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TCAP - Transformational Tools & Technologies Project

AMR for SBLI

Olsen, Lillard

Introduction

Method/Flows

Results

Bachalo-Johnson
Bump

Brown-Brown-Kuss
Flare

Driver CS0 Flow

Conclusions

Using Adaptive Mesh Refinement to Study Grid Resolution Effects for Shock/Boundary-Layer Interactions

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AIAA Aviation Forum



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When you're up to your neck in alligators,
it's difficult to remember that your intent was to drain the pool

Simple task: Grid converged answer on bump flowfield for R_{ij} model

- ① Use AMR (push it to its limits, find out how it works as well)
- ② Start with already reasonable grid (See how reasonable it was)
- ③ Vet methodology to get "Continuous answer" (Sharpen the saw)



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Introduction/Motivation

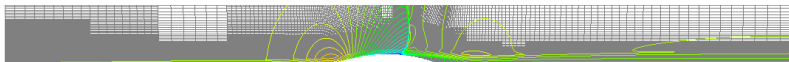


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Bachalo-Johnson

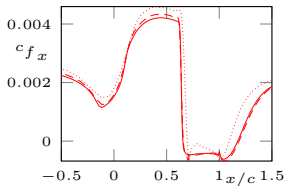
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Brown-Brown-Kussov

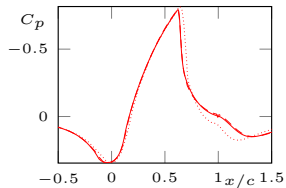
Flare

Driver CS0 Flow

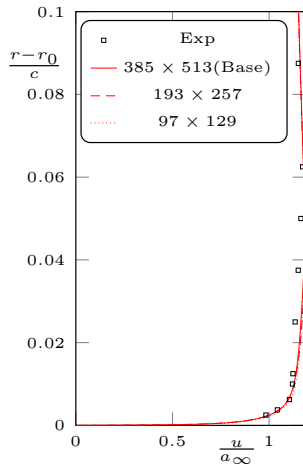
Conclusions



Skin friction



Pressure coefficient



Velocity $x/c = 0.625$



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Outcome:

- ① u_i , R_{ij} keep changing (Implementation bug? – no)
- ② try simpler ν_t model ("Emergent behaviour" in R_{ij} model? – no)
- ③ try verified ν_t implementation (Model-development code bug? – no)

Same behavior for SA-noft2 & SST models in "production overflow"!

- ④ Eventually, pool drained. (Along with two adjacent pools)



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Scope

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- Scope: inherently "academic" (turbulence model development)
 - Continous limit? mathematical model requirement
 - Limited to non-exotic models (here) ν_t models inherently "nice"
 - Work (the initial pool) was for next generation model development
 - Turbulence modeling implications scrupulously avoided
 - Of interest if considering AMR (what to look for, how to)
- Implications(from the cases studied here)
 - Surface quantities (even c_f) grid converge first
 - Velocity profiles (and the functions they control) converge later
 - Shocks always benefit.
 - Separated zones benefit
 - Expansion fans benefit
 - Boundary-layer edges benefit (usually unimportant)

Bottom line: New models will benefit most (flow history driven, less diffusive)



Solver: Overflow 2.2k[modified and production]

- Matrix dissipation (AIAA 2001-2664)
- **No multigrid** (but grid sequencing/full multigrid always)
- Error reduction, not time to solution, was governing goal (⇒ continuous solution)
- AMR Sensor: second undivided difference function (linearity)
- Near body refinement, converged at each grid level
- Solutions agreed with uniform refinement two levels deep

Flowfields/Experiment:

- ① Bachalo/Johnson Bump ($M_\infty = 0.875$)
- ② Brown/Brown/Kusoy Flare ($M_\infty = 2.89$)
- ③ Driver CS0 ($M_\infty = 0.1$)



