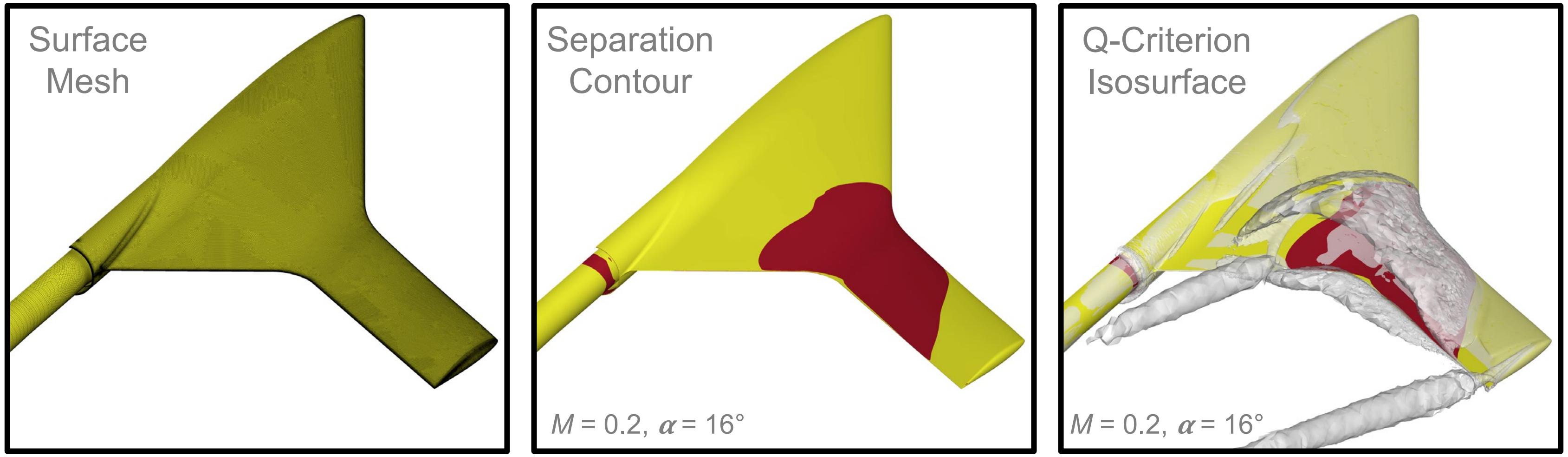
Steady-state RANS Pretest CFD Comparisons for the SWiFT NTF Test

(presentation only)



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AIAA SciTech 2025

Orlando, Florida

SWiFT
Swept Wing Flow Test

Outline

- **Team and Objectives**
- **Computational Scope**
- **Technical Approach**
- **Pretest CFD Comparisons**
  - Transonic Cruise
  - Low-speed Separation Onset
- **Concluding Remarks**

Pretest CFD Team and Objectives

- **Objectives**
  - Generate computational database to assess CFD predictions relative to SWiFT National Transonic Facility (NTF) data
    - Unique opportunity for "blind" comparisons
    - Explore Reynolds number effects on low-speed separation onset
  - Guide experimental setup related to flowfield diagnostics
    - Pressure Sensitive Paint (PSP) and Femtosecond Laser Electronic Excitation Tagging (FLEET)

- **Team Overview**
  - 12 participants
  - 7 institutions
  - 8 CFD solvers

CFD Contributors	Organization	Solvers
Coppin	Dstl	Cobalt
Hiller/Luckring	NASA Langley	USM3D/FUN3D
Humphrey/Graves	AFRL	Kestrel
Maina/Costagliola-Ray	ARA	TAU
Prince/Rana	Cranfield University	Fluent
Prosser/Ghee	NAVAIR	Kestrel
Sullivan	Northrop Grumman	GCNS/Overflow

Computational Scope

- **Focus on fully turbulent simulations following transition predictions conducted by the Transition Fixing Team (TFT)**

- **Explored Reynolds number effects with various modeling fidelities**
  - RANS (Reynolds-averaged Navier-Stokes) in 2021
  - URANS (Unsteady Reynolds-averaged Navier-Stokes) in 2022
  - DDES (Delayed Detached Eddy Simulation) in 2023

- **Pretest CFD solutions scoped to cover Reynolds number range**
  - Low-speed: $M = 0.2$, $Re_{MAC} = [2.5, 7.5, 34]$ million
  - Transonic: $M = 0.8$, $Re_{MAC} = [7.5, 34]$ million

Pretest CFD Solutions

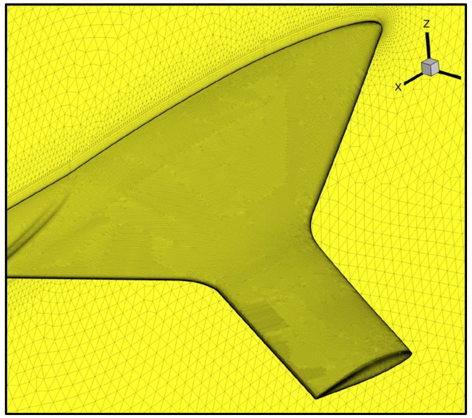
Re_{MAC} (10^6)	Mach 0.2	0.3	0.5	0.8
2.5	✓ (red)			
3.75	✓	✓		
5.75	✓	✓	✓	
7.5	✓	✓	✓	✓ (red)
11	✓	✓	✓	
16	✓	✓		✓
24	✓	✓		
34	✓			✓

✓ (green) = Test Point, ✓ (red) = Includes Forced Transition Testing

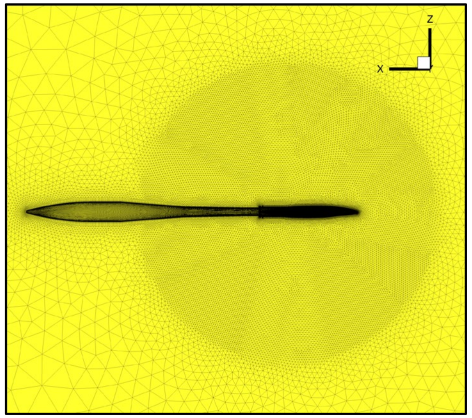
Technical Approach – Setup

- **Computational Grid**
  - Developed mixed-element, unstructured baseline grid per team's best practices and lessons from AIAA Drag Prediction Workshop
    - Free-air semispan model with NTF sting
    - Includes radial nearfield-wing volume source
    - Grid created for each simulated Reynolds number
  - Select grid refinement studies completed using USM3D showed limited RANS solution variability
    - Due to resource limitations, many participants used common grid or custom grids (for solver compatibility) using best practices

- **Participants encouraged to use CFD flow solver of choice**
  - Turbulence modeling default option
    - Spalart-Allmaras (SA) with Rotation/Curvature (RC) and Quadratic Constitutive Relation (QCR2000) corrections



SWiFT NTF Grid – Model Surface

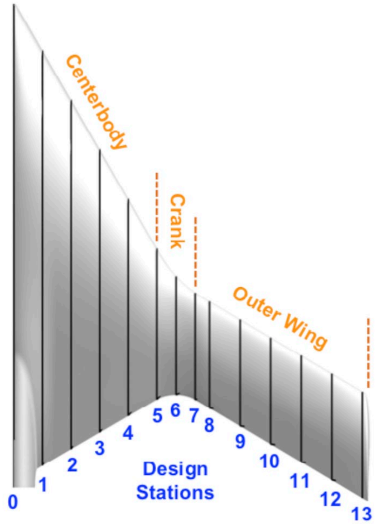


SWiFT NTF Grid – Symmetry Plane

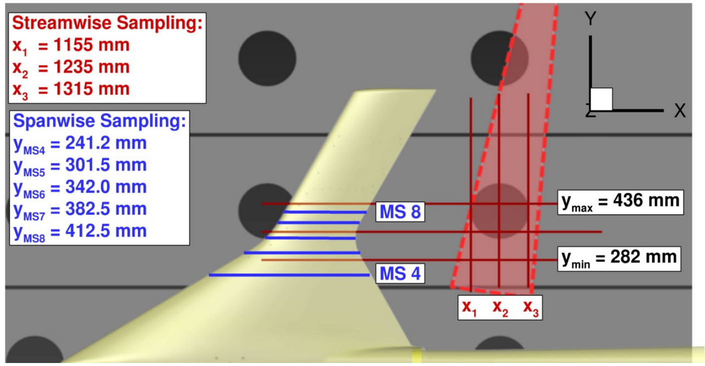
Technical Approach – Data Collection

- **Forces and moments** (required)
  - Longitudinal coefficients (C_L, C_D, C_m)

- **Surface and volume data sampling** (within resources)
  - Section
    - Pressure and skin-friction distributions at Model Stations (MS) 0 to 13
  - Surface
    - Pressure and skin-friction contour data
  - Volume
    - Q-criterion isosurfaces, streamwise planes (FLEET – shown right)
  - Probe
    - Time-accurate unsteady pressure tap data



