

High Reynolds Number Testing of the NATO AVT-298 SWiFT Configuration at the National Transonic Facility

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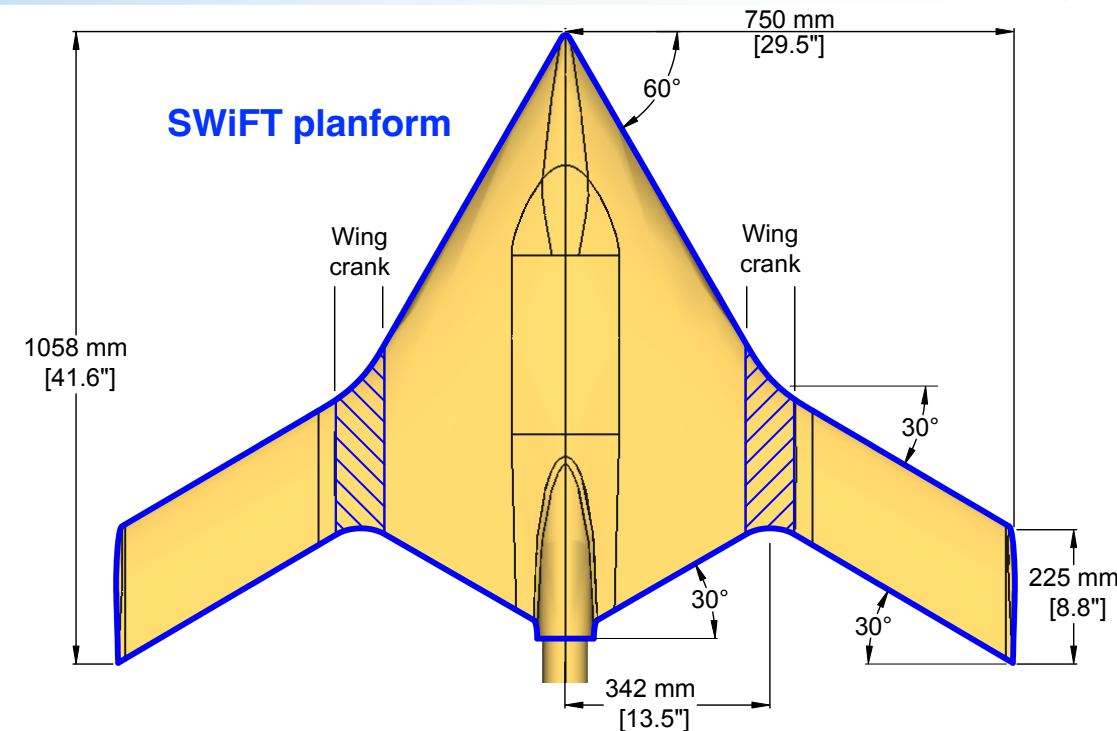
- **Introduction**
- **Wind Tunnel Facility**
- **Test Article**
- **Experiment Setup**
- **Test Results**
- **Summary**

• Motivation

- Conventional WT testing and CFD do not reliably predict **low-speed** aerodynamic characteristics for configurations with moderately swept wings
 - 30° – 60° LE sweep typical of BWB / HWB / UCAV
 - Uncertainty in predictions likely due to smooth body separation dependence on Reynolds number
- ➔ Larger safety margins and risk in design

