Turbulence Modeling Effects

Aeroelastic Prediction Workshop 2

January 2 2016
San Diego

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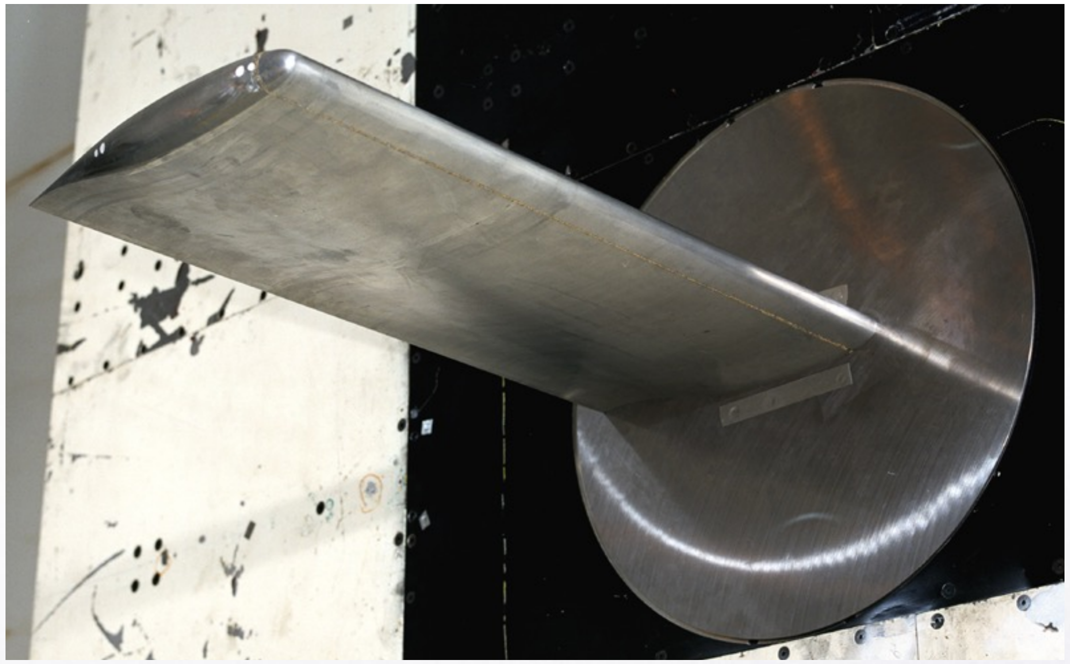
Outline

- Overview of turbulence model classes and models used by workshop analysts
- Overview of Reynolds stress models
- Effect of turbulence models on one of the static cases
  - Case 3A (Mach = 0.85, AOA = 5 deg, Gas: R-134a)
- Effect of turbulence models on one of the dynamic cases
  - Case 2 (Mach = 0.74, AOA = 0 deg, Gas: R-12)
- Summary and future outlook



RANS Turbulence Model Classes

- Linear eddy viscosity models (LEVM)
  - Based on the Boussinesq assumption
  - Involves the solution of one or more partial differential equations (could also be algebraic)
- Non-linear eddy viscosity models (NLEVM) and algebraic explicit Reynolds stress models (EARSM)
  - Based on a linear model as the background model
- Reynolds stress models (RSM, also known as second-moment closure models)
- Hybrid RANS/LES (sometimes also known as DES)

Turbulence Models Employed

Code	Team	CFD code	Model	Class
A	FOI	EDGE	SA	LEVM
B	Embraer	CFD++	SST	LEVM
C	NASA east	FUN3D	SA	LEVM
D	Technion	EZNSS	SA, SST, TNT	LEVM
E	UMich	SUMad	SA	LEVM
F	ZHAW	EDGE, SU2	SA, ?	LEVM, EARSM
G	ANSYS	Fluent	SA, SST	LEVM
H	ATA	Loci	SA, SST	LEVM

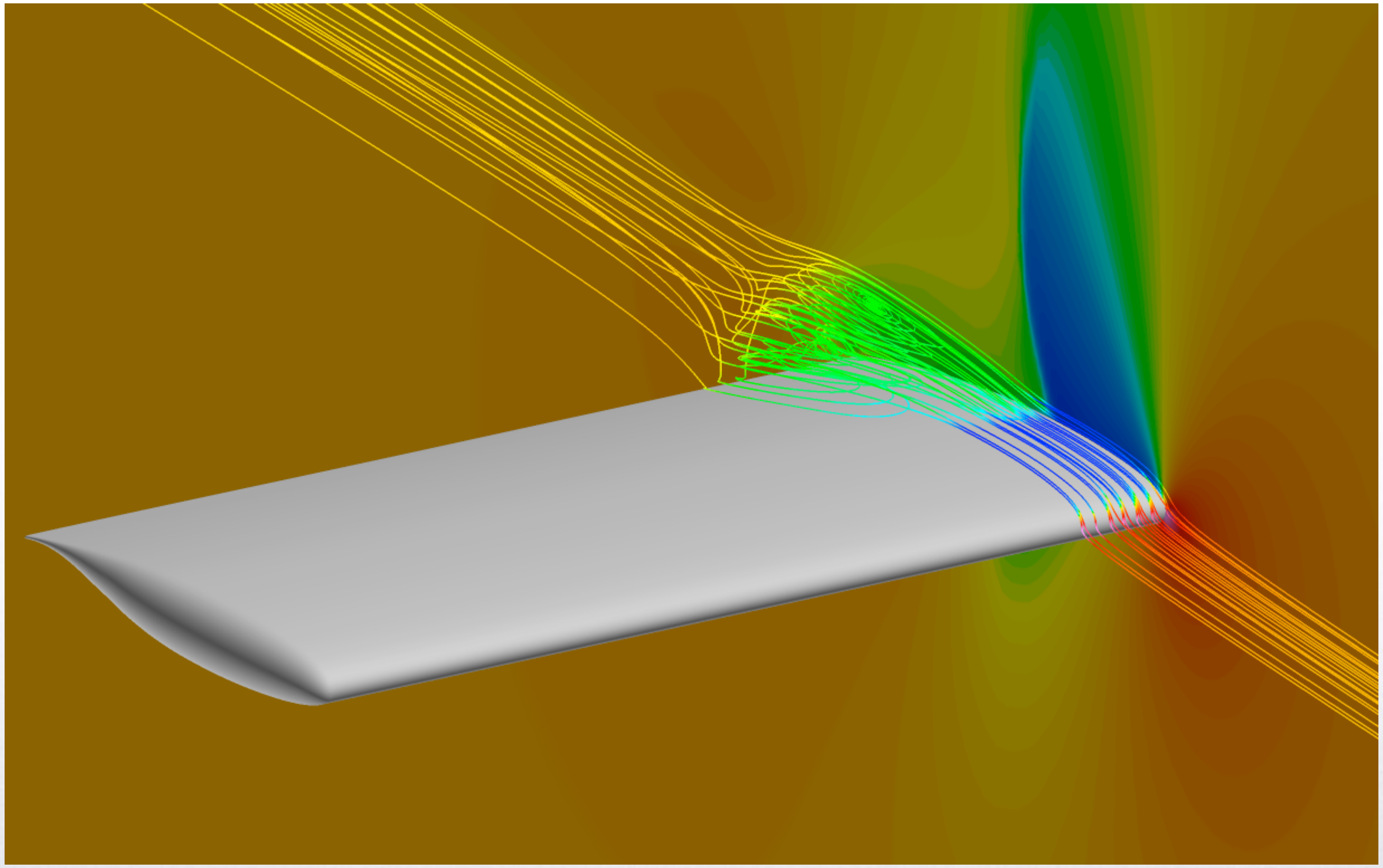
Turbulence Models Employed

Code	Team	CFD code	Model	Class
I	NRC	OpenFoam		
J	NLR	EDGE		
K	ITA	SU2		
L	NASA west	LAVA		
M	CDADAPCO	STAR-CCM+	SST	LEVM
N	Milano	Various	None	
O	Rafael	EZAir	TNT	LEVM
P	Strasbourg			