SWiFT Design Stations



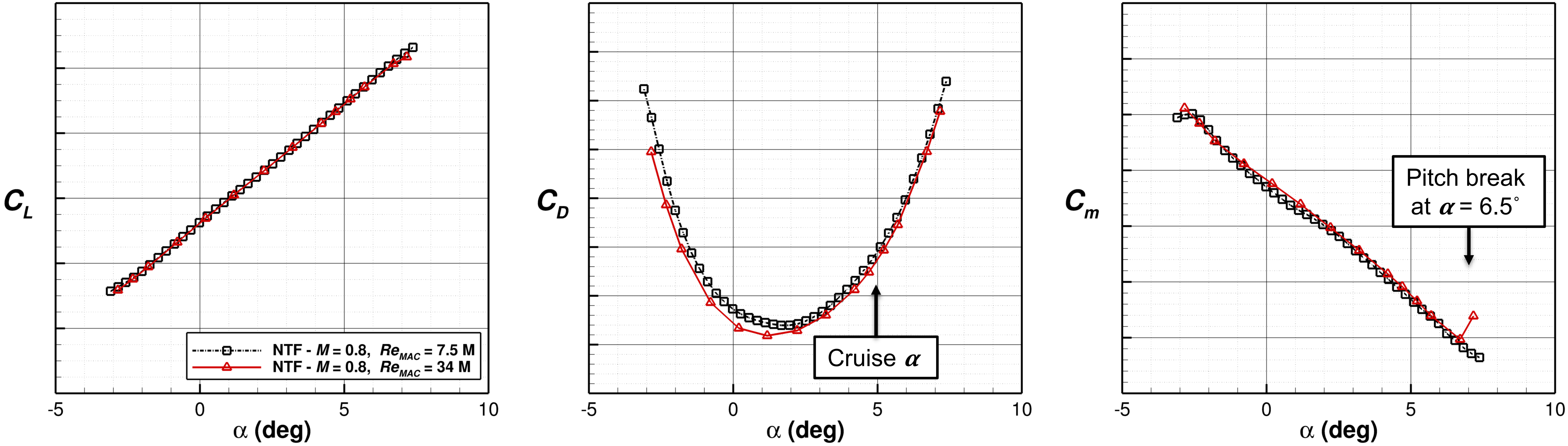
Flowfield Sampling for FLEET

Pretest CFD Comparisons

Exploration of Reynolds Number Effects at Transonic Cruise

Transonic Cruise – Forces and Moments

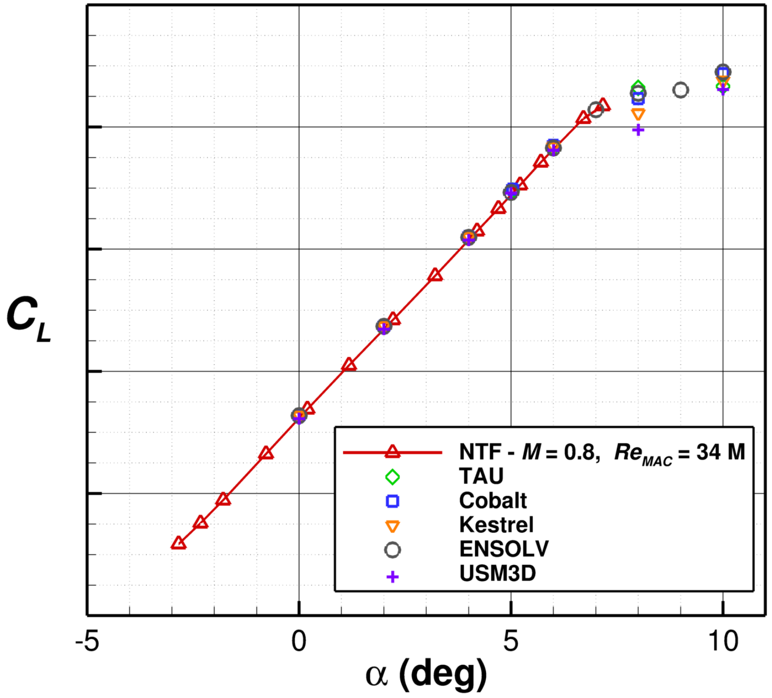
M = 0.8, Re_{MAC} = [7.5 M and 34 M], α = [-3° to 7°]

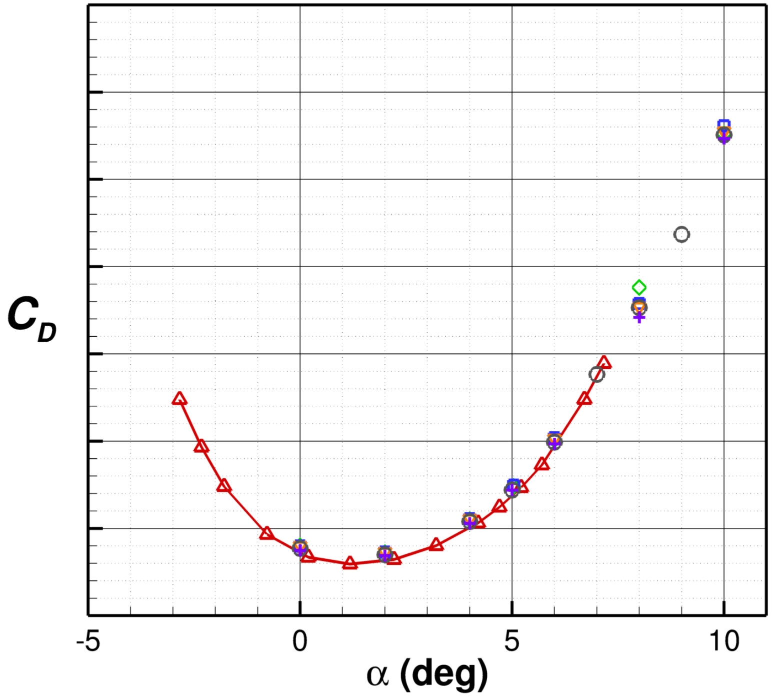


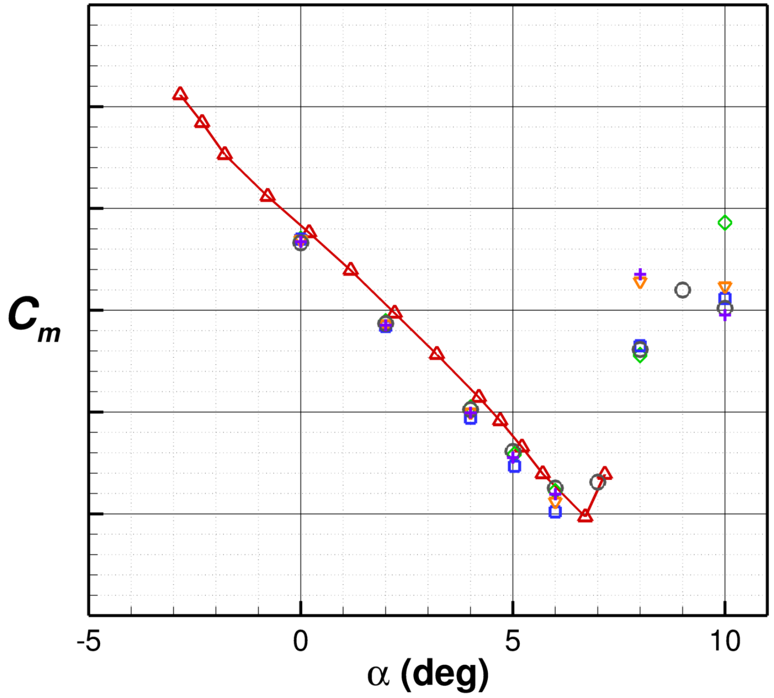
NTF experiment showed limited Reynolds number variation on transonic cruise performance

Transonic Cruise – Forces and Moments

M **= 0.8,** ***Re***$_{MAC}$ **= 34 M,** α **= [-3˚ to 10˚]**



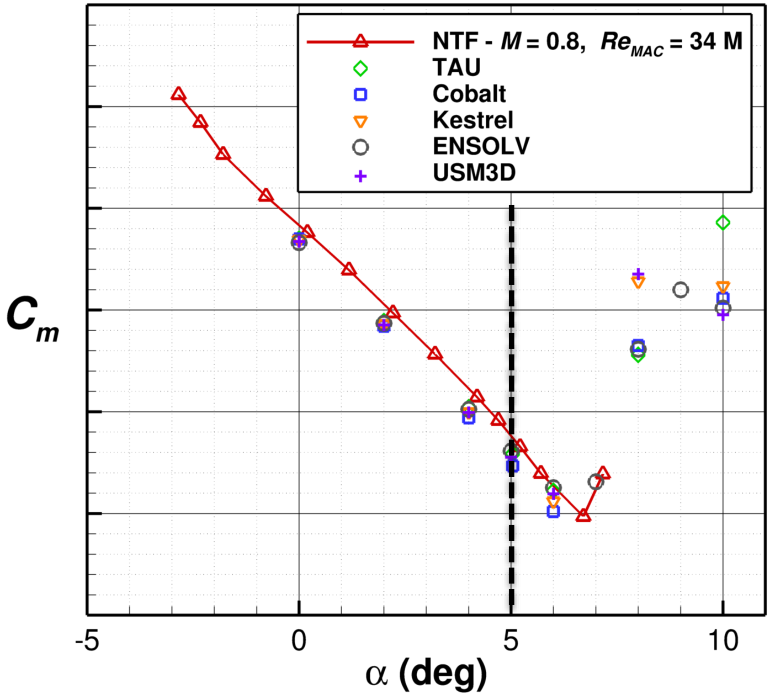


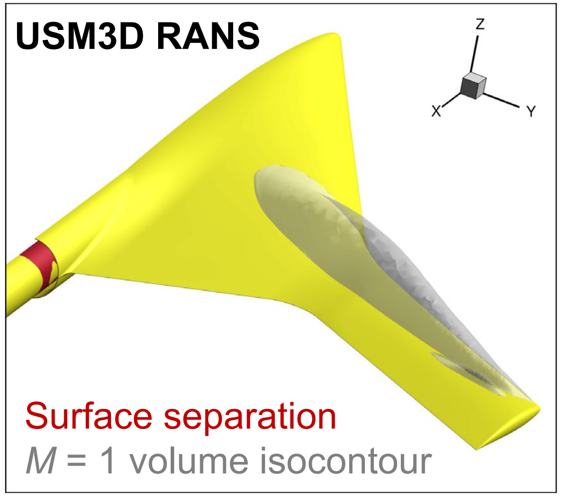


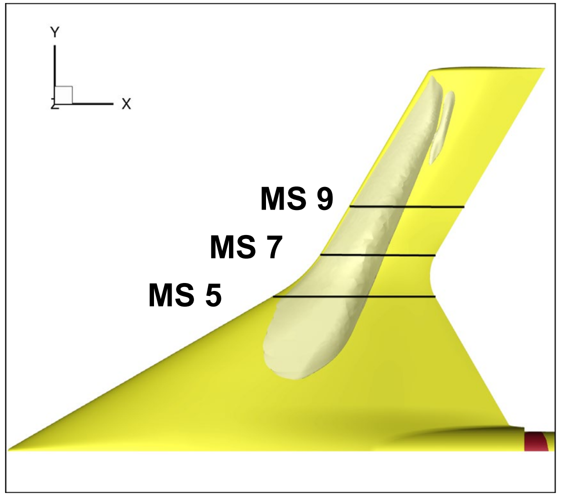
At transonic cruise, RANS results showed limited variability and good agreement with NTF data. Correctly predicted drag rise and pitching moment break through polar range

