM_TOT
KE	0.499	0.03086	-0.1427
SZL	0.477	0.02630	-0.1324
Girimaji	0.485	0.02728	-0.1378

Lift Curve on Medium Grids

Mach =0.75, Re=5*10^6



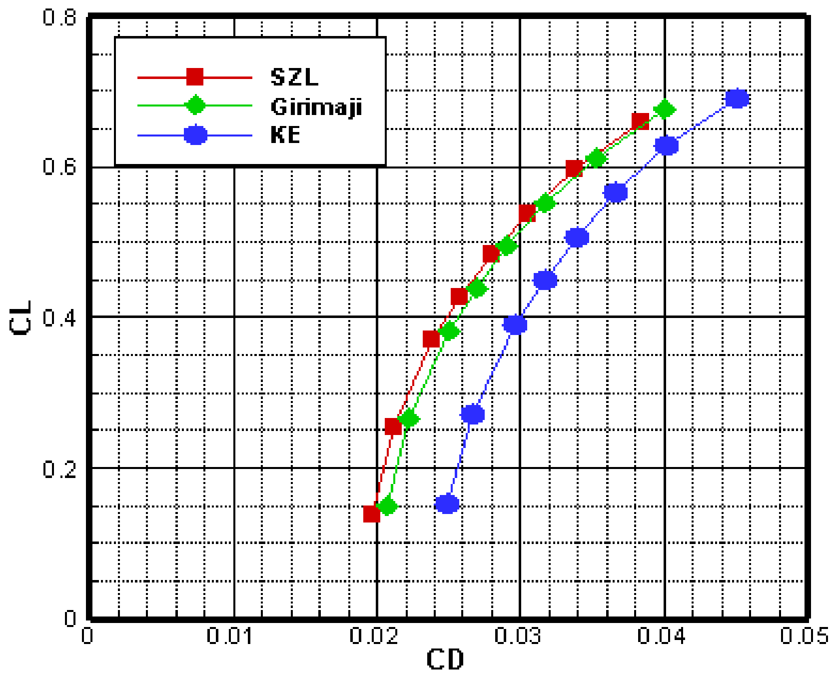