Spalart Allmaras Turbulence Model

- The standard model heavily relies on calibration to a wide range of experimental data
- Has advantage over other models when applied to attached flows
- Suffers from excessive separation at junction flows and has shortcoming when simulating unsteady flows involving considerable separation
- Has many versions, each developed to address certain issues

Example of Excessive Separation around Junction: Static Case 3A



k-ω-SST Turbulence Model

- The original version is considered the standard version
- Also has many versions
- The most popular two equation model
- Like all linear models, the main shortcomings are its difficulty to accurately predict unsteady flows involving massive separation and flows involving streamline curvature

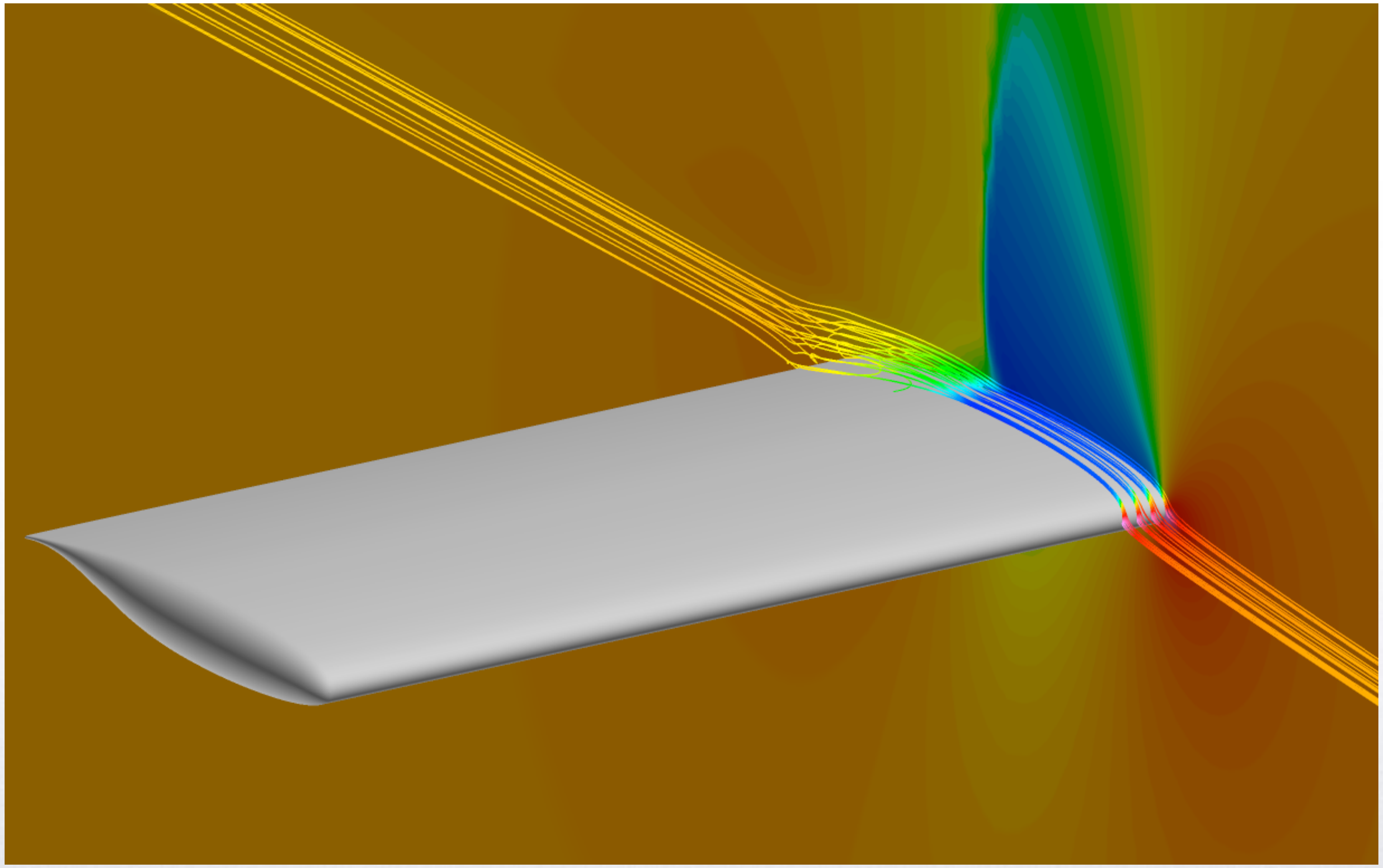
Reynolds Stress Models

- RSM are not based on the Boussinesq assumption and therefore the assumption that the turbulent shearing stress is proportional to the rate of mean strain is dropped
- Exact transport equations for the Reynolds stresses are derived from the Navier-Stokes equation and the models are based on the solution of these equations
- The production term does not require approximations
    - The production term is primarily responsible for the anisotropy and the selective response of turbulence to different strain types
- RSM are becoming more affordable

RSM Varieties Considered

- SSG/LRR-ω (AIAA J. 2015)
  - Omega based model
  - Uses a blend of two pressure-strain models, the LRR model is activated in the near wall region while the SSG model is activated further away
- MCL (AIAA J. 1999)
  - A modification for compressible flow of the Craft-Launder closure model (TCL)
  - Employs a cubic pressure-strain model
  - Topology free (no need for wall distance)

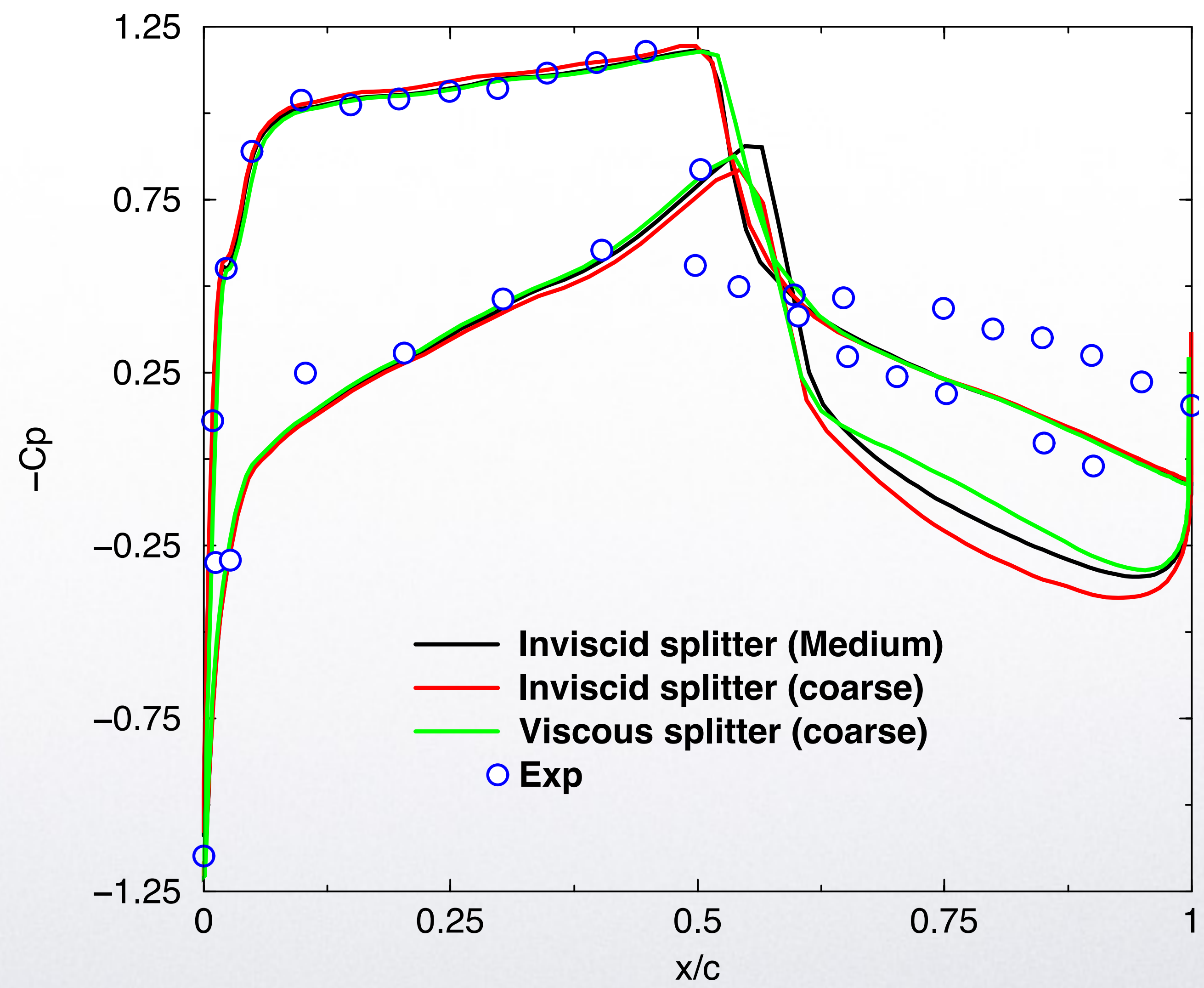
Predicted Junction Flow by the SSG/LRR-ω Model: Static Case 3A