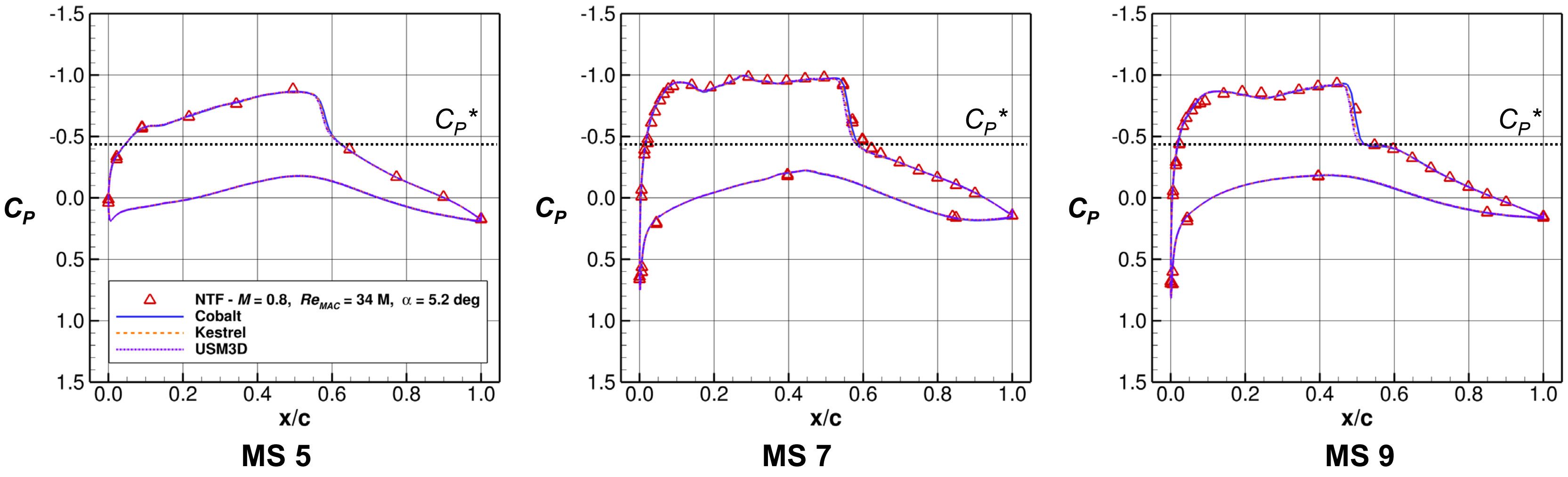
Transonic Cruise – RANS Surface Pressures

M = 0.8, Re_{MAC} = 34 M, $\alpha = 5^{\circ}$





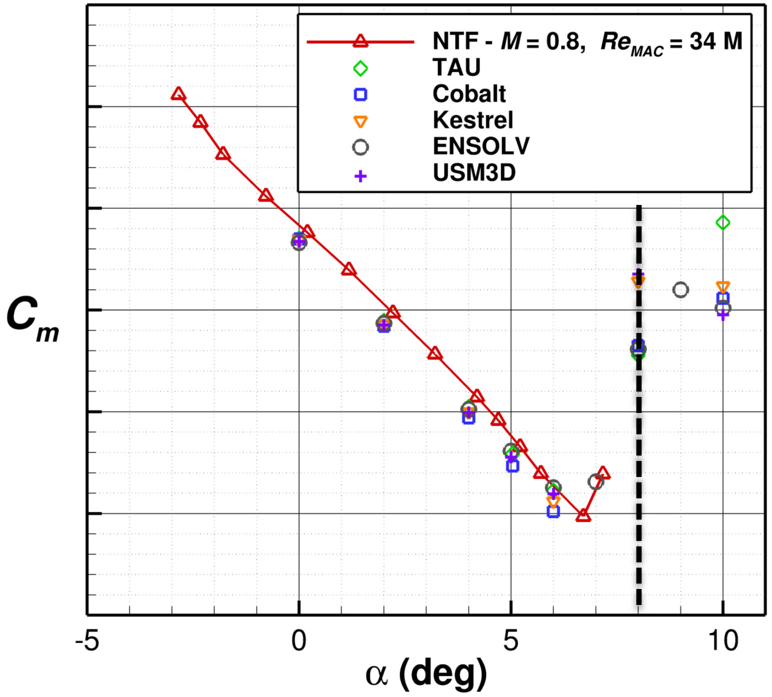


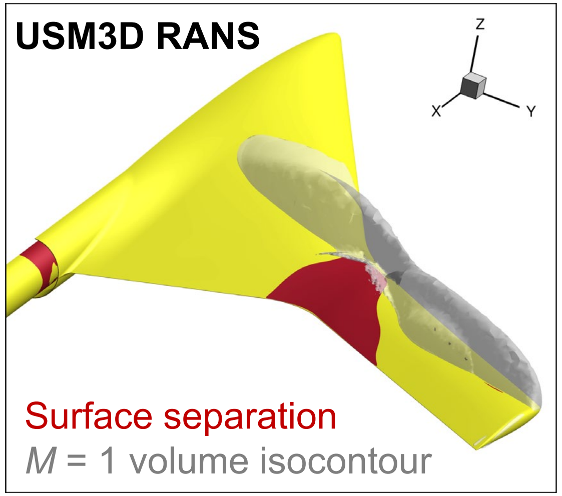


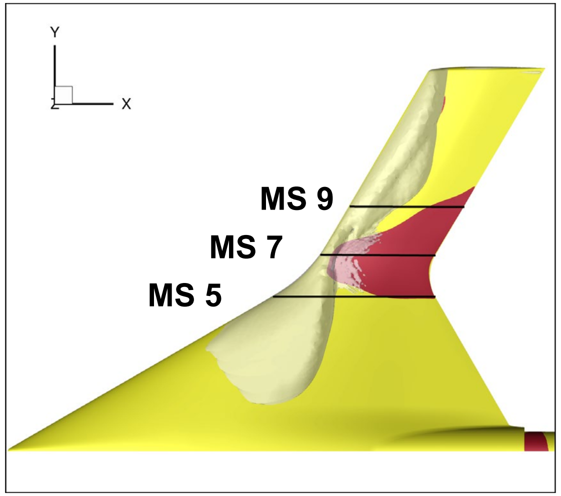
Excellent agreement at cruise angle of attack

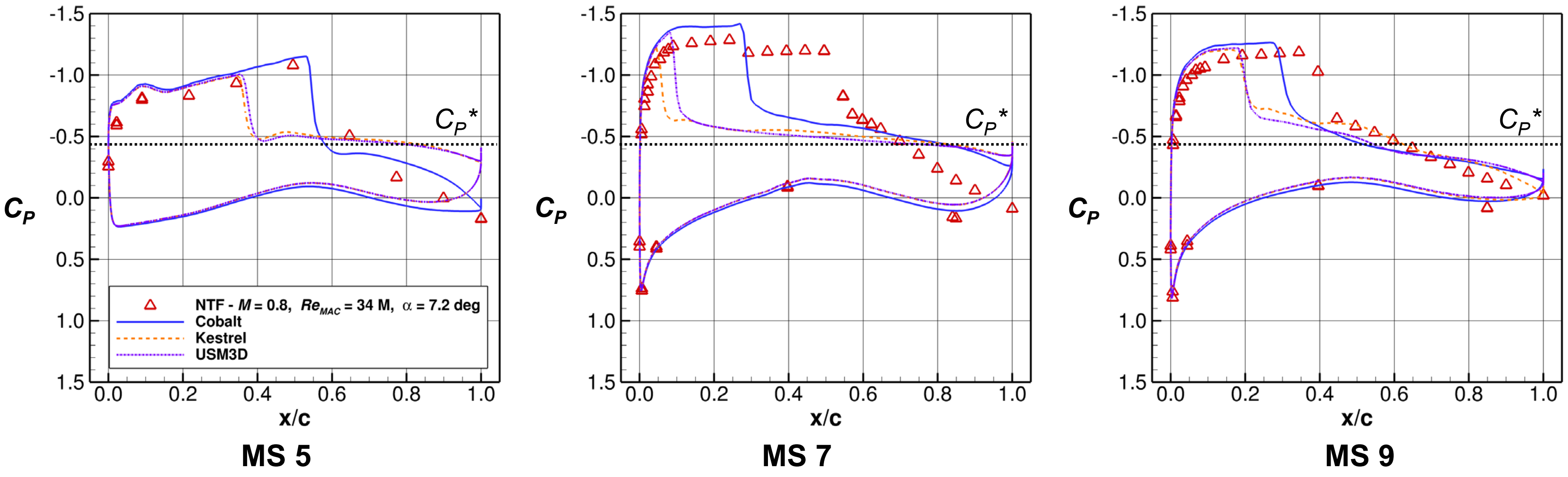
Transonic Cruise – RANS Surface Pressures

***M* = 0.8, Re_{MAC} = 34 M, α = 8°**









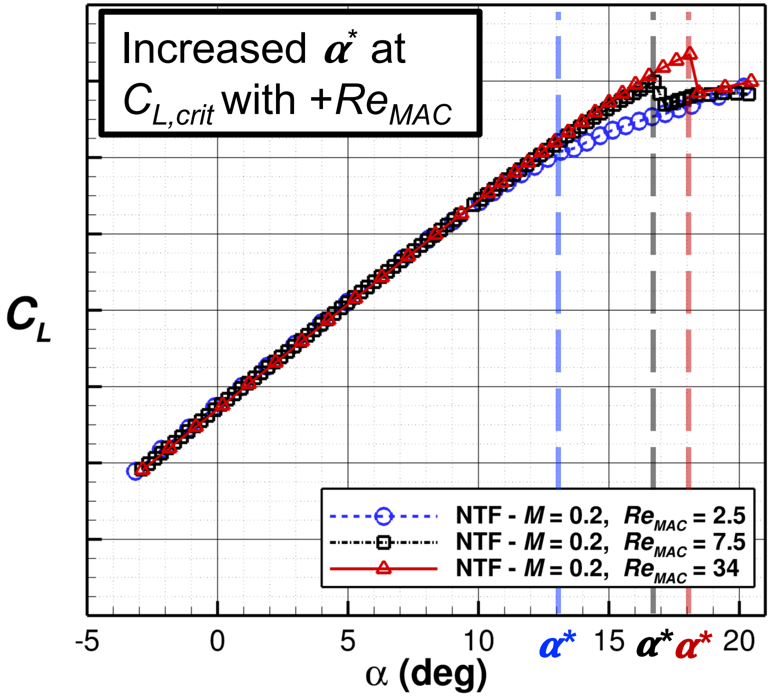
Predicted pitch break near α = 7°, CFD variation in separation onset