F6-WB



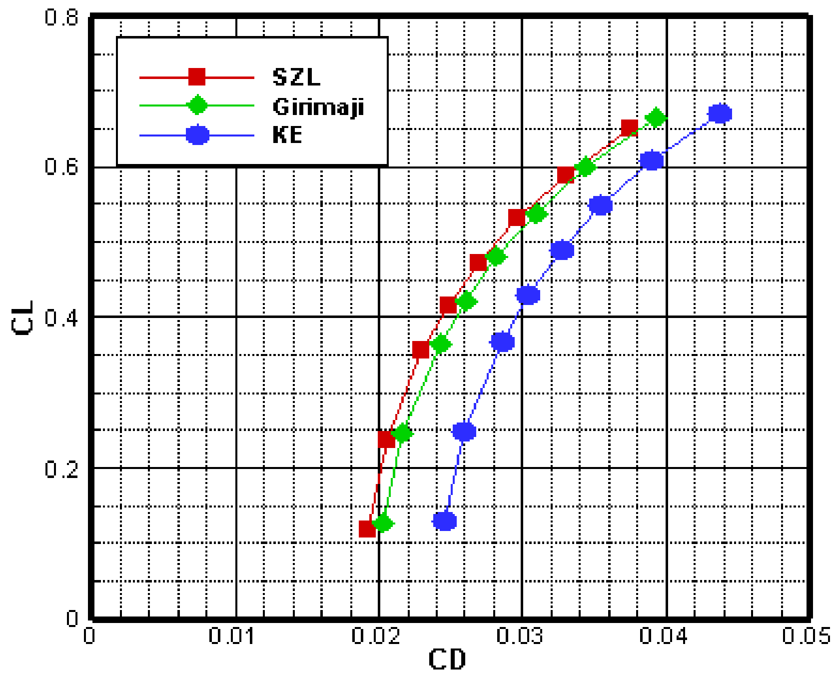
FX2B

Drag Polar on Medium Grids

Mach =0.75, Re=5*10^6

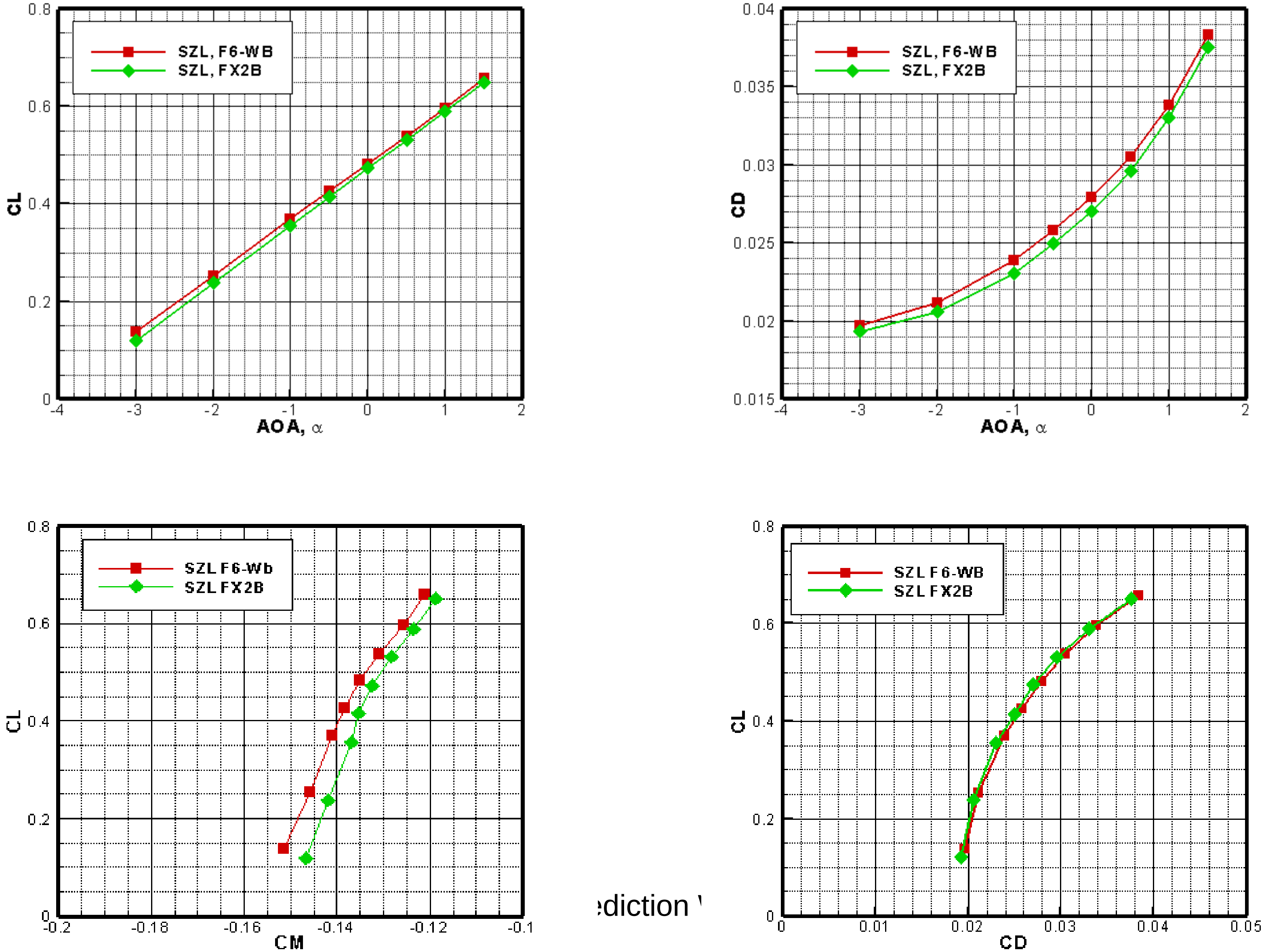


F6-WB



FX2B