Turbulence Model Effects on Shock Prediction: Static Case 3A

SA-Edwards

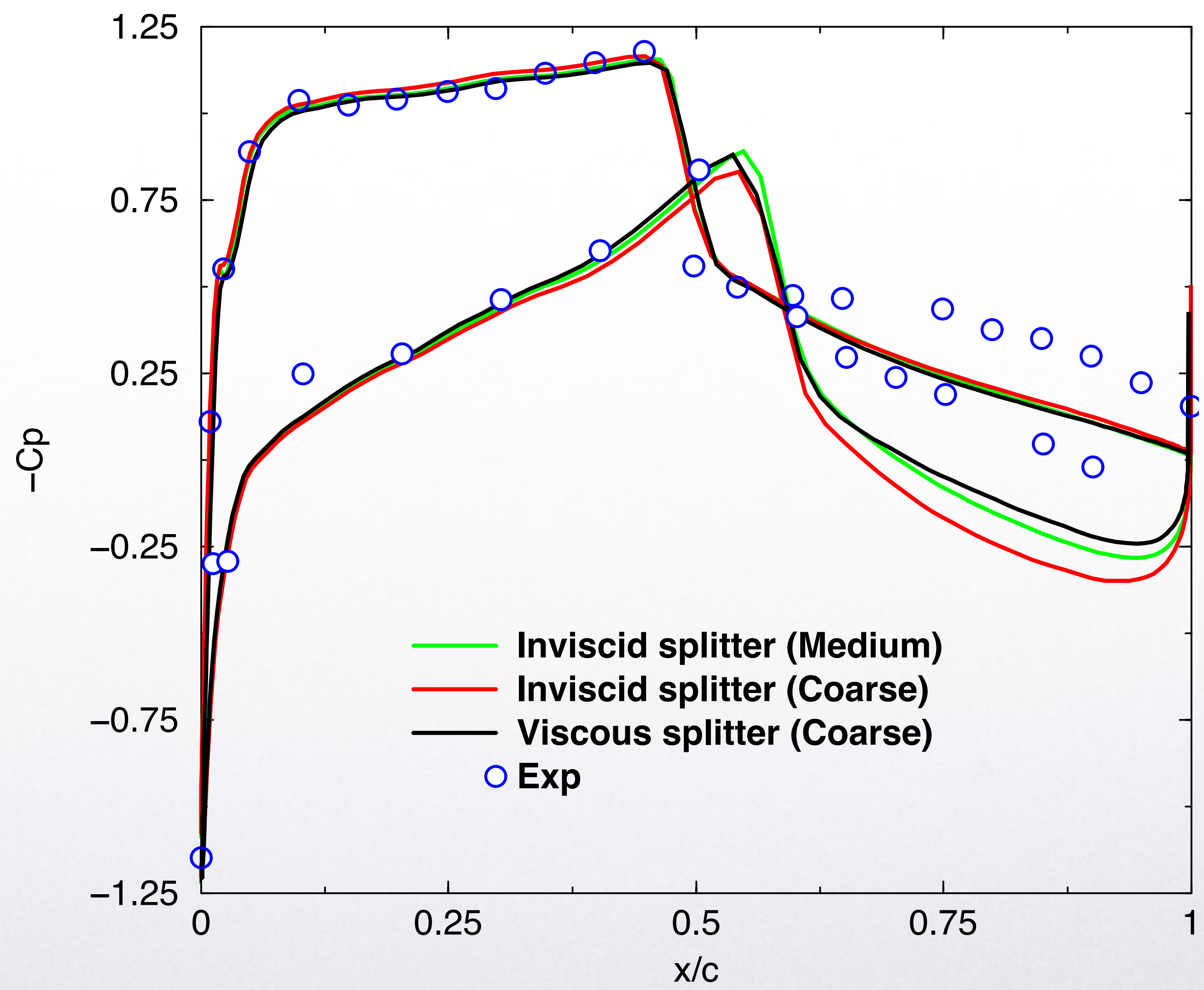
y/b = 0.6



Turbulence Model Effects on Shock Prediction: Static Case 3A

SST-2003

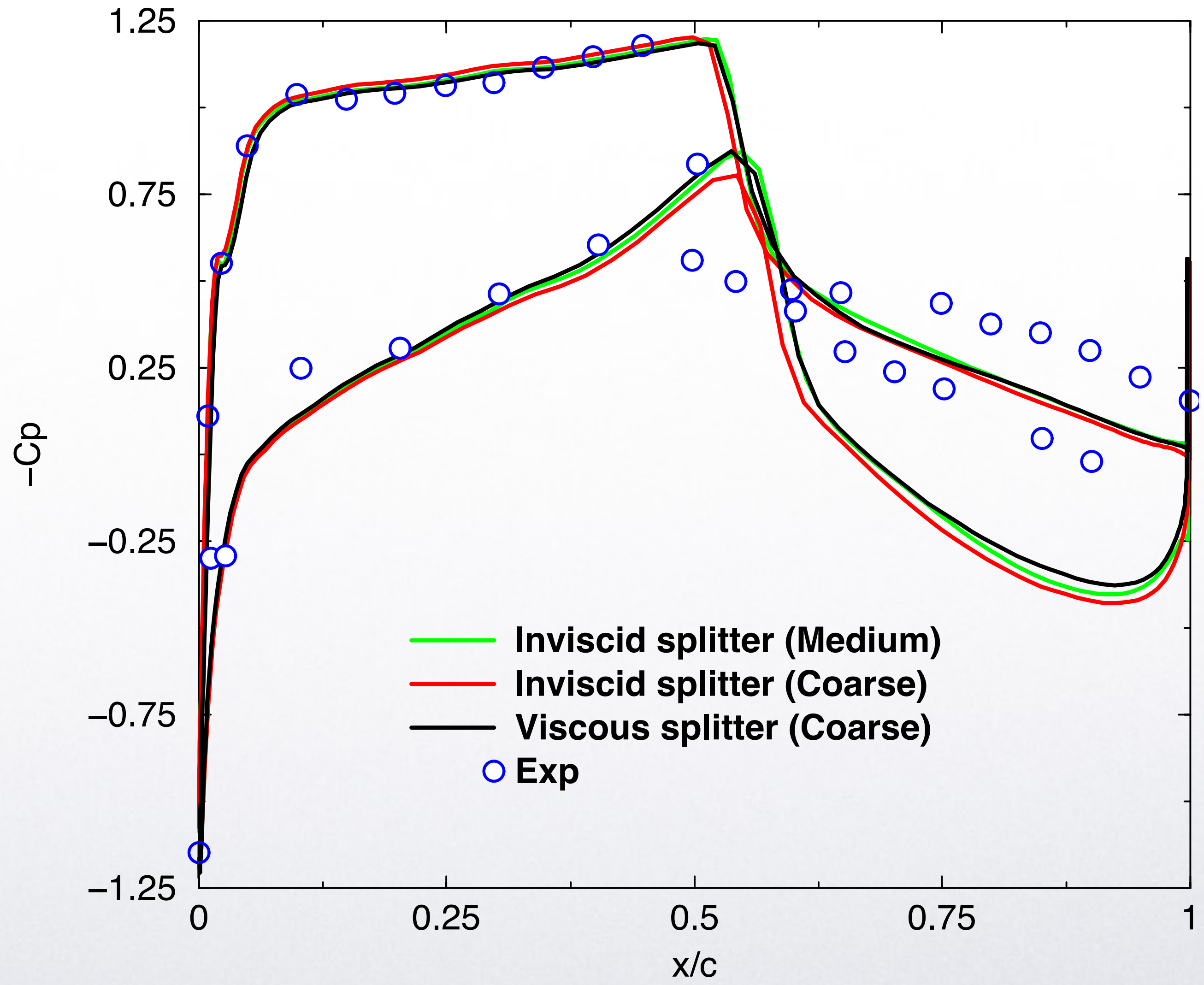
y/b = 0.6



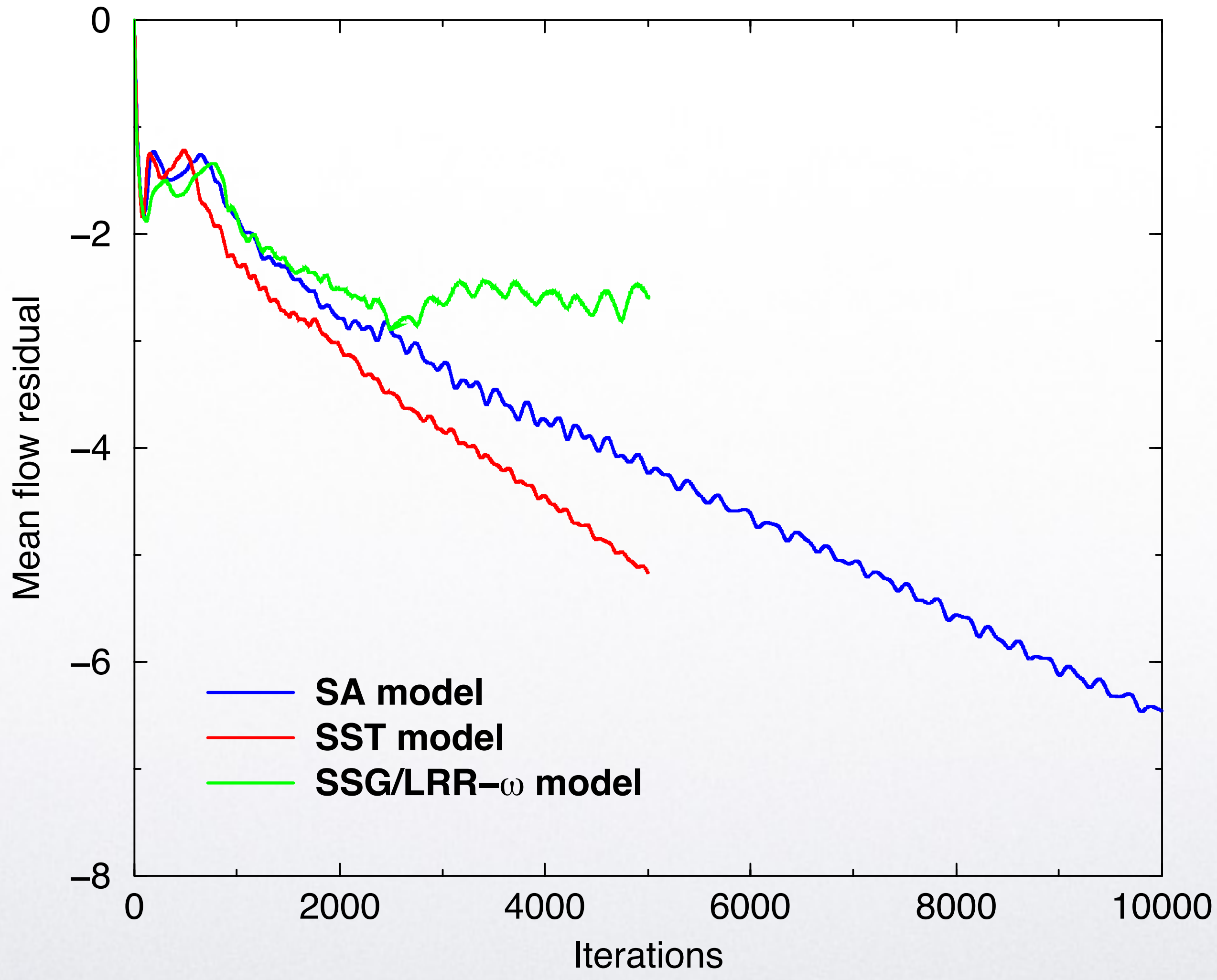
Turbulence Model Effects on Shock Prediction: Static Case 3A