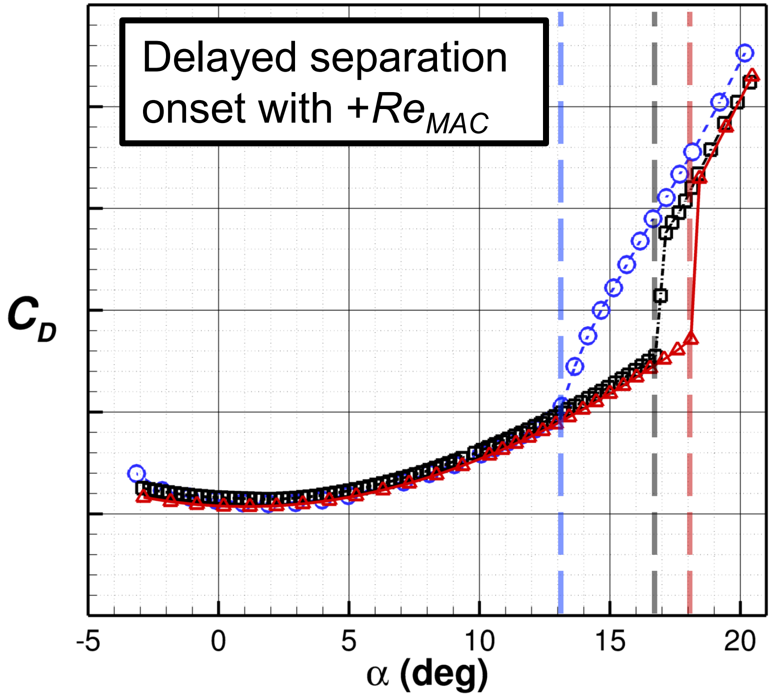
Pretest CFD Comparisons

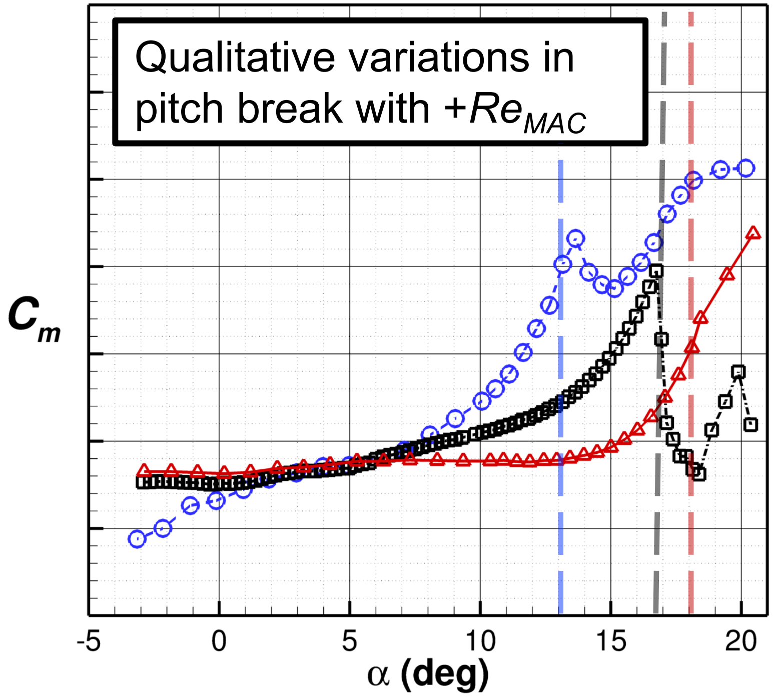
Exploration of Reynolds Number Effects
on Low-Speed Separation Onset

Low Speed Separation Onset – Forces and Moments

M = 0.2, Re_{MAC} = [2.5 M, 7.5 M, and 34 M], α = [-4° to 20°]



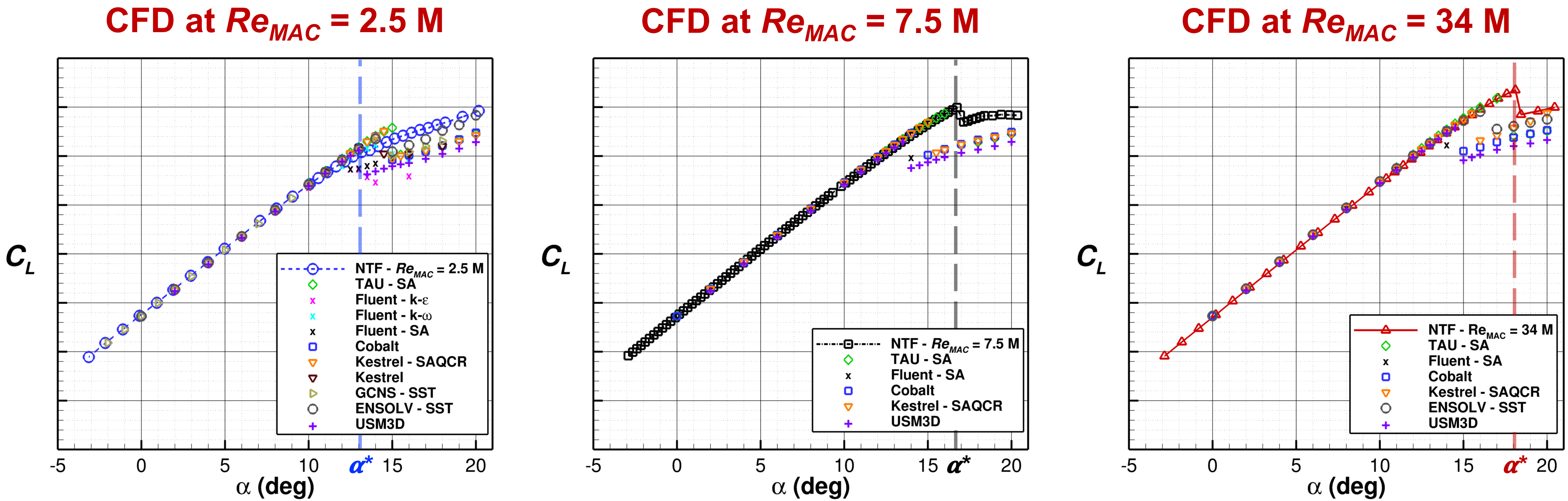




NTF experiment showed notable Reynolds number variation on low-speed separation onset

Low Speed Separation Onset – Forces and Moments

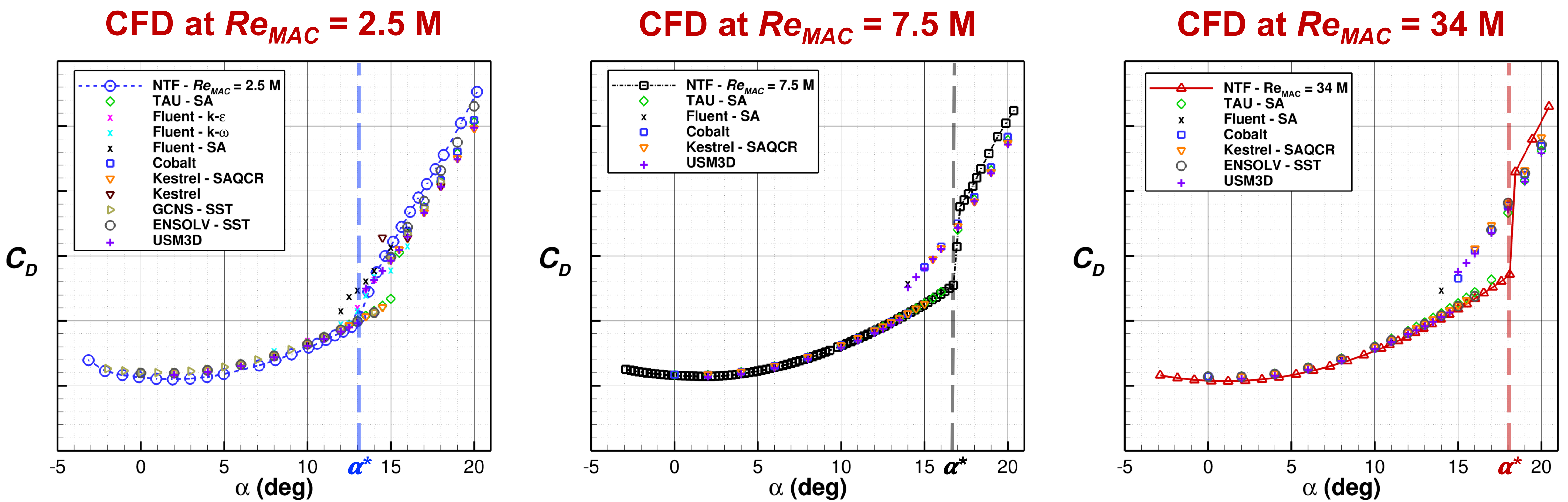
M = 0.2, α = [-4° to 20°]



RANS produces favorable agreement through linear lift curve range.
Generally underpredicts $C_{L,crit}$ and post-stall behavior.

Low Speed Separation Onset – Forces and Moments

M = 0.2, α = [-4° to 20°]

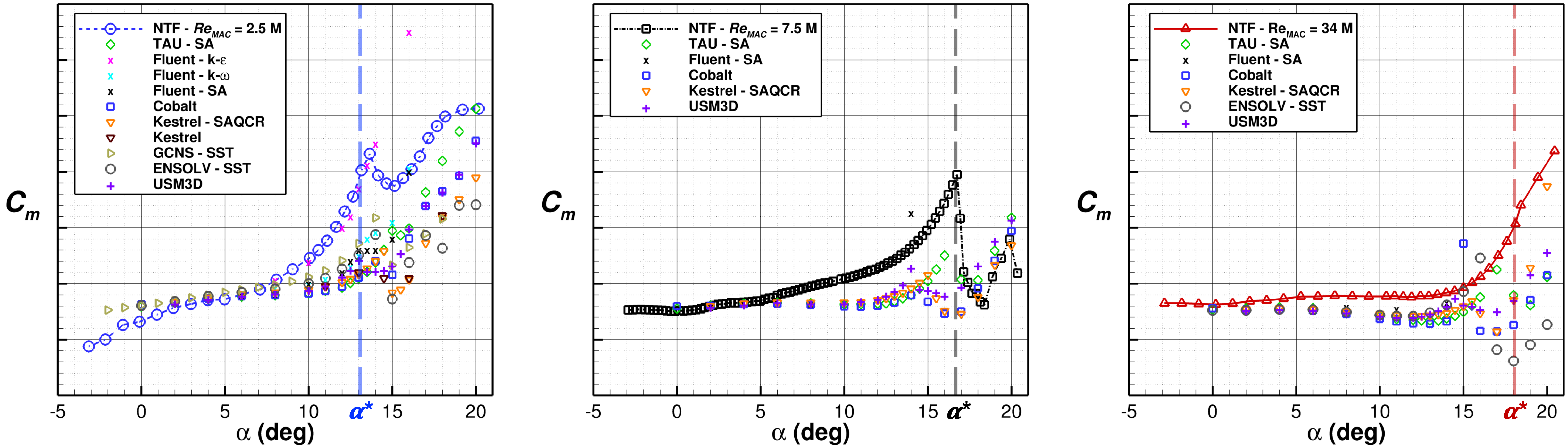


RANS generally predicts early separation onset at intermediate and high Re_{MAC}

Low Speed Separation Onset – Forces and Moments

M = 0.2, α = [-4° to 20°]