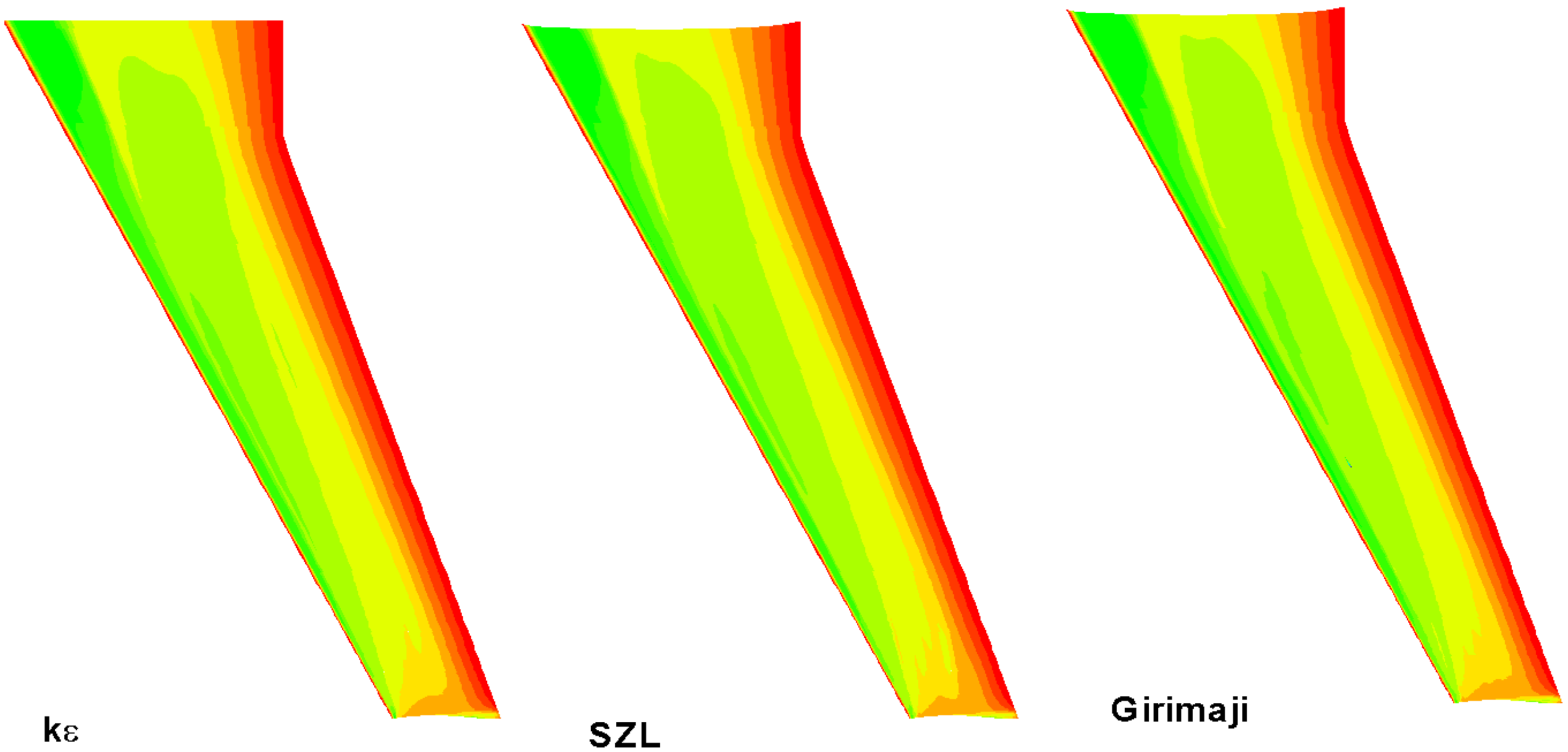
F6_WB and FX2B Comparison, SZL



:diction \

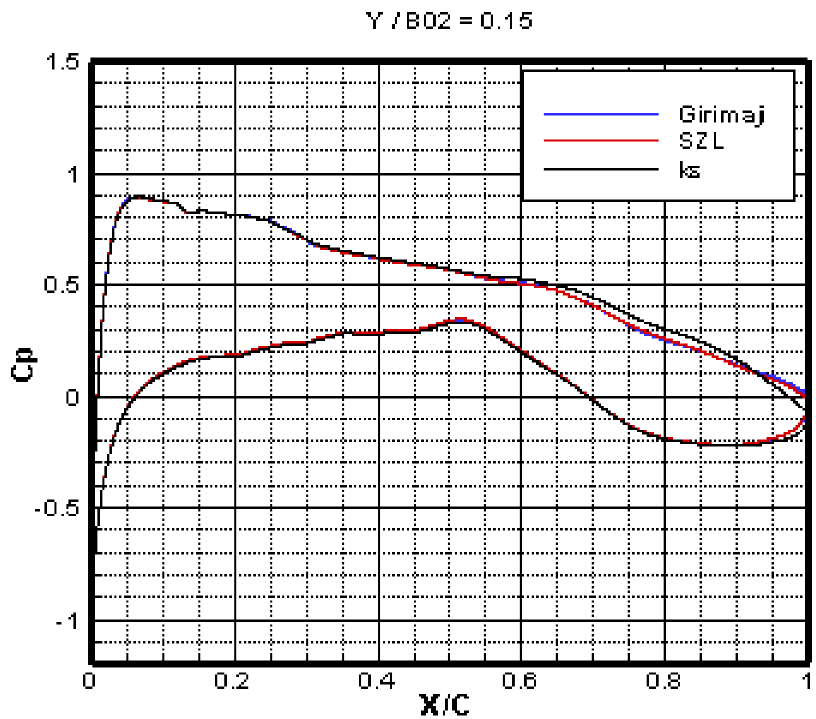
Coefficient of Pressure

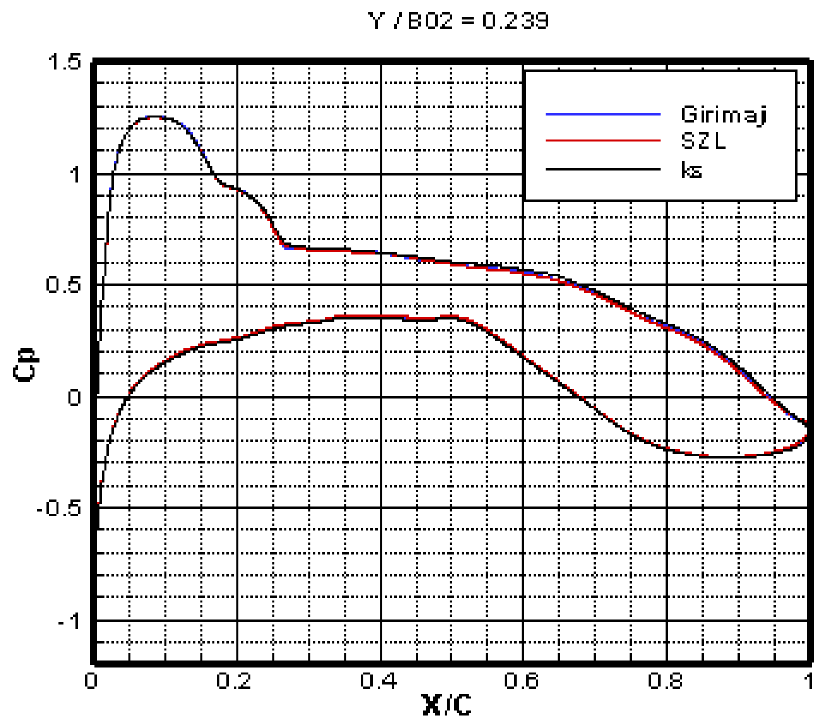