SSG/LRR-ω

y/b = 0.6



Turbulence Model Effects
Convergence of Static Case 3A



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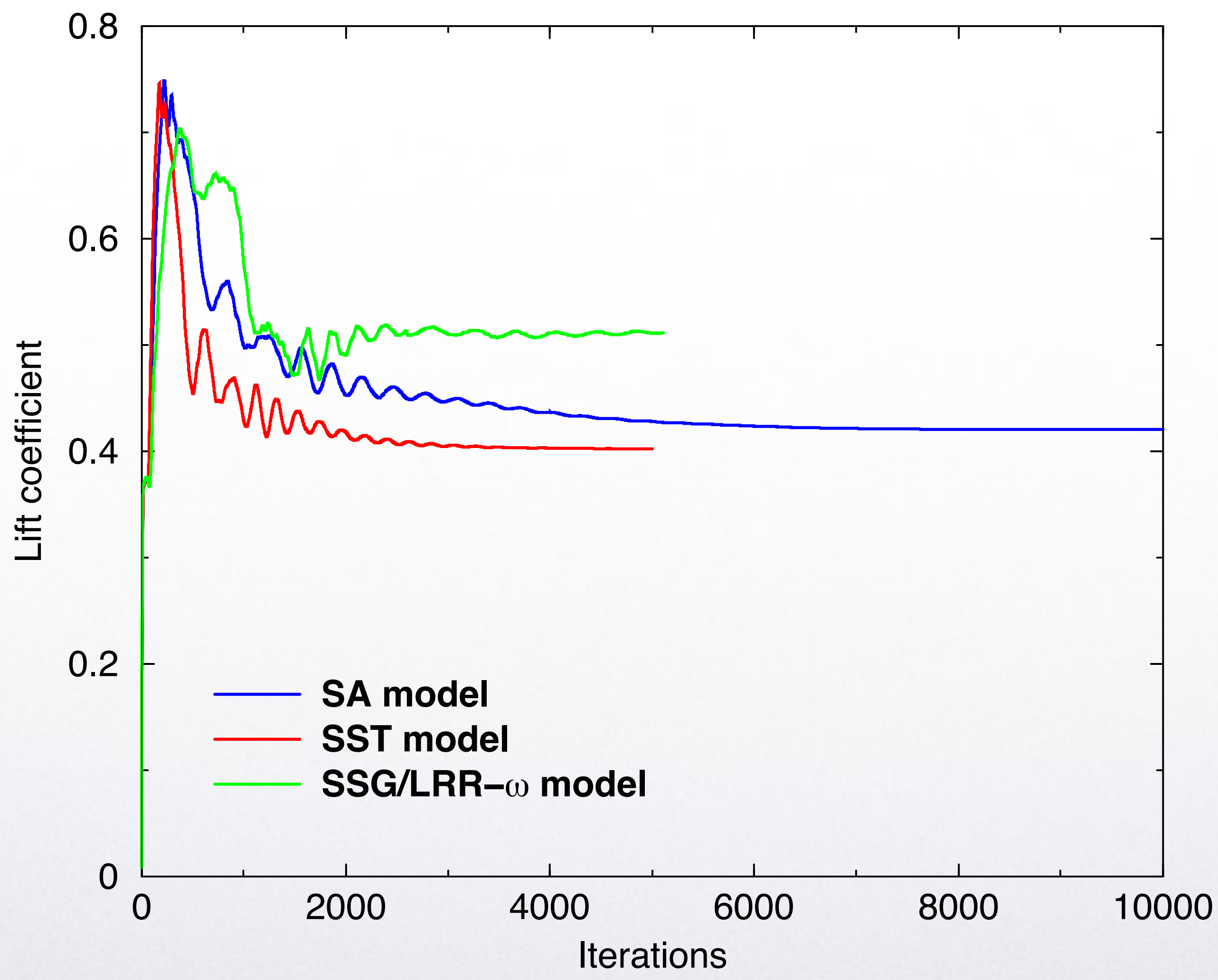
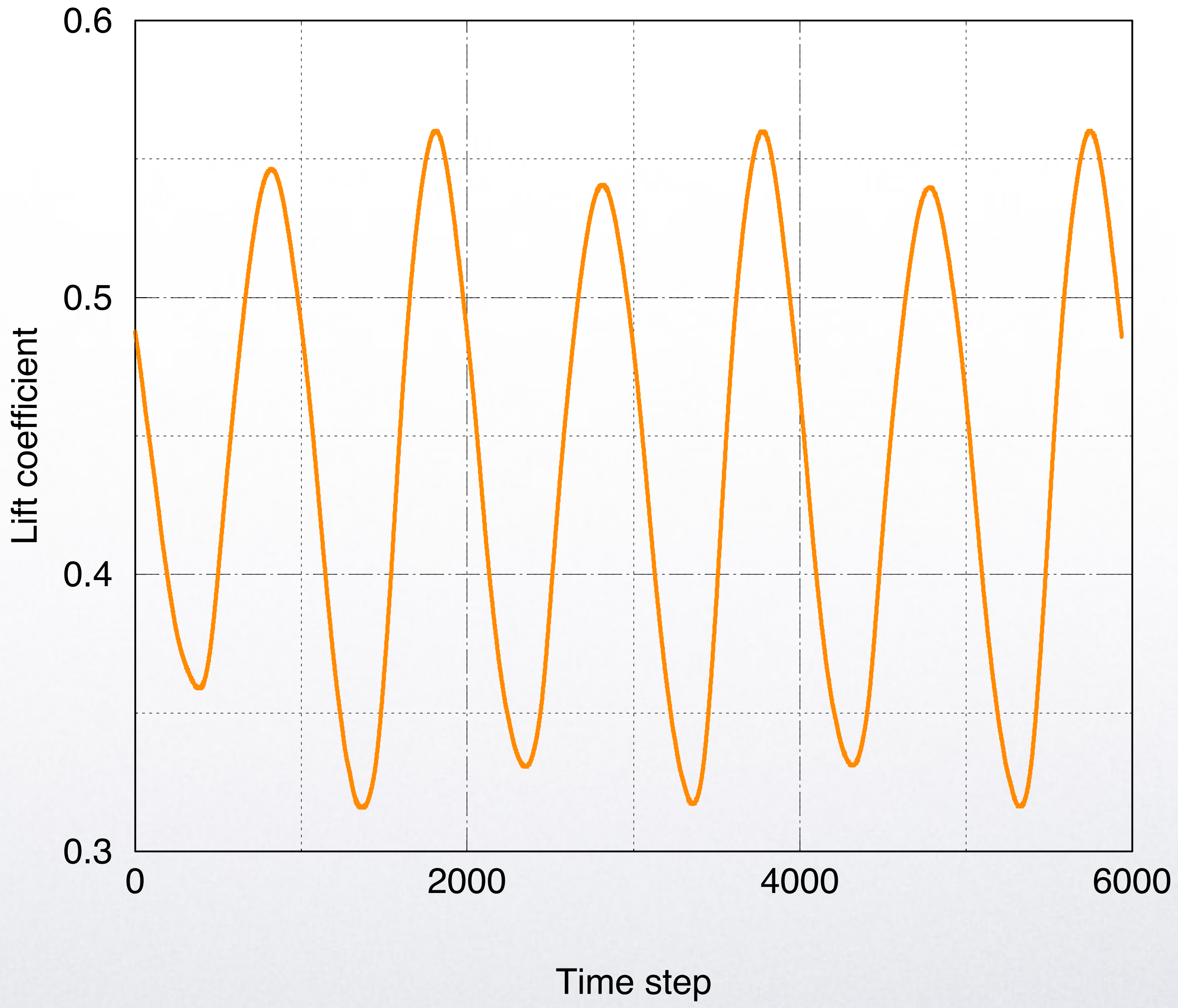


Turbulence Model Effects on Static Case
Inviscid Splitter Plate, MCL Model, Time-Accurate