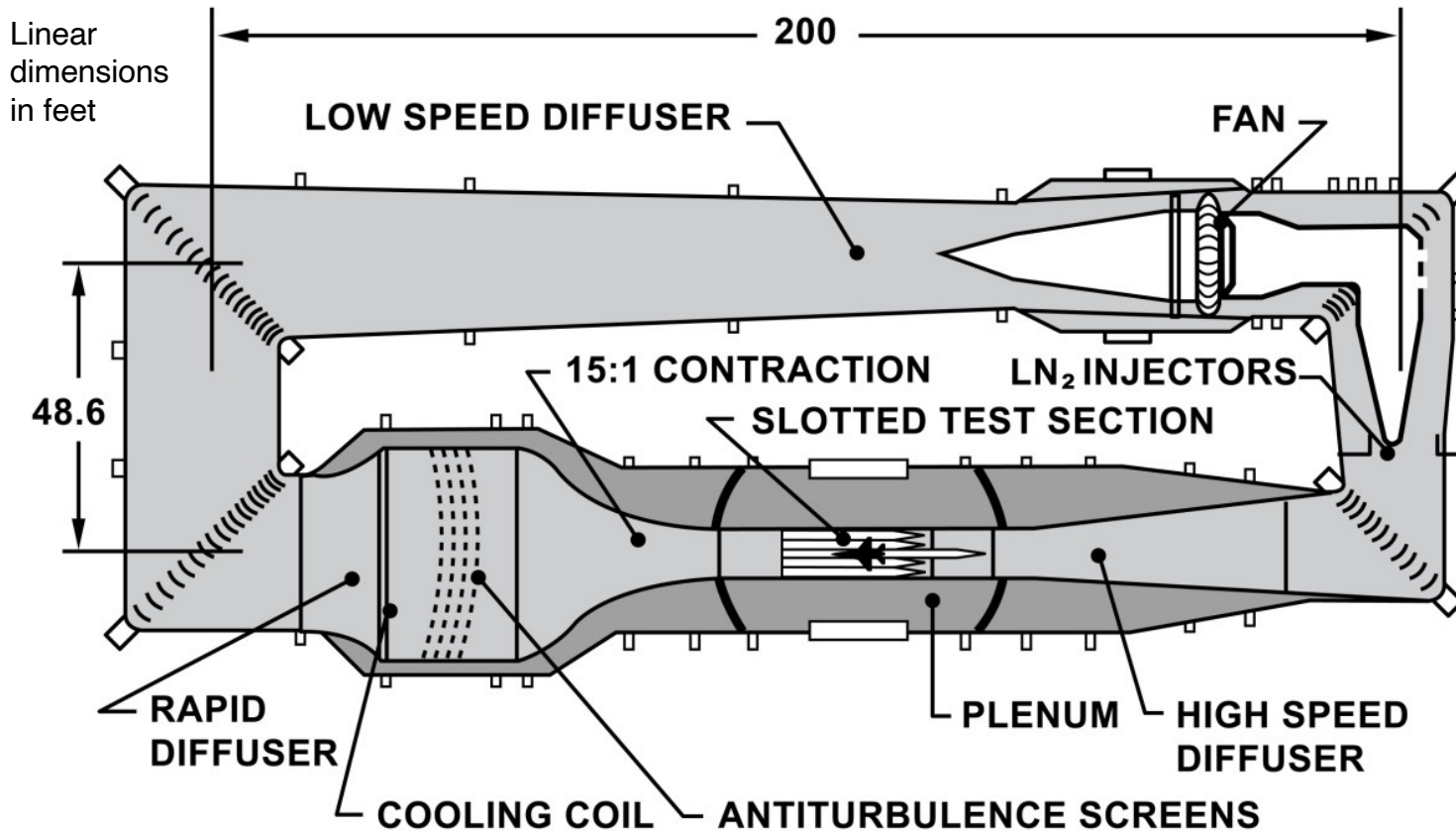
• Approach

- NATO STO **AVT–298** research task group
 - Dstl, NASA, AFRL + several other organizations
 - WT test, pre-test CFD, & transition fixing subteams
- **Swept Wing Flow Test (SWiFT)** research configuration with relevance to BWB / HWB / UCAV
 - Understand flow physics for this class of planform
- Capstone high Reynolds number experiment in **National Transonic Facility (NTF)**



NATO – North Atlantic Treaty Organization
 STO – Science and Technology Organization
 AVT – Applied Vehicle Technology
 Dstl – Defence Science and Technology Laboratory (U.K.)
 NASA – National Aeronautics and Space Administration (USA)
 AFRL – Air Force Research Laboratory (USA)
 BWB – Blended Wing Body HWB – Hybrid Wing Body
 UCAV – Unmanned Combat Aerial Vehicle
 WT – Wind Tunnel CFD – Computational Fluid Dynamics
 LE – Leading Edge

National Transonic Facility (NTF)