Mach =0.75, Re=5*10^6, AOA=0.0



Turbulence Model Effect on Cp

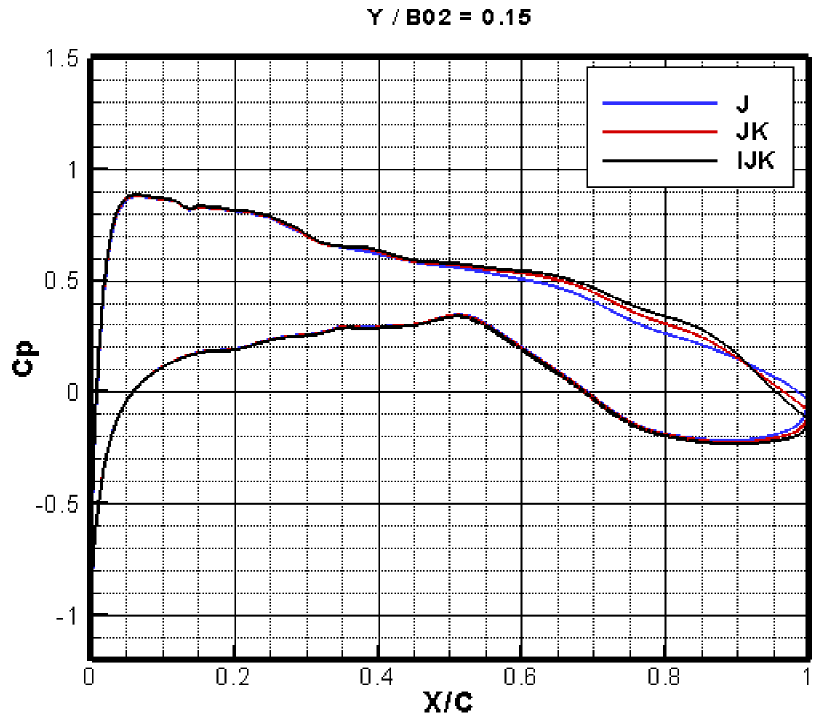
Mach =0.75, Re=5*10^6, AOA=0.0

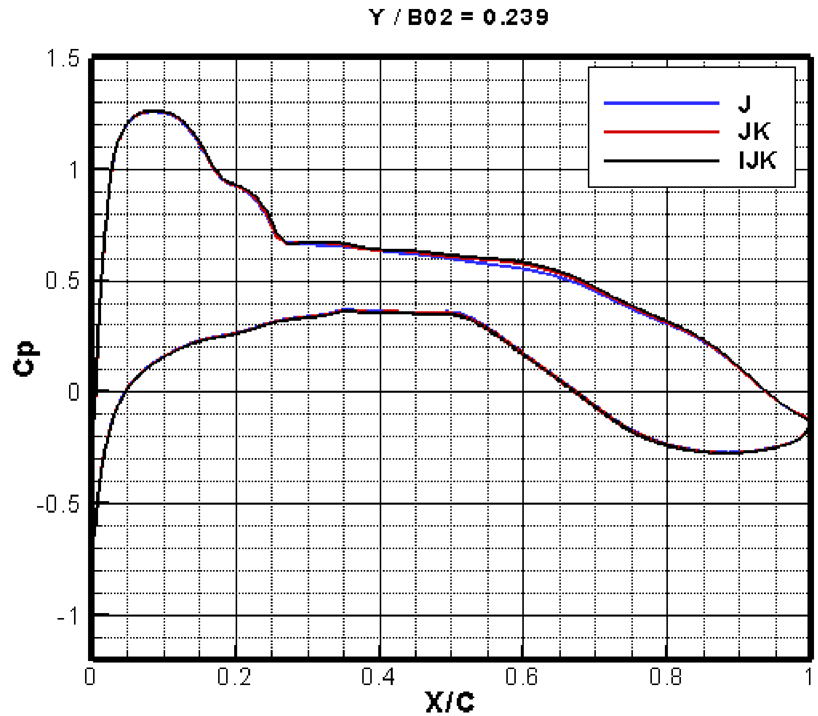