CFD at Re_{MAC} = 2.5 M | CFD at Re_{MAC} = 7.5 M | CFD at Re_{MAC} = 34 M



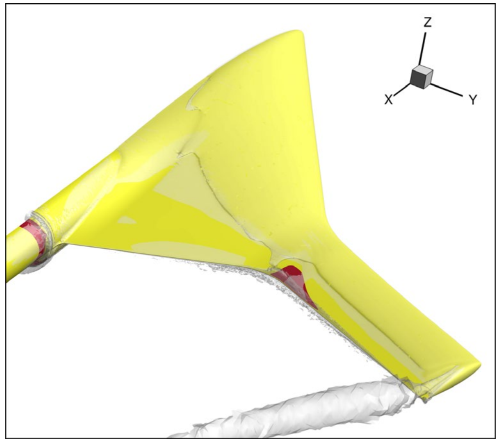
Greater code-to-code variability and underestimates magnitude of C_m,
captures stabilizing effect with +Re_{MAC} but qualitative variations are missed, especially at higher Re_{MAC}

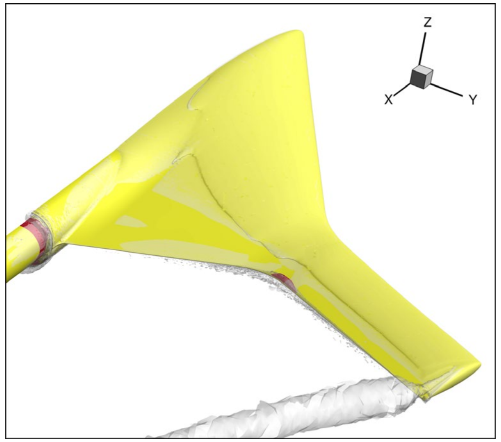
Low Speed Separation Onset – RANS Separation Predictions

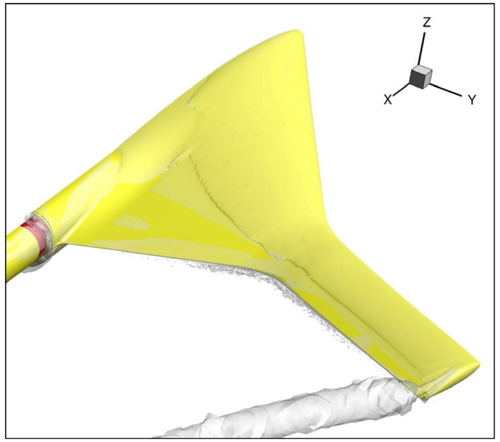
$M = 0.2$
$\alpha = 13^\circ$

Re_{MAC} = 2.5 M | Re_{MAC} = 7.5 M | Re_{MAC} = 34 M

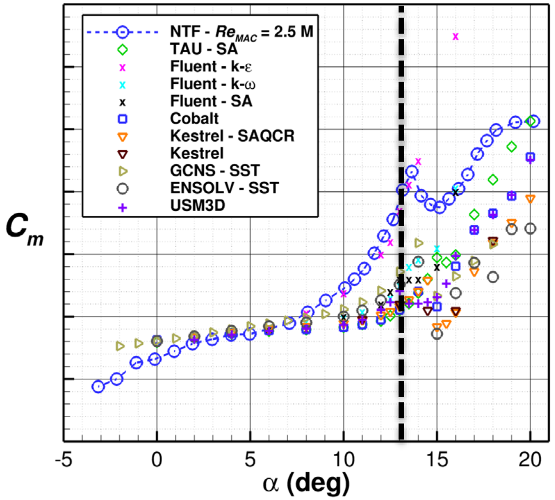
USM3D RANS
Surface separation
Q-crit isocontour

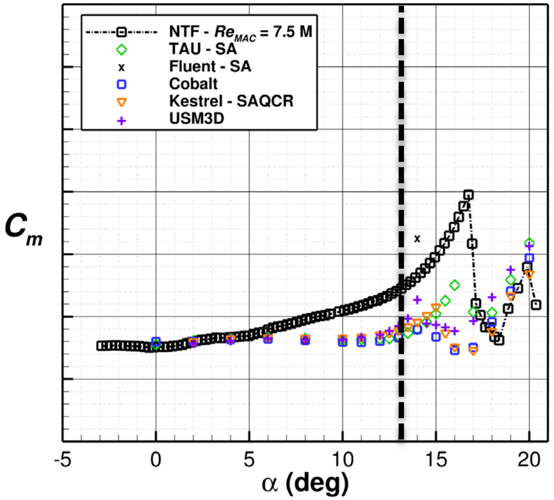


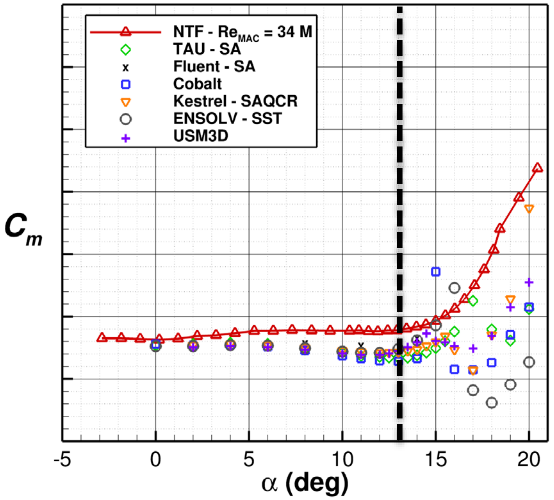




Pretest CFD







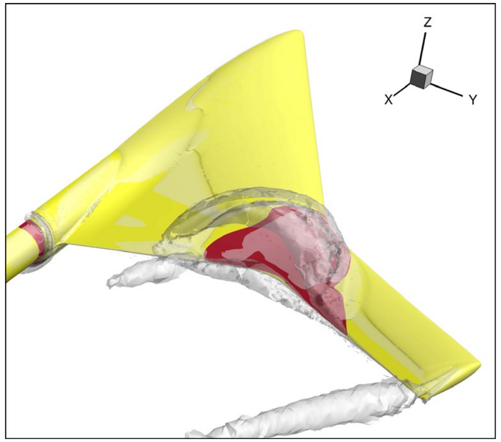
At $\alpha = 13^\circ$, RANS predicts pitch break due to TE separation near crank for Re_{MAC} = 2.5 M

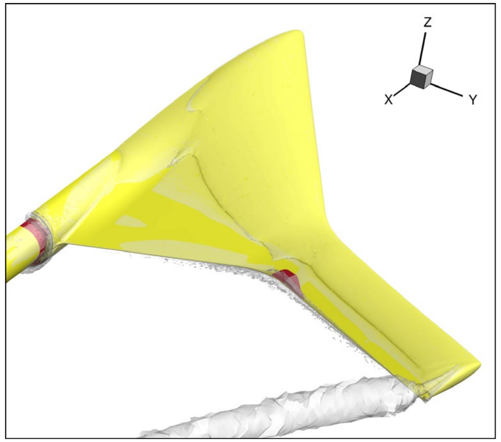
Low Speed Separation Onset – RANS Separation Predictions

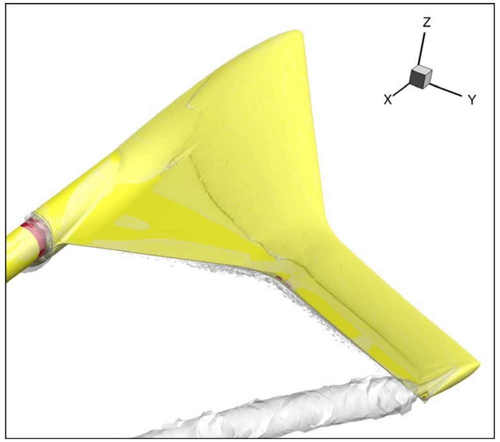
$M = 0.2$
$\alpha = 13.5^{\circ}$

Re_{MAC} = 2.5 M | Re_{MAC} = 7.5 M | Re_{MAC} = 34 M

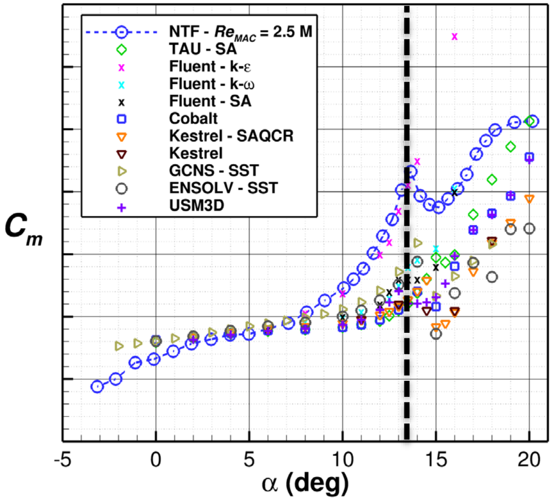
USM3D RANS
Surface separation
Q-crit isocontour