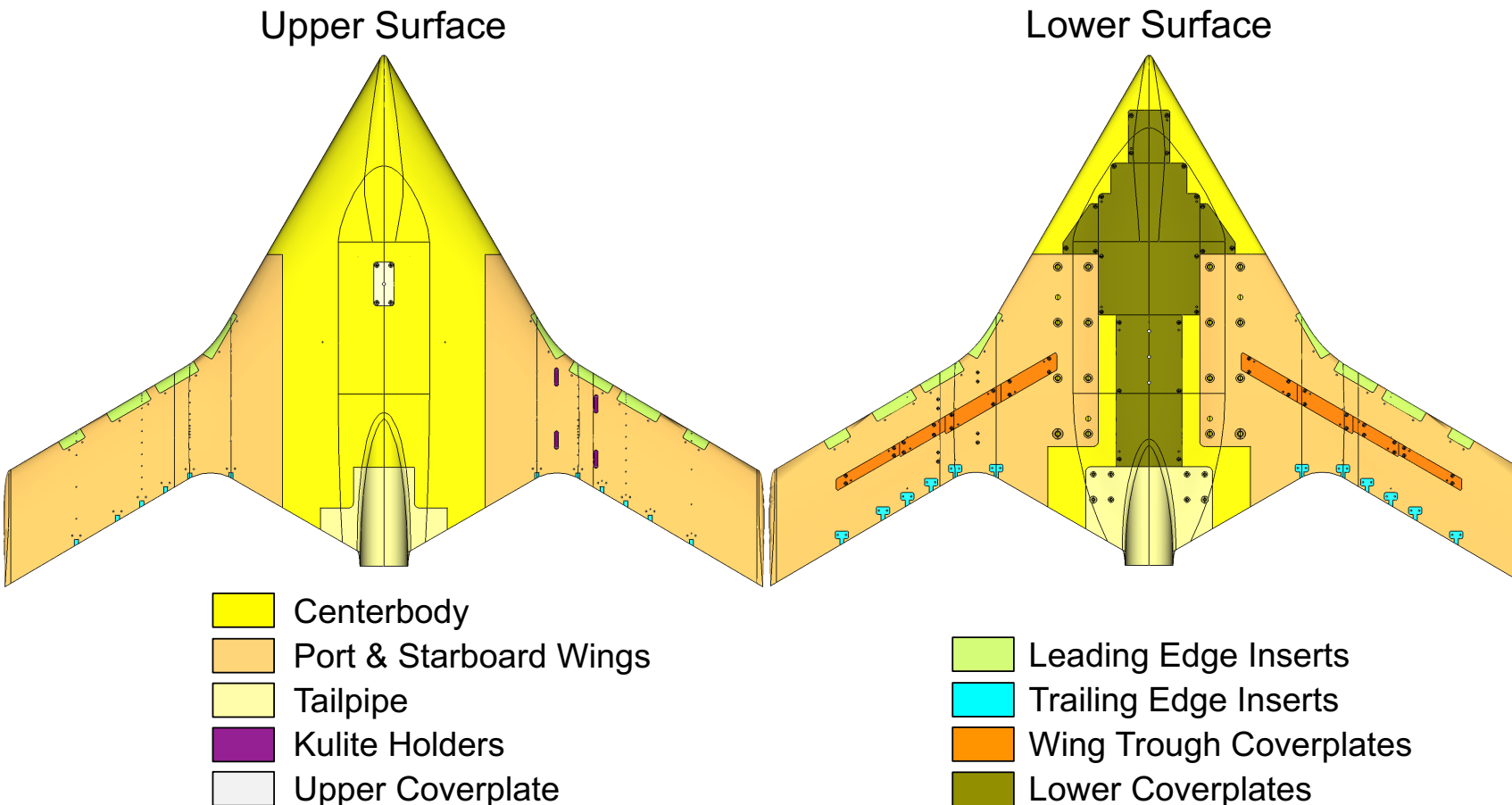
Photos : NASA

- Located at the NASA Langley Research Center
- Pressurized, cryogenic wind tunnel
- Operate in dry air or gaseous nitrogen
- Achieve very high Reynolds numbers
 - Flight or near-flight for many vehicles