Bachalo-Johnson bump — surface stress



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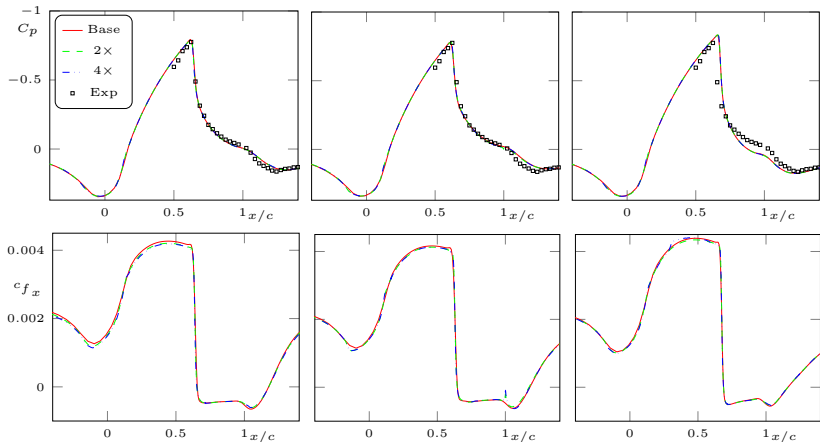
Results

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Conclusions



Lag- ν_T

SST

SA-noft2

- Coarsest grid here is finest on previous slide (Baseline)
- Skin friction and pressure completely define surface state
- Converged, with nothing happening with two grid refinements
- Answers agree with uniform refinement results to these levels



Velocity profiles showing the effect of AMR



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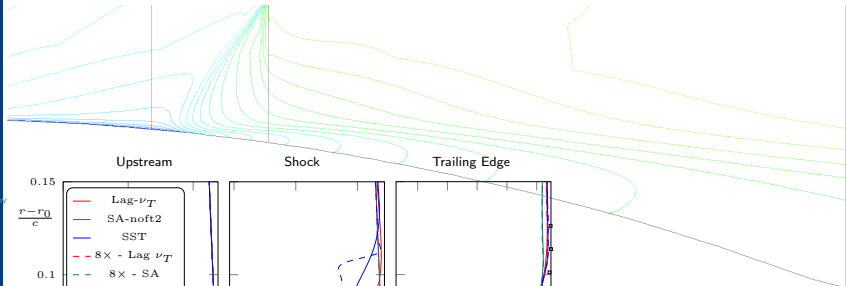
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Conclusions



AMR Effects

- Upstream — small
- Shock — large
- TE — moderate

- Separated region velocity field changes (8x "Converged")
- Shock structure continues to clarify with further refinement
- λ structure (with weak downstream shock) for Lag- ν_t and SST

AMR for SBLI

Olsen, Lillard

Introduction

Method/Flows

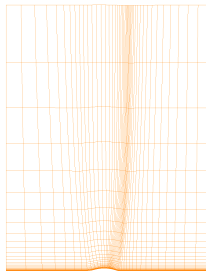
Results

Bachalo-Johnson
Bump

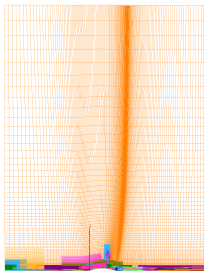
Brown-Brown-Kusner
Flare

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Conclusions



Baseline (every 4th)



AMR , refinement level 3

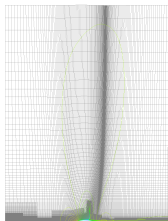
Grid

Baseline grid

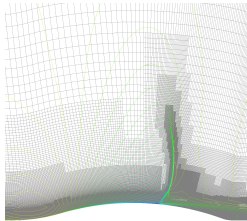
- Already pretty fine
- Concentration – bump, downstream
- Farfield already coarse

AMR grid refinements

- Boundary layer (edge)
- Shock
- Separated zone
- Post shock



Overall



Bump Closeup

Solution(ρ)



Bachalo-Johnson shock structure



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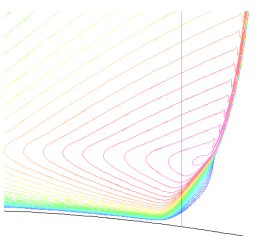
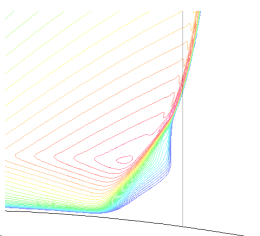
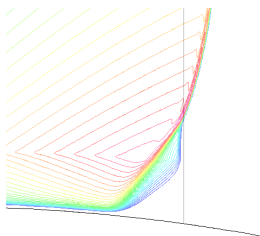
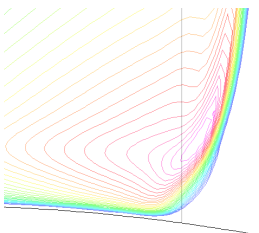
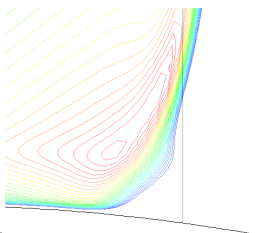
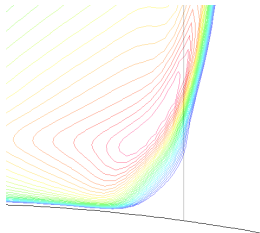
Brown-Brown-Kusson
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Driver CS0 Flow