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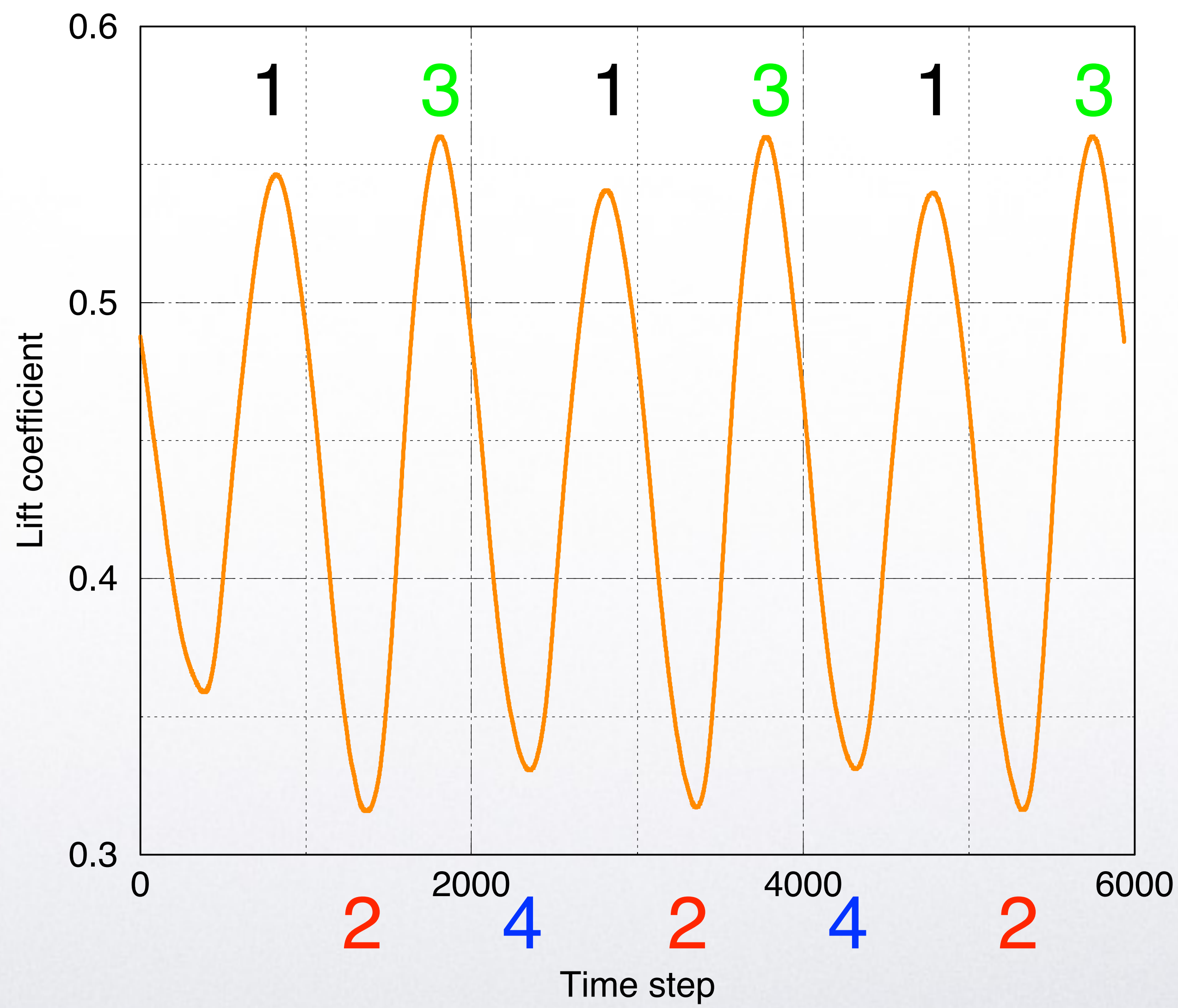

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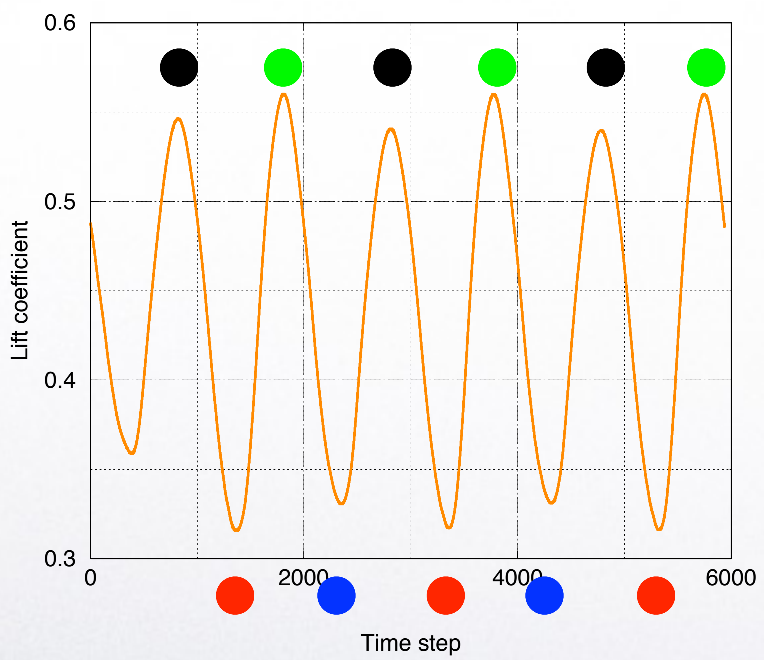