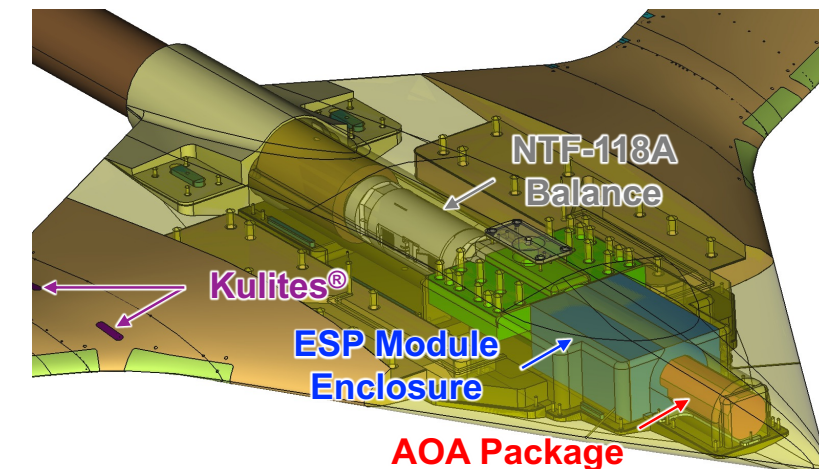
Test Gas	<u>Air</u>	<u>Nitrogen</u>
Mach Number	0.1 – 1.10	0.1 – 1.20
Max Unit Reynolds Number	20x10 ⁶ / ft	145x10 ⁶ / ft
Total Pressure	1 – 8.3 atm	1 – 8.3 atm
Total Temperature	80°F to 130°F	-250°F to 80°F

• SWiFT cryogenic WT model

- Designed and fabricated by Aircraft Research Association (ARA) using C200 maraging steel
- Smooth upper surface with minimal part seams and fastener holes
- Instrumentation : 6-component balance, AOA package, 2 ESP modules (126 static taps), 4 kulites



Symbol	Metric Units	Imperial Units
S_{ref}	0.6076 m ²	6.5403 ft ²
$\bar{c}$	559.1 mm	22.012 in.
b	1500 mm	59.055 in.
R	3.703	3.703



• Test Objectives

- Investigate Reynolds number (Re_{mac}) effects on low-speed stability & control (S&C) characteristics
- Evaluate transonic wing design performance
- Assess effectiveness of boundary layer (BL) transition fixing schemes guided by CFD simulations

• Test Conditions

- $M_\infty = 0.2, 0.3, 0.5, 0.8$, $Re_{mac} = 2.5M$ to $34M$
- $T_0 = 100^\circ F$ (Air), $-50^\circ F$ (N_2), $-200^\circ F$ (N_2)
- $\alpha = -4^\circ$ to 20° , $\beta = -10^\circ$ to 10°

• Test Matrix

- Baseline to match ARA low Re_{mac} conditions
- Re_{mac} variation at each Mach number
- Forced BL transition and transition detection
- Flow visualization



Re_{mac} (10^6)	Mach Number			
	0.2	0.3	0.5	0.8
2.5	✓, T, S, P, F			
3.75	✓, F	✓		
5.75	✓	✓	✓	
7.5	✓, P, F	✓	✓	✓, T, S
11	✓	✓	✓	
16	✓	✓		✓, P, F
24	✓	✓		
34	✓			✓