Conclusions

Baseline

AMR level 3 (8x)



Lag- ν_T

SST

SA-noft2



AMR grid size comparisons – Cost/Efficiency



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AMR for SBLL

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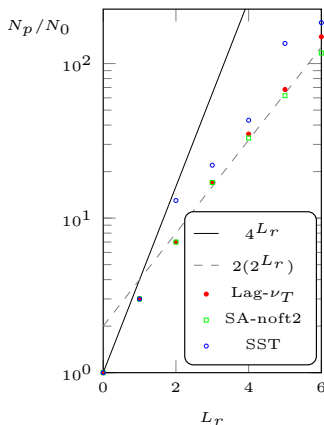
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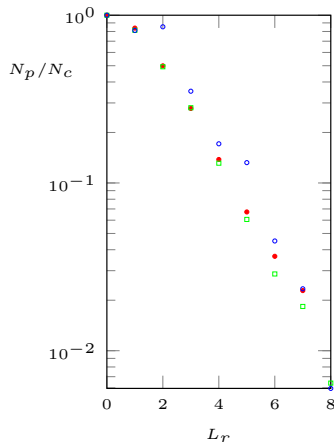
Conclusions

AMR/baseline



Cost

AMR/uniform



Efficiency



Residual History(Grid Refinement Level L_r)



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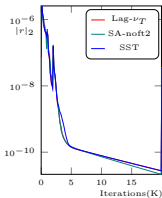
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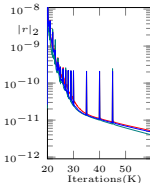
Driver CS0 Flow

Conclusions

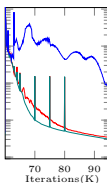


Baseline

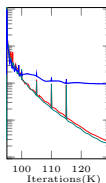
- Iterations required don't increase with L_r
- 20K iterations at each new L_r , +10K insurance
- 20K iterations to get baseline (include grid sequencing)
- Reasonable, predictable cost (t_{CPU}/N_{grid} insensitive)
- Well converged solutions (\mapsto continuous)



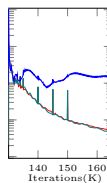
$L_r = 1$



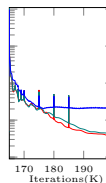
$L_r = 2$



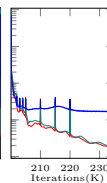
$L_r = 3$



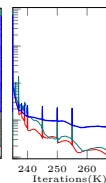
$L_r = 4$



$L_r = 5$



$L_r = 6$



$L_r = 7$



Brown-Brown-Kussoy Flare grid and solution



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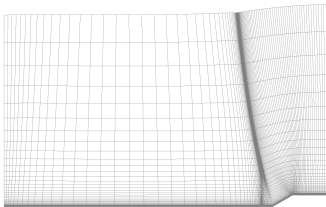
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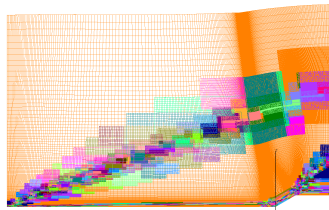
Brown-Brown-Kussoy
Flare

Driver CS0 Flow

Conclusions

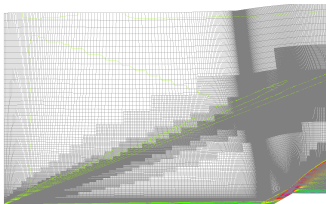


Baseline (every 4th)



AMR , refinement level 3

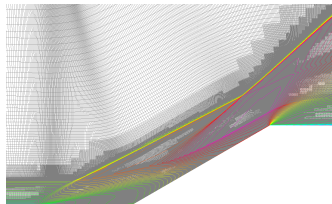
Grid



Overall

AMR grid refinements:

- Boundary layer **edge**
- **Shocks**



Corner Closeup

Solution(ρ)