Thin Shear Layer Effect on Cp

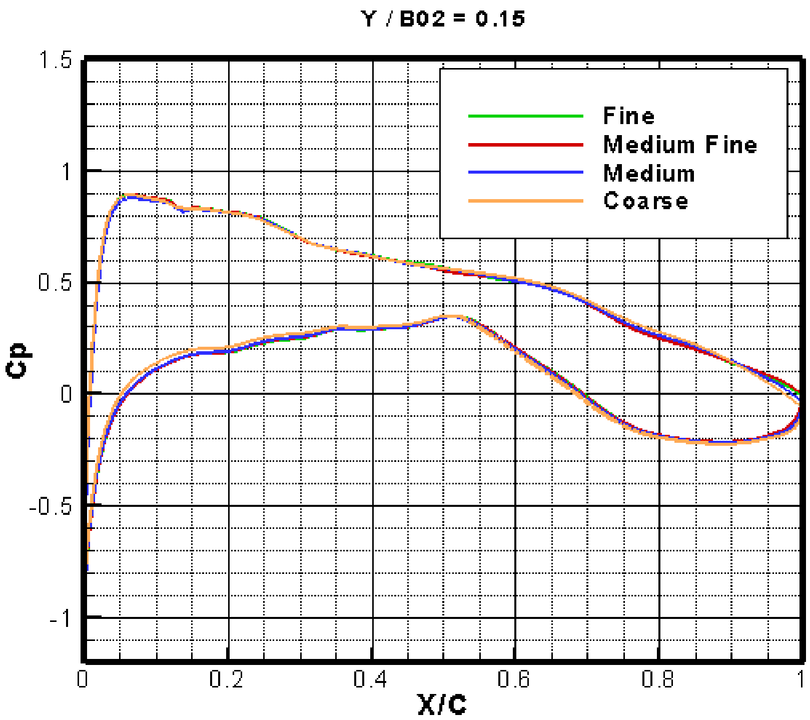
Mach =0.75, Re=5*10^6, AOA=0.0, SZL

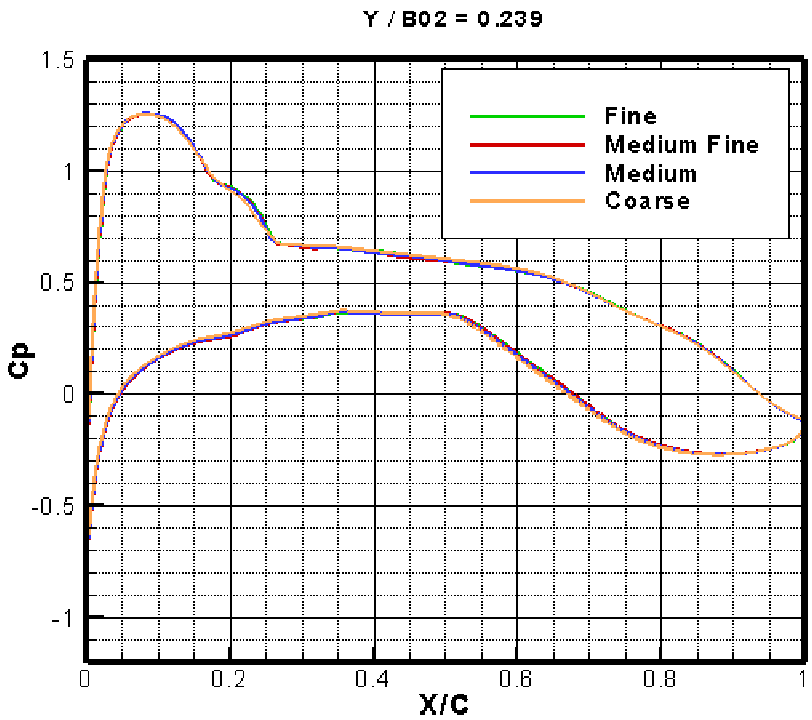




Grid Effect on Cp