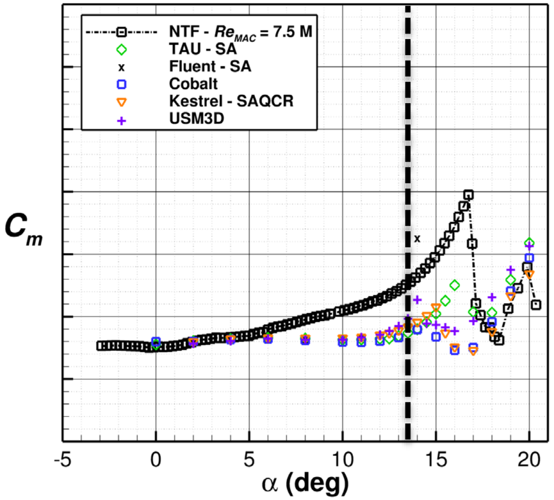


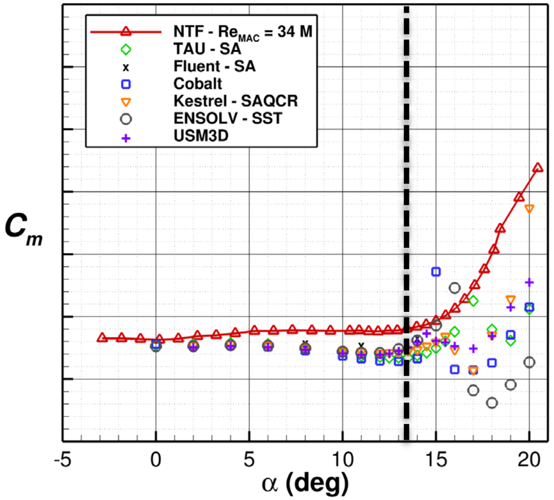




Pretest CFD







With 0.5° increment, RANS predicts full chord crank separation for Re_{MAC} = 2.5 M

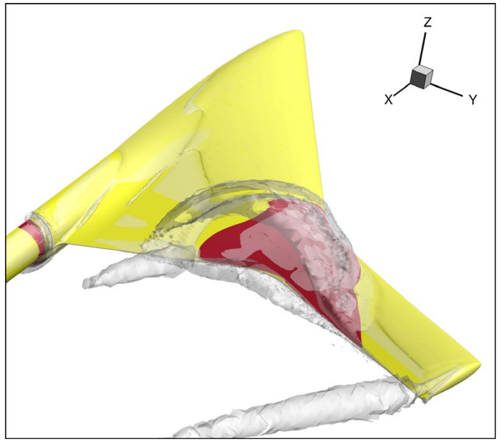
TE separation begins for Re_{MAC} = 7.5 M

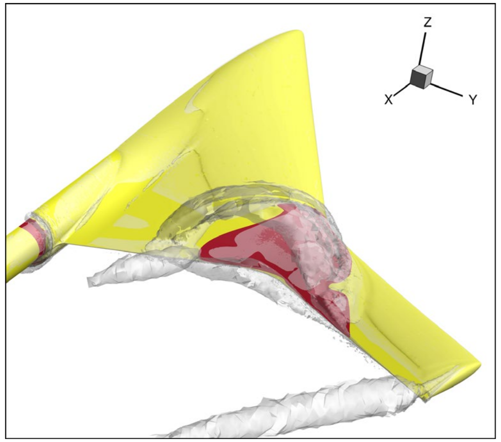
Low Speed Separation Onset – RANS Separation Predictions

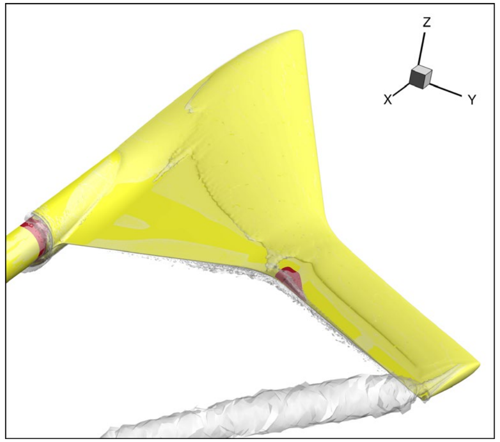
$M = 0.2$
$\alpha = 14.5^{\circ}$

USM3D RANS
Surface separation
Q-crit isocontour

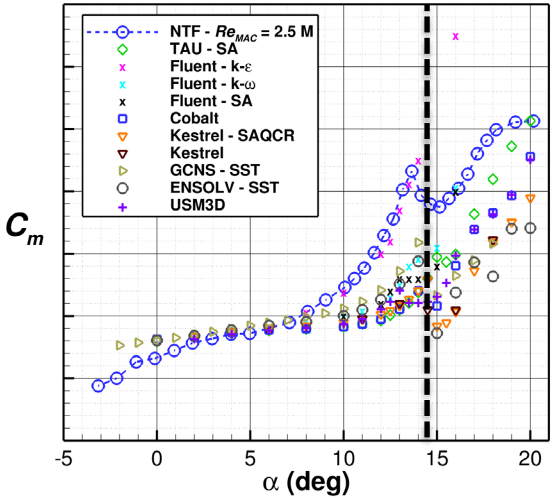
Re_{MAC} = 2.5 M	Re_{MAC} = 7.5 M	Re_{MAC} = 34 M

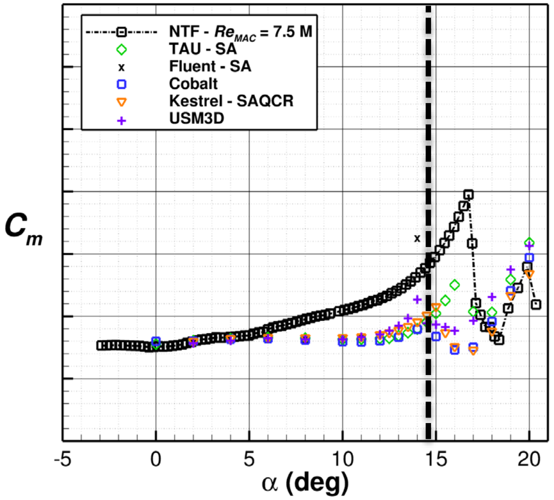


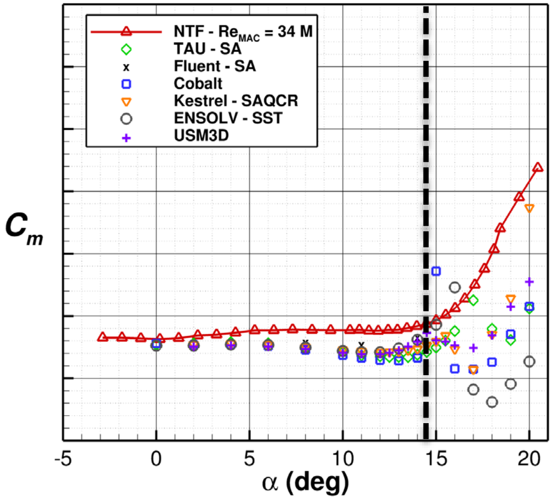




Pretest CFD







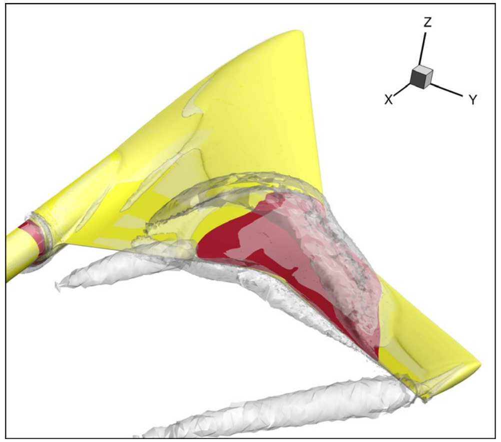
With additional degree increment at $\alpha = 14.5^{\circ}$, RANS predicts complete crank separation for Re_{MAC} = 7.5 M and onset near TE for Re_{MAC} = 34 M

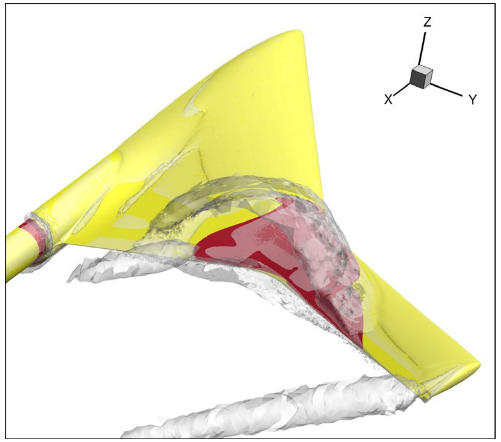
Low Speed Separation Onset – RANS Separation Predictions

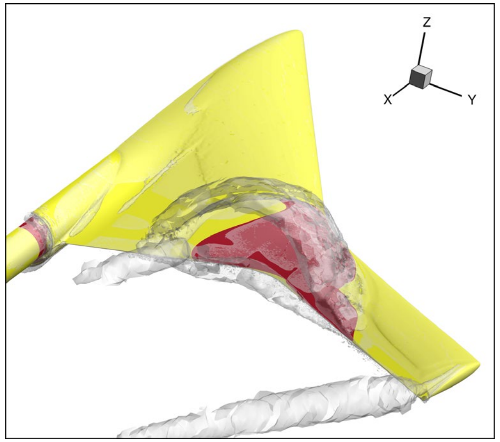
$M = 0.2$
$\alpha = 15.5^\circ$

	Re_{MAC} = 2.5 M	Re_{MAC} = 7.5 M	Re_{MAC} = 34 M

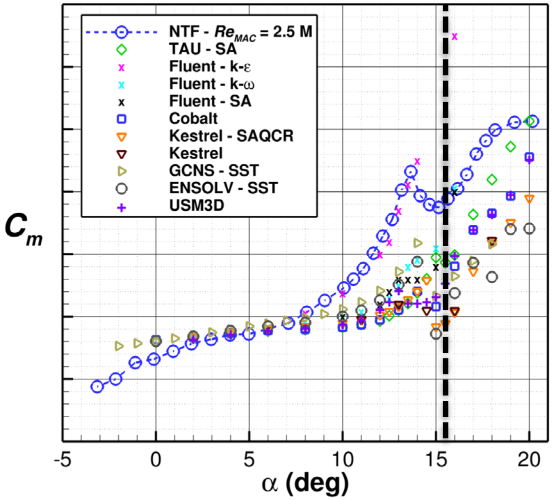
USM3D RANS
Surface separation
Q-crit isocontour