- Separation/Reattachment
- Expansion Fan



Brown-Brown-Kussoy Flare — surface stress



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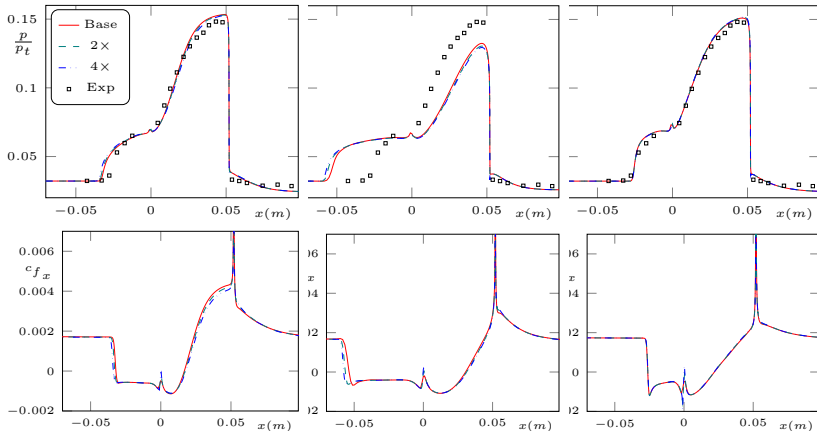
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Lag- ν_T

SST

SA-noft2

- Skin friction and pressure completely define surface state
- Grid converged, with separation fixed at 2x refinement



Velocity profiles showing the effect of AMR



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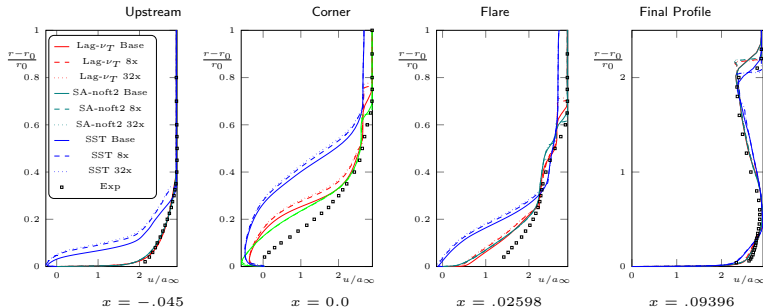
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Driver CS0 Flow

Conclusions



AMR Effects:(Upstream — small, Separated — large, Exit — moderate)

- $L_r \geq 1$ AMR solutions in general agreement (except for...)
- Separated region $L_r \geq 3$ in general agreement (except for...)
- Shock regions continue to evolve (shocks sharpen)



Driver CS0 - AMR Grid and Solution



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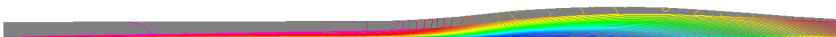
Flare

Driver CS0 Flow

Conclusions



AMR grid system, refinement level 3



solution (axial velocity), refinement level 3

AMR grid refinements

- Boundary layer
- Shear layer
- Refinement "everywhere"
- More what was expected with AMR (no shocks, C_∞ thinking)



Driver CS0 Flow— surface stress



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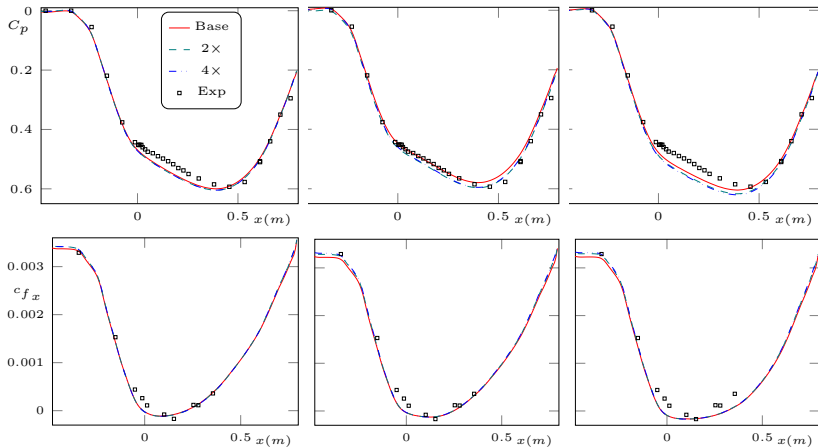
Bump

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Conclusions



Lag- ν_T

SST

SA-noft2

- Baseline Solution already close, $L_r \geq 1$ tiny changes
- Skin friction and pressure completely define surface state
- Converged, with small changes after one grid refinement



Velocity profiles showing the effect of AMR



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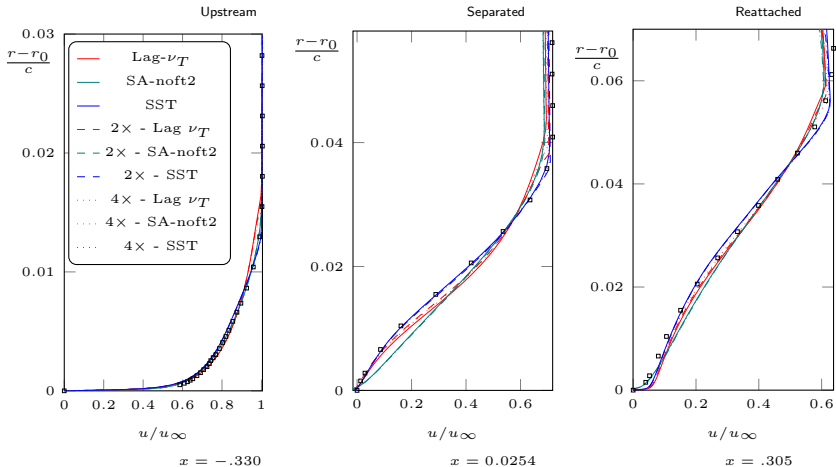
Bump

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Driver CS0 Flow

Conclusions



AMR Effects: Upstream — small, Separated & Downstream — moderate

- Boundary-layer edge/shear layer small changes
- Much smaller changes overall
- No shocks \mapsto less surprise



AMR grid size comparisons – Cost/Efficiency



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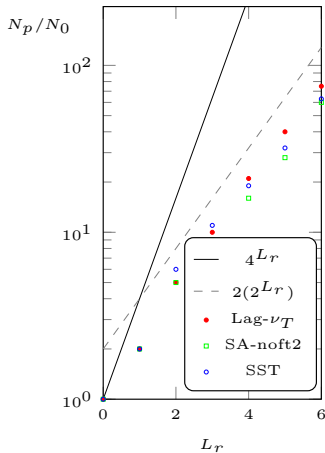
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Flare

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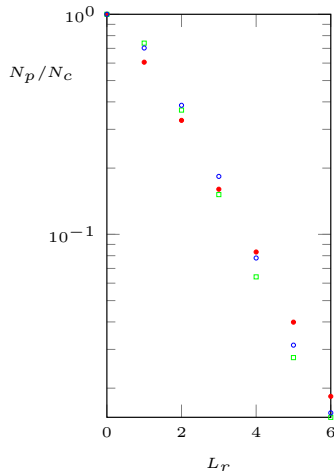
Conclusions

AMR/baseline



Cost

AMR/uniform



Efficiency



Residual History(Grid Refinement Level L_r)



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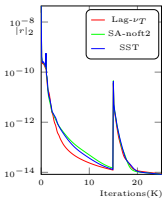
Bump

Brown-Brown-Kussov

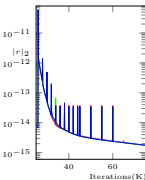
Flare

Driver CS0 Flow

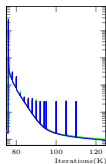
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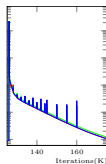
Baseline



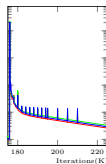
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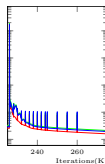
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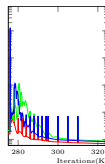
$L_r = 3$



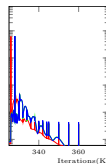
$L_r = 4$



$L_r = 5$



$L_r = 6$



$L_r = 7$

- Iterations required don't increase with L_r
- Same pattern as supersonic/transonic cases
- Low Mach flow required more iterations in general
- Reasonable, predictable cost (t_{CPU}/N_{grid} insensitive)
- Well converged solutions (\mapsto continuous)



Conclusions

- AMR exercised on subsonic, transonic and supersonic flowfields
- Solutions did not require more iterations as L_r increased
- Shocks and separated regions were regions with most effect
- AMR provided great efficiency in getting high accuracy answers

Can now pass to continuous limit (turbulence model dev. requirement)

From here...

- Utilize technique in turbulence modeling work going forward (R_{ij} , T_{ijk} models — ∂u_i details more important)
- 3D flow: CRM, FAITH hill,...? (Revisit Chow-Zilliac—**Vortices**)
- AMR for unsteady flows would be wonderful.