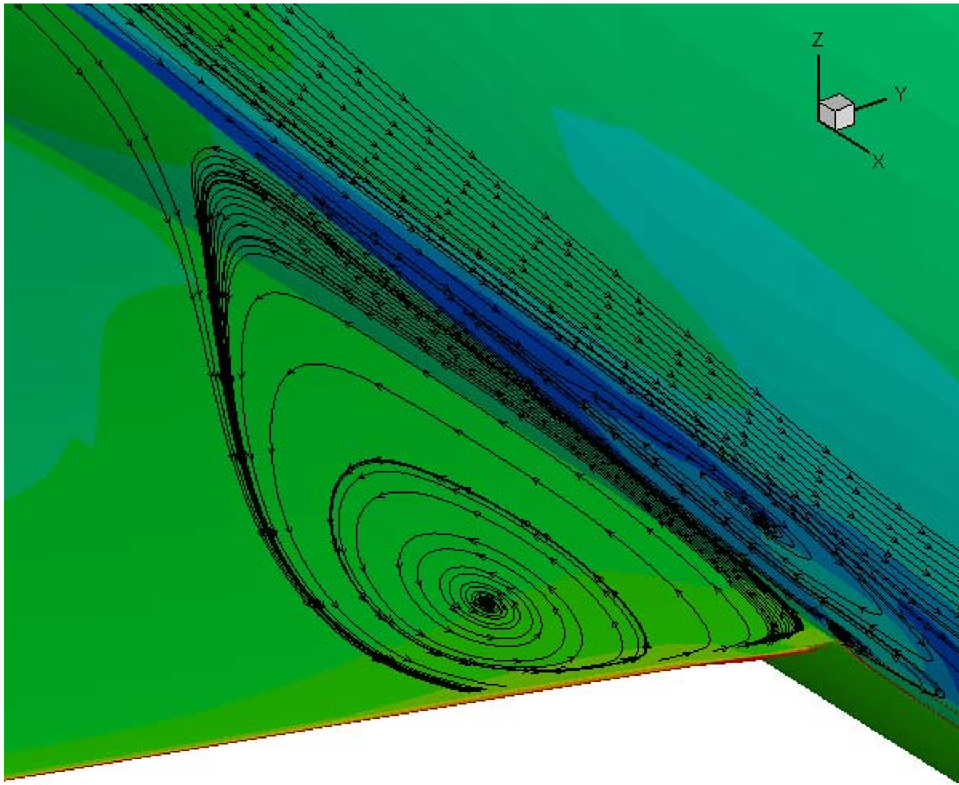
Mach =0.75, Re=5*10^6, AOA=0.0



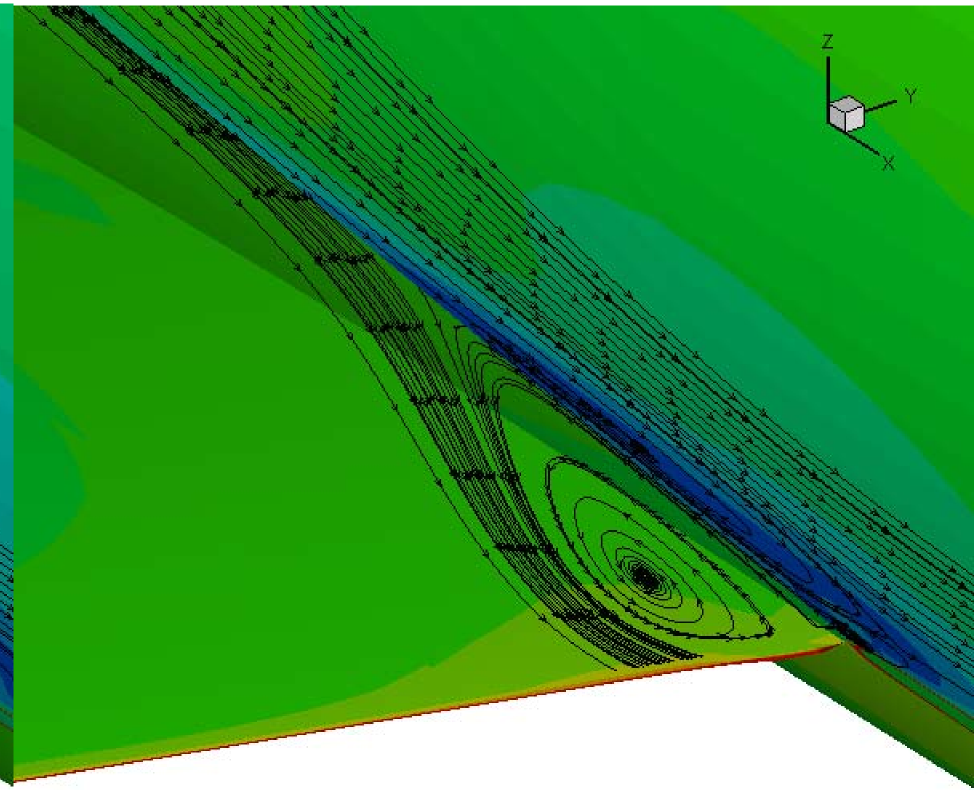


Upper Wing Streamlines, F6-WB

Mach =0.75, Re=5*10^6, AOA=0.0