✓ - F&M / Pressure

T - Transition Fixing

P - PSP

S - Sublimation

F - FLEET

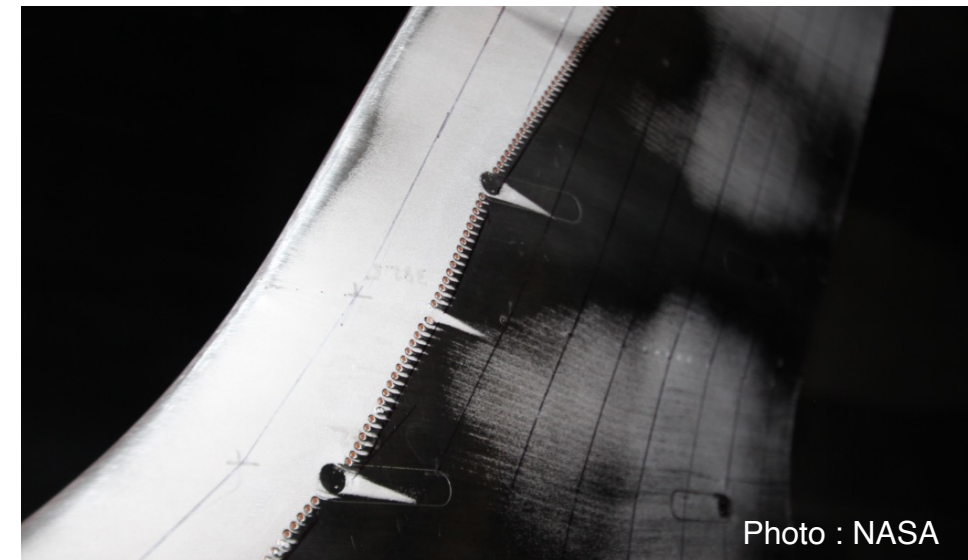
• Forced BL Transition

- Hybrid approach (classical + CFD) for upper and lower surfaces
- Low-speed (Mach 0.2) and transonic (Mach 0.8)
- Jim Luckring, et al., “An Application of CFD to Guide Forced Boundary-Layer Transition at Subsonic and Transonic Speeds for a Lambda-Wing Configuration”,
Thur. 1:00PM, APA-75, Bayhill 30



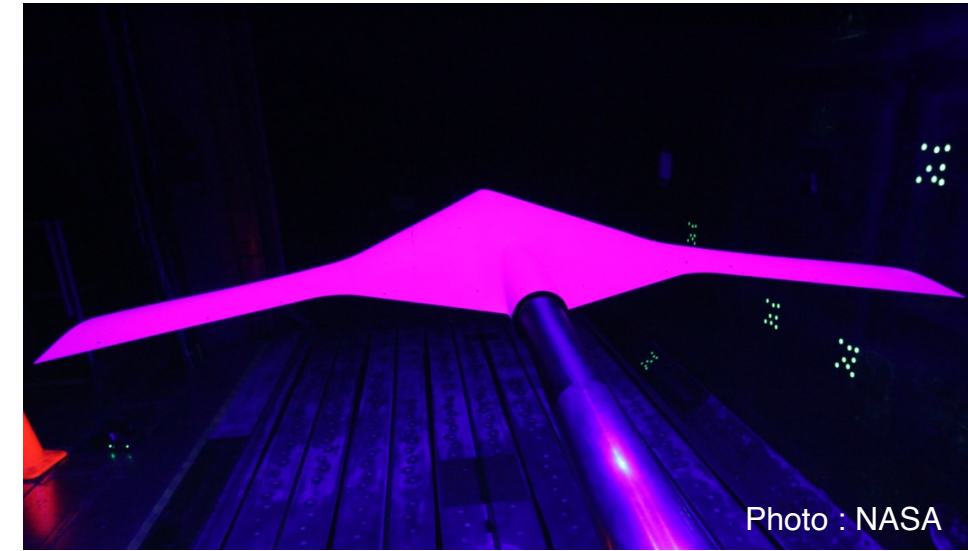
• BL Transition Detection

- Classical technique using sublimating chemicals
- New novel technique using static surface pressure data and kulite dynamic pressure data
- All Mach numbers (0.2 – 0.8)
- Jenna Eppink, et al., “Transition Measurements on the SWiFT Model in the National Transonic Facility”,
Thur. 1:20PM, APA-75, Bayhill 30