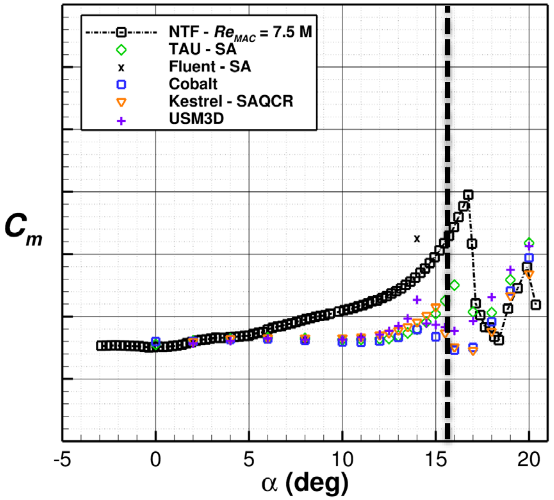


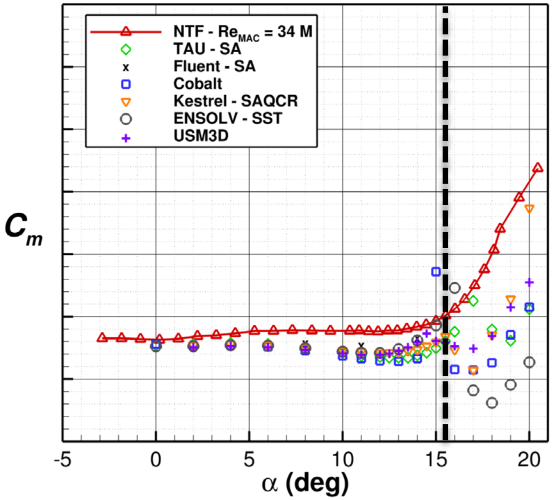




Pretest CFD







By 15.5˚, RANS predicts complete crank separation for Re_{MAC} = 34 M

RANS predicts rapid pitch break due to crank separation with conservative estimates for α^*, especially at higher Reynolds numbers

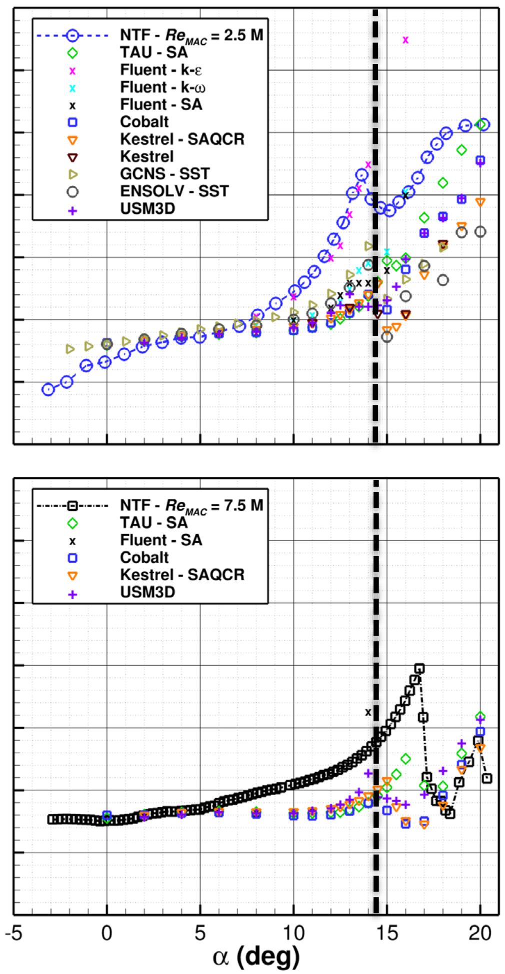
Low Speed Separation Onset – RANS vs PSP

M = 0.2, α = 14.5°

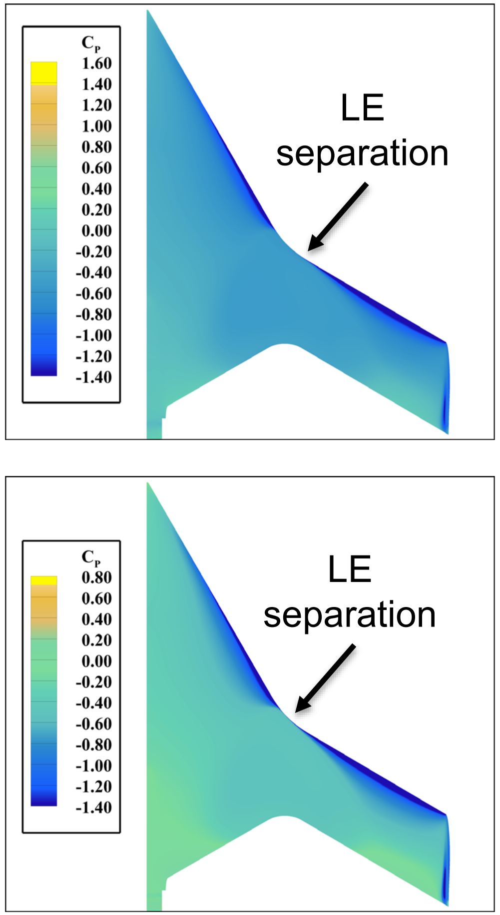
F&M Comparisons

Re_{MAC} **= 2.5 M**

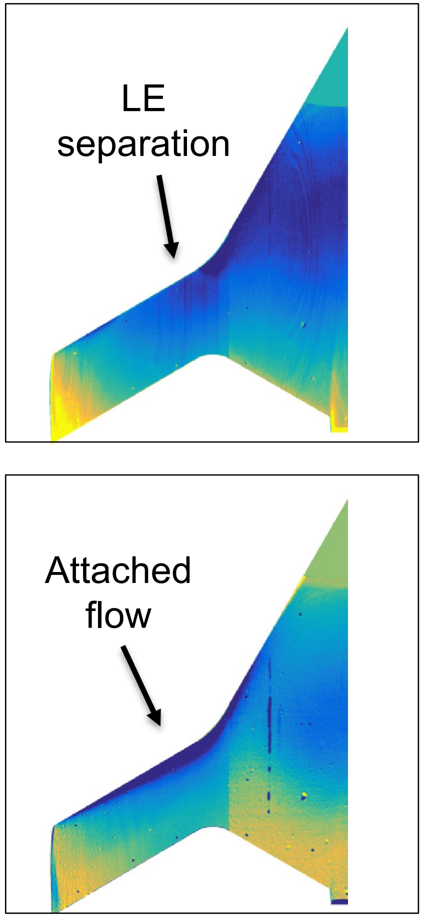
Re_{MAC} **= 7.5 M**



USM3D RANS



NTF PSP



NTF PSP data confirms crank separation for Re_{MAC} = 2.5M, approximately 1° beyond RANS

For Re_{MAC} = 7.5M, PSP data shows sustained loading at crank without separation, i.e., RANS conservative

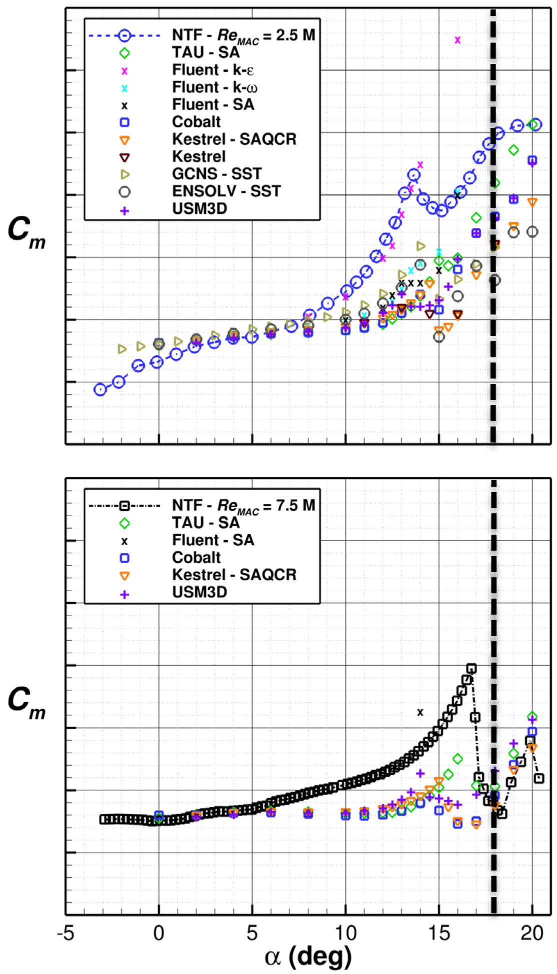
Low Speed Separation Onset – RANS vs PSP