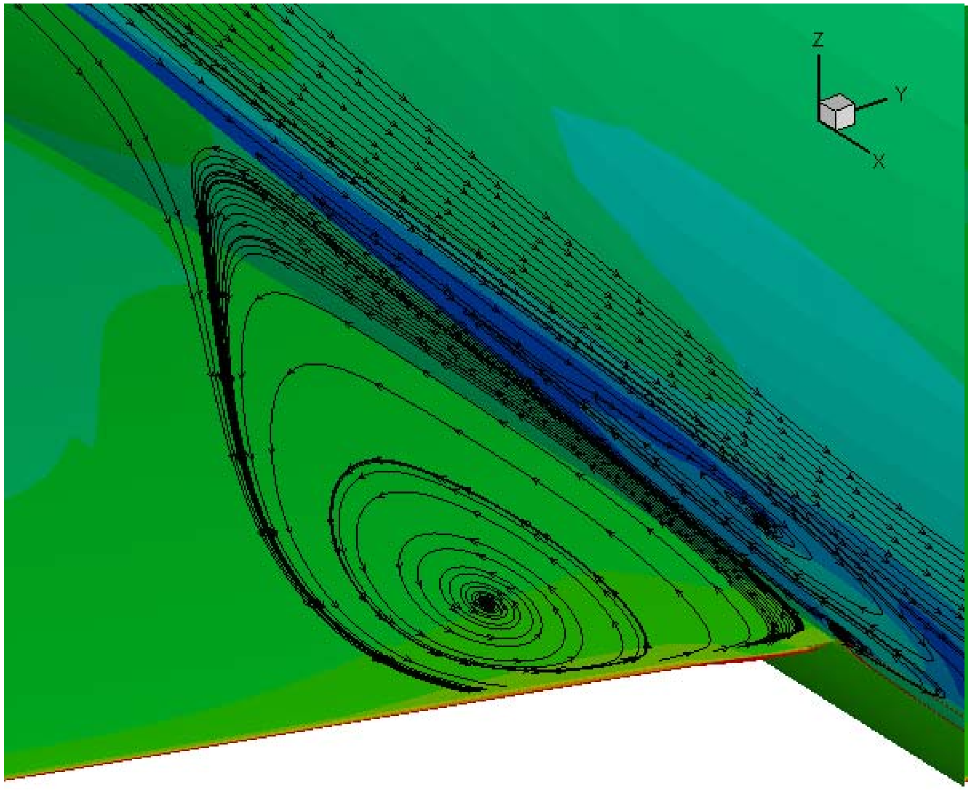
SZL medium grid
Thin Shear Layer in 2 directions



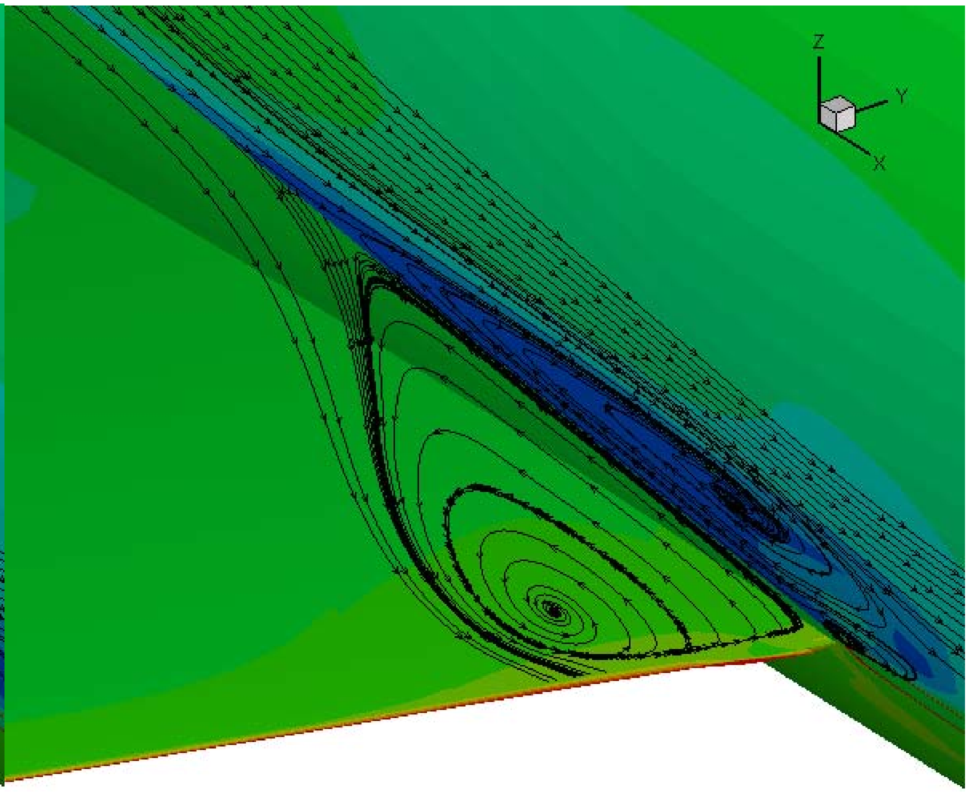
kε medium grid
Thin Shear Layer in 2 directions