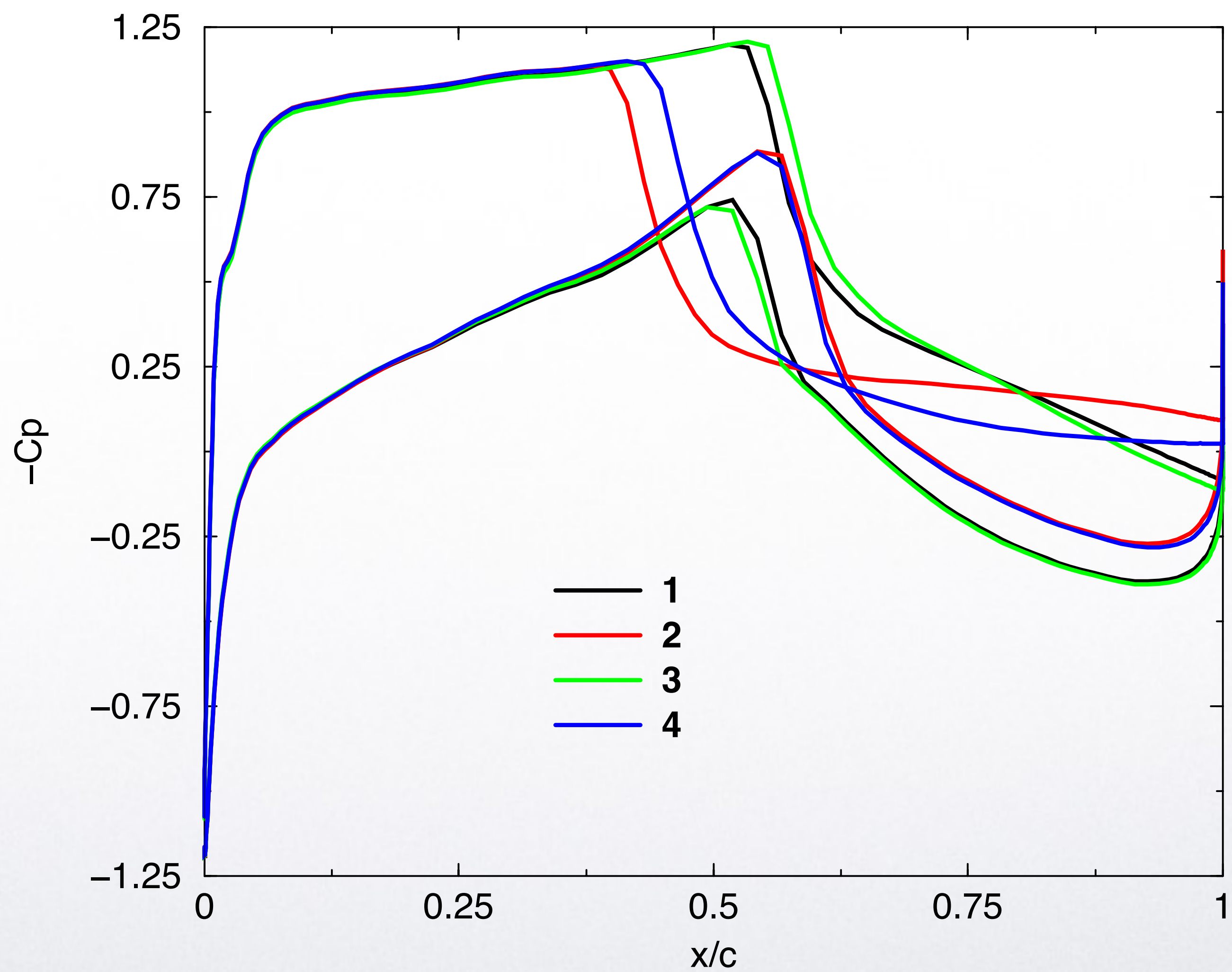

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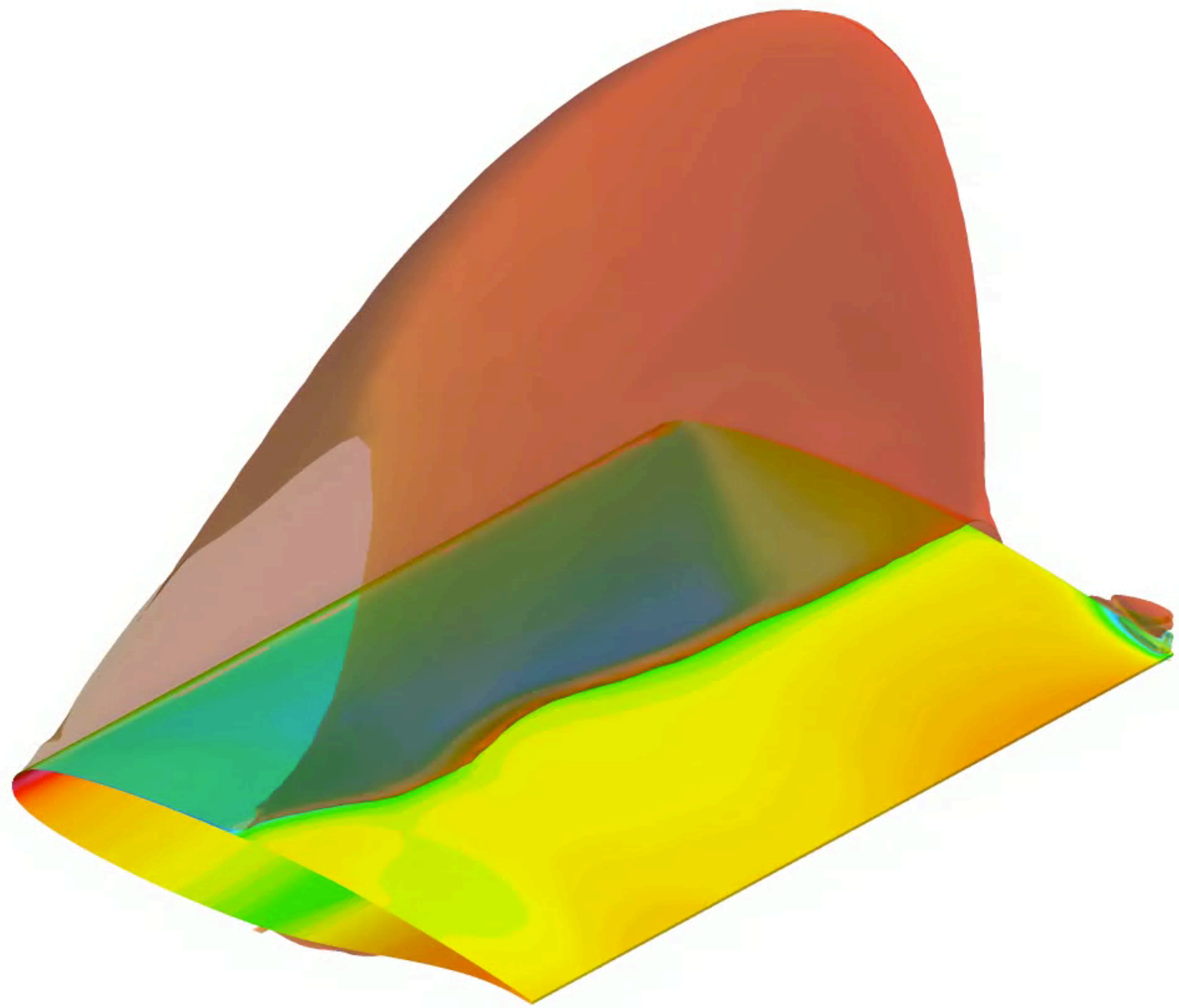