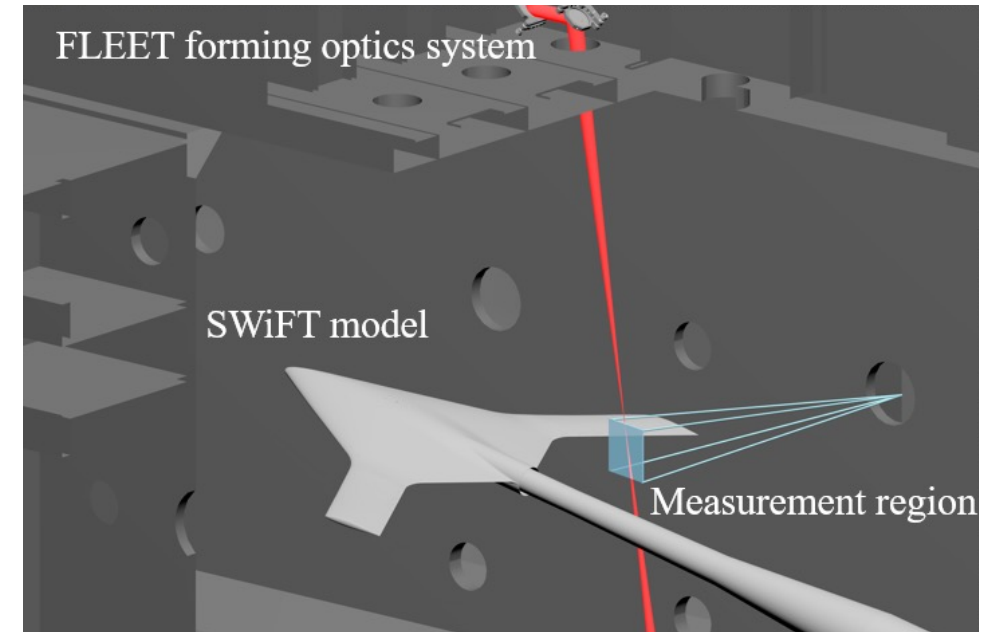
- **Pressure Sensitive Paint (PSP)**

- Global surface pressure map on model
- 2 cameras (1 center + 1 focused on port wing crank)
- Low-speed (Mach 0.2) and transonic (Mach 0.8)
- Neal Watkins, et al., “Application of PSP on the SWiFT Model in the National Transonic Facility”,
Thur. 2:00PM, APA-75, Bayhill 30



- **Femtosecond Laser Electronic Excitation Tagging (FLEET)**

- Velocity measurements in wake downstream of starboard wing crank
- Low-speed (Mach 0.2) and transonic (Mach 0.8)
- Jian Gao, et al., “Velocity Measurements in the Wake of the Swept Wing Flow Test Model at the National Transonic Facility”,
Thur. 2:20PM, APA-75, Bayhill 30

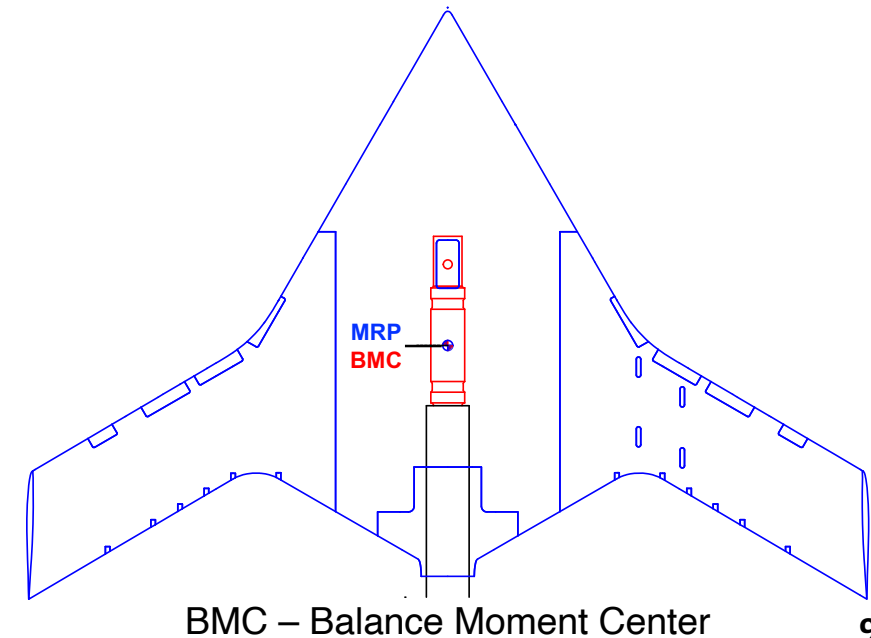