Upper Wing Streamlines, F6-WB

Mach =0.75, Re=5*10^6, AOA=0.0



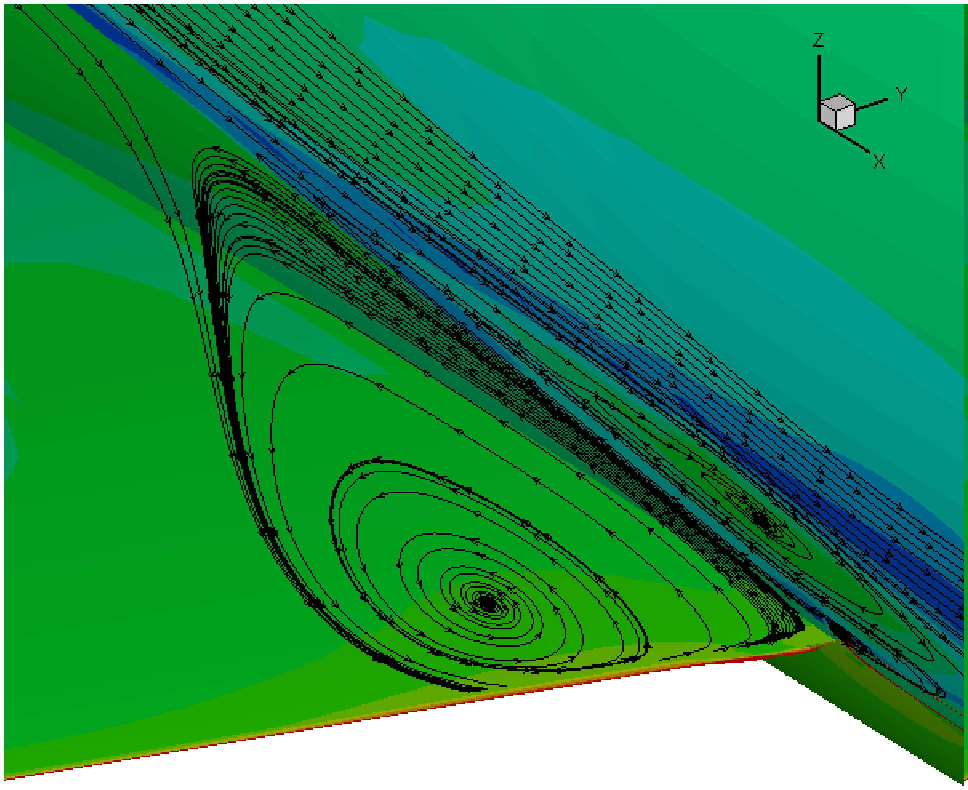
SZL medium grid



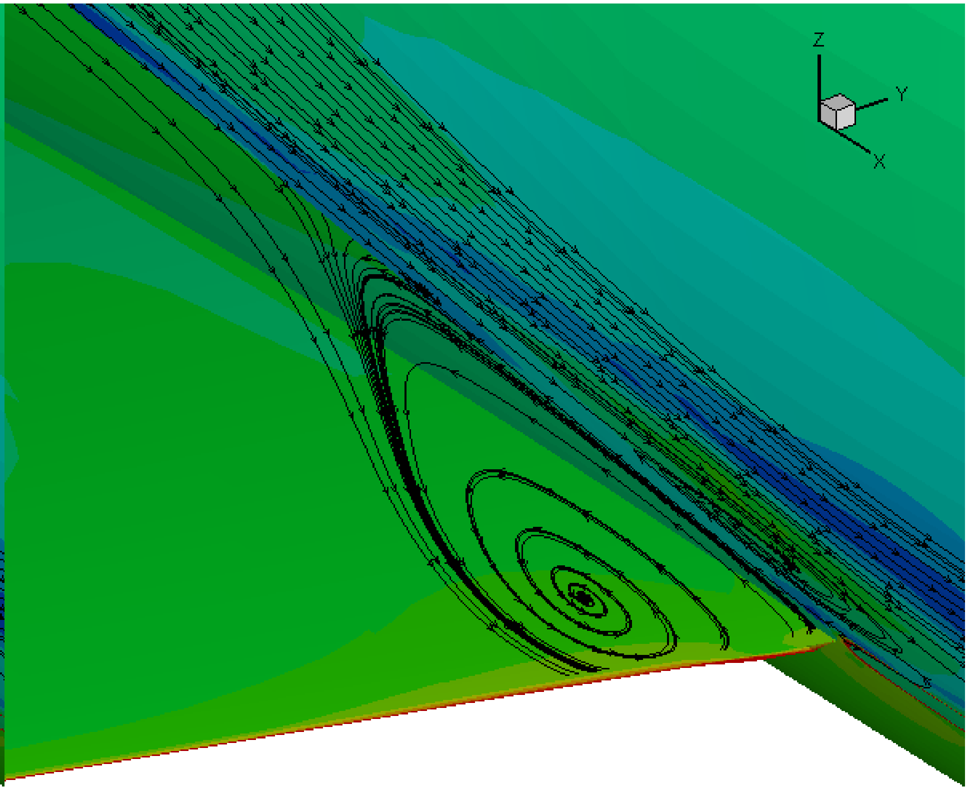
Girimaji medium grid

Upper Wing Streamlines, F6-WB

Mach =0.75, Re=$5*10^6$, AOA=0.0, SZL



Thin Shear Layer in 2 directions, JK



Thin Shear Layer in 3 directions, IJK

Summary

- PAB3D was utilized to compute the flow field of DLR F6-Wb & FX2B
- Three different turbulence Models and four different grid resolutions were utilized
- AS expected kε models produced the highest skin friction
- SZL & Girmaji algebraic Reynolds Stress models predicts similar separation bubbles
- Turbulence model affects size of separation bubble.
- Same suite of algebraic Reynolds Stress models are ported into USM3D

Need to develop innovative turbulence models for flow separation
and
implement the models within state-of-the-art RANS flow solvers