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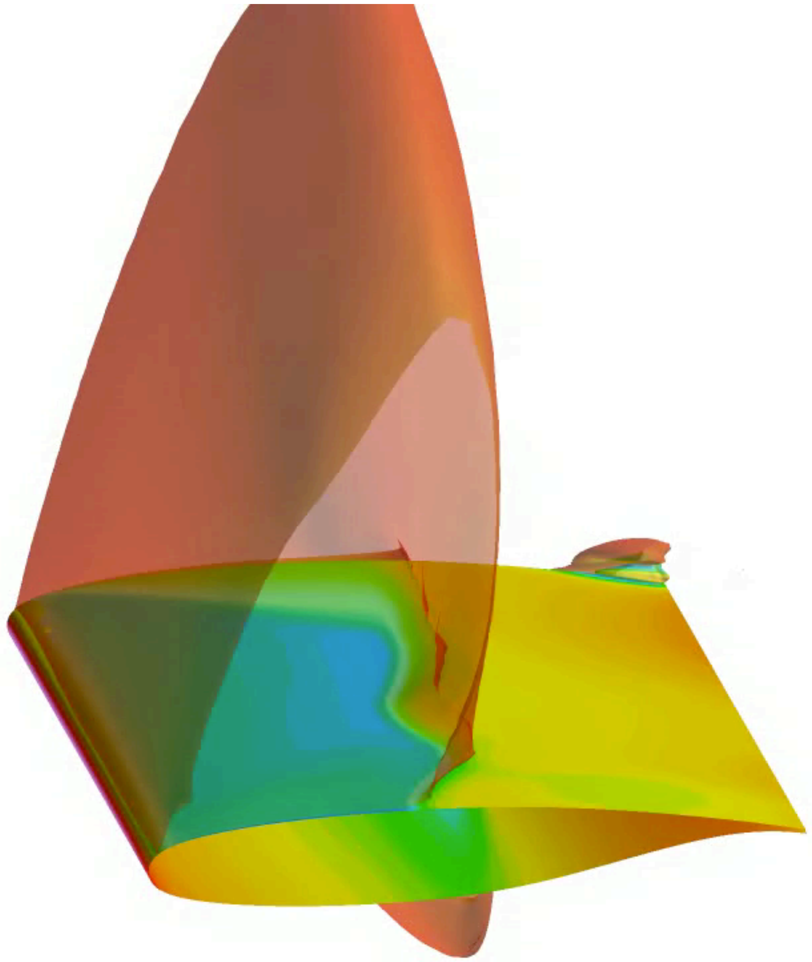
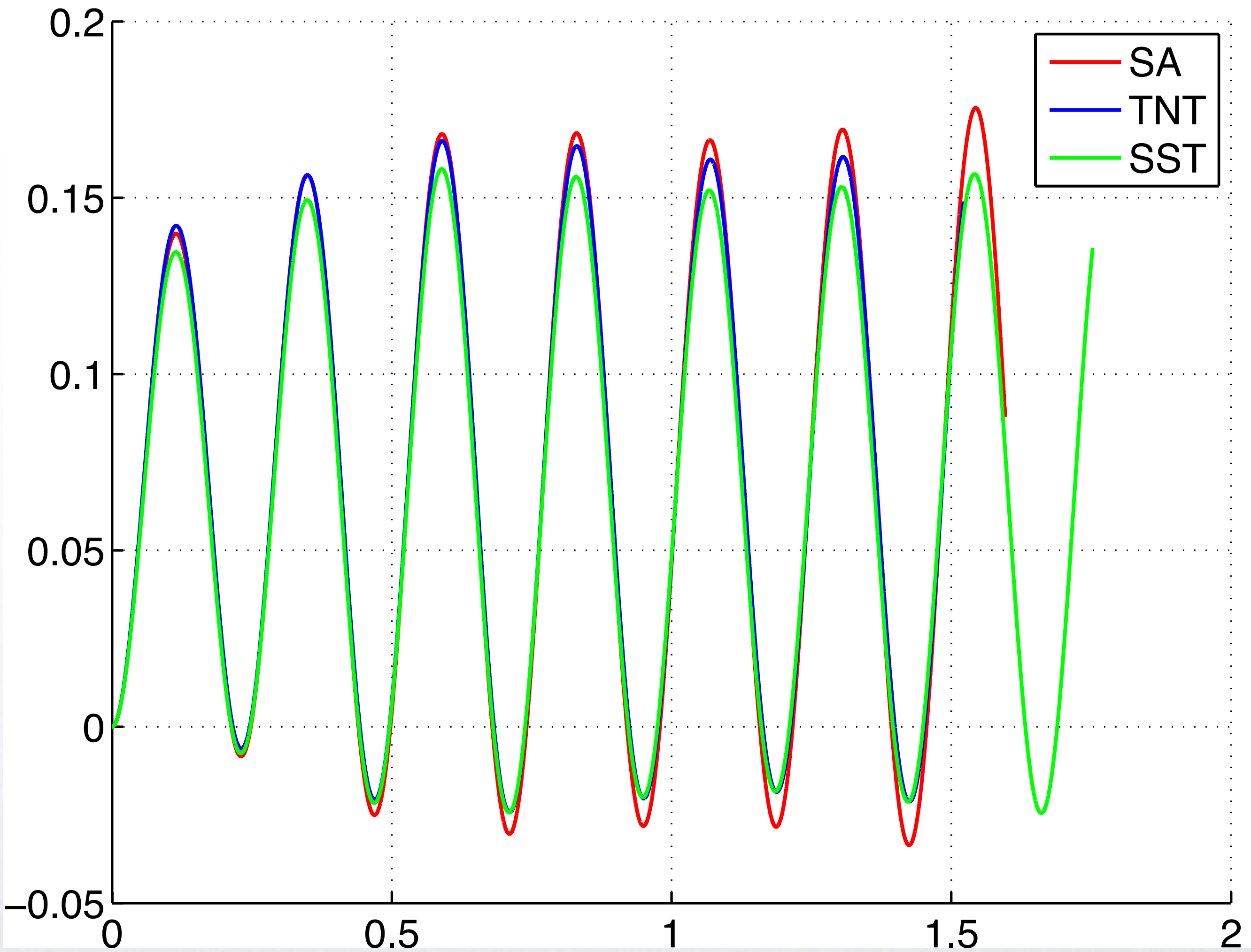


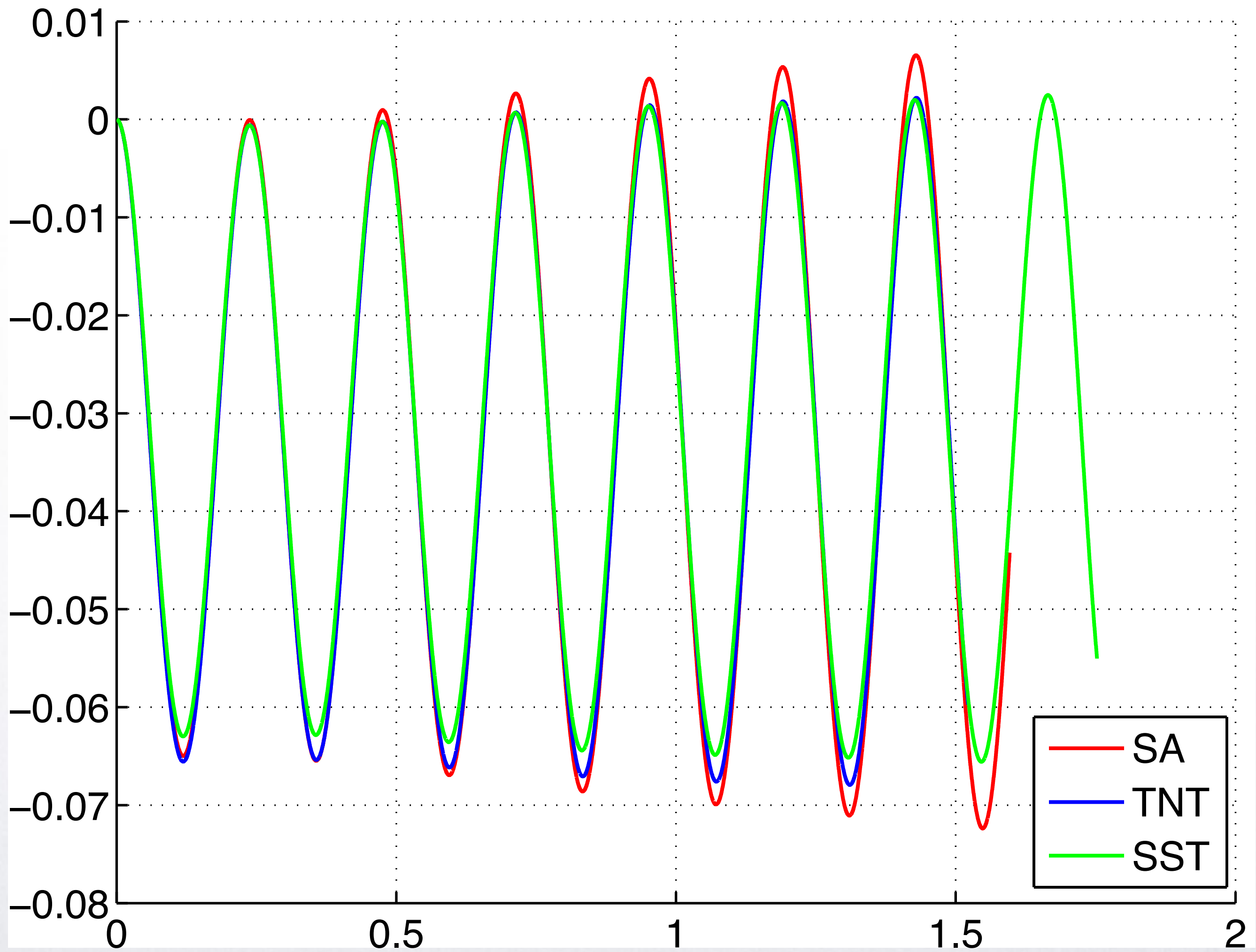
Turbulence Model Effects
Flutter, Mach = 0.74, AOA = 0.0

First mode



Turbulence Model Effects
Flutter, Mach = 0.74, AOA = 0.0

Second mode



Summary

- Results concerning the prediction of the most challenging static case may significantly vary (case 3A, Mach = 0.85, AOA = 5)
    - All LEVM converge to a steady flow
    - SA and SGG/LRR-ω fail to predict the correct shock locations
    - SST predicts the (average?) shock location
    - MCL model fails to converge to a steady flow
        - Time accurate simulations result in shock oscillations that are similar to the experiment
- LEVM have very little effect on flutter case 2

Future Outlook

- Recent results show that adding a second nonlinear term to the linear Reynolds stress tensor — the so called quadratic constitutive relation (QCR) — may alleviate the excessive junction flow separation problem
  - SA-Edwards-QCR2000
  - SST-2003-QCR2000
- Since Reynolds stress models become more affordable, they may provide other means for accurately simulating complex, unsteady, massively separated flows
- Hybrid models?

Thank You