***M* = 0.2, *α* = 18°**

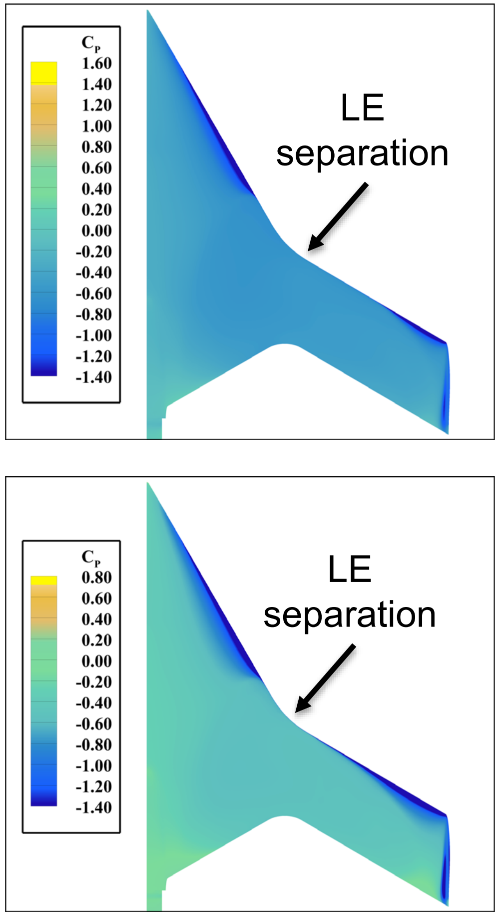
F&M Comparisons

Re_{MAC} = 2.5 M

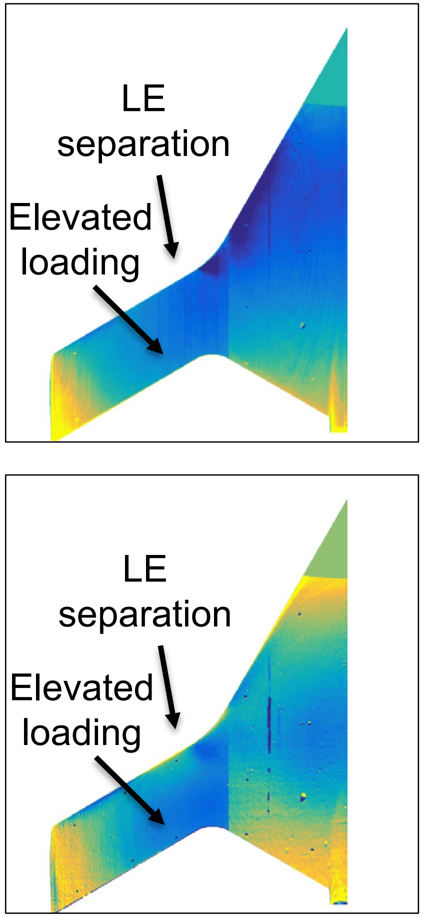
Re_{MAC} = 7.5 M



USM3D RANS



NTF PSP

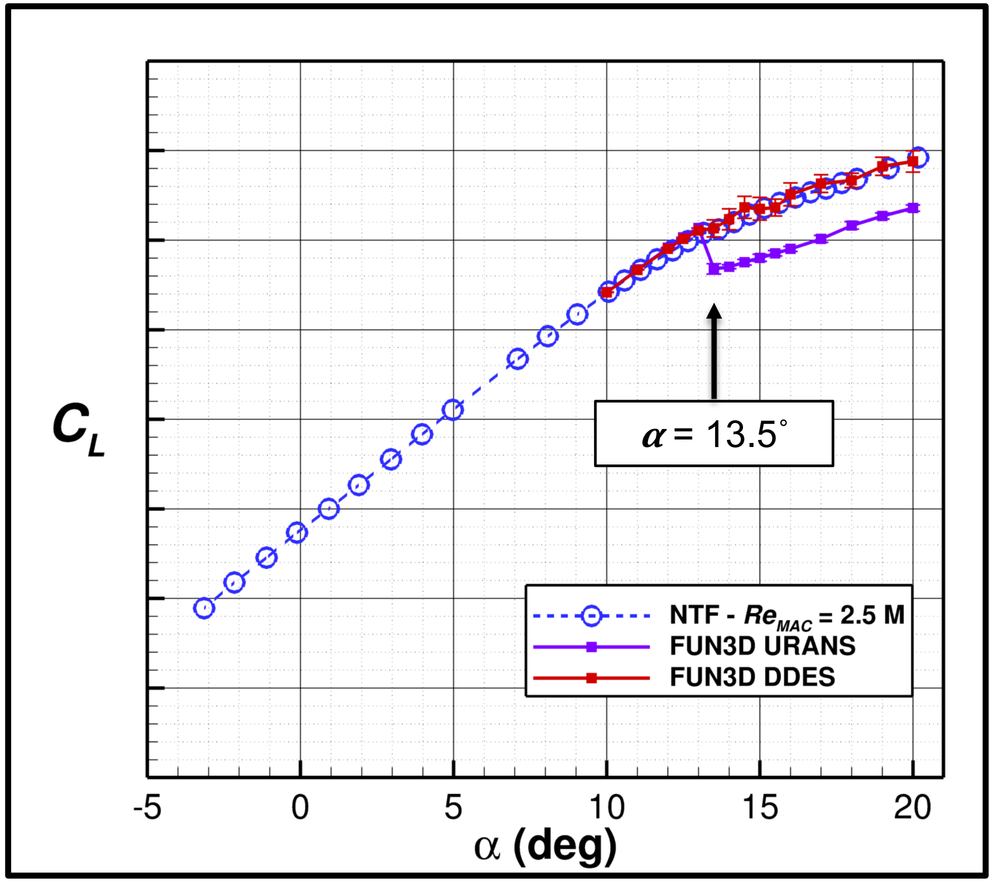


NTF PSP data confirms crank crank separation for Re_{MAC} = 7.5M,

PSP data also shows elevated loading behind LE separation area not captured by RANS

Low Speed Separation Onset – URANS and DDES Results

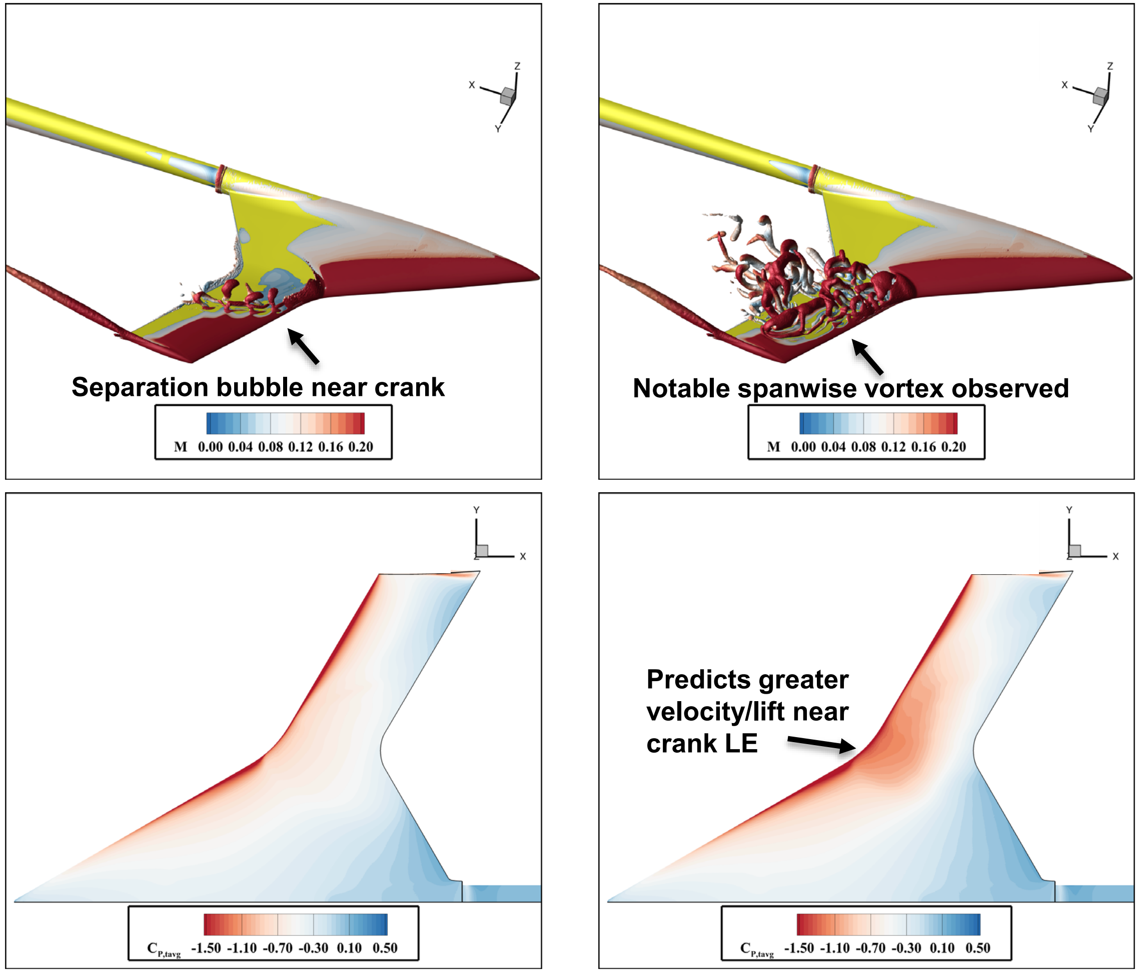
$M = 0.2$, $Re_{MAC} = 2.5$ M



URANS | DDES

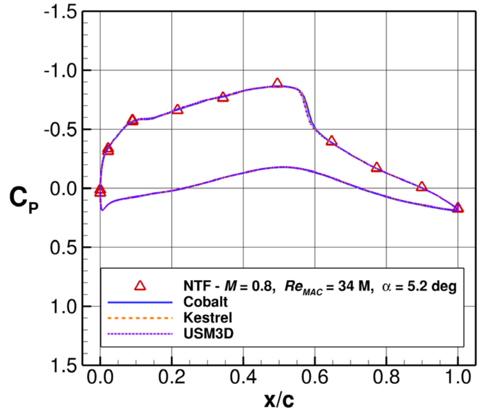
Q-criterion Isosurface

Time-averaged C_P

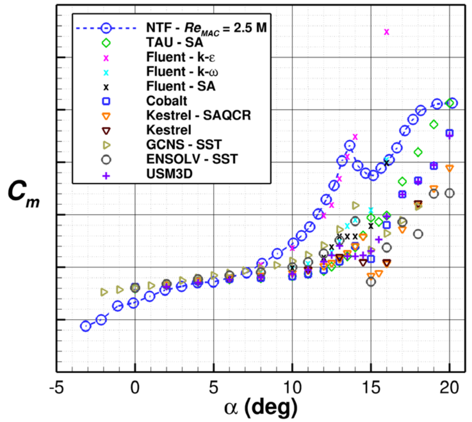


Concluding Remarks

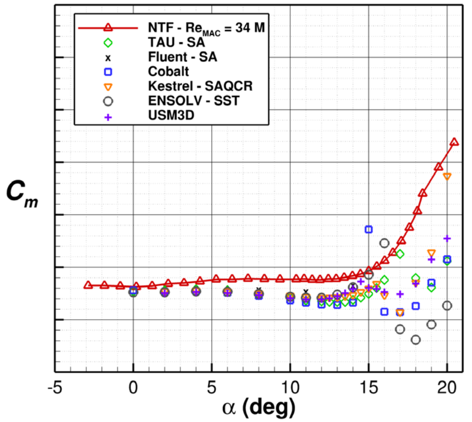
- **Computational database generated for fully turbulent CFD comparisons to NTF experimental data**
  - Enabled code-to-code RANS assessments for lambda-wing type configuration at transonic and low-speed Mach numbers
  - Useful for test matrix guidance and experimental setup
- **Transonic data (*M* = 0.8)**
  - Excellent RANS agreement with NTF forces and moments
  - Correctly captures shock progression with angle of attack and separation onset leading to pitch break
- **Low-speed data (*M* = 0.2)**
  - Good RANS agreement in attached flow regime for $\alpha < 10^{\circ}$
  - Adequate prediction of pitch break α at Re_{MAC} = 2.5 M, useful in characterizing separation onset regions along the wing
  - RANS misses the prediction of Reynolds number effects on forces and moments at intermediate and high Reynolds numbers
  - PSP comparisons and DDES solutions suggest complex vortex aerodynamics involved in separation onset



RANS Transonic Pressure Predictions
***M* = 0.8, Re_{MAC} = 34 M, $\alpha = 5^{\circ}$**



RANS Low-Speed C_m
***M* = 0.2, Re_{MAC} = 2.5 M**



RANS Low-Speed C_m
***M* = 0.2, Re_{MAC} = 34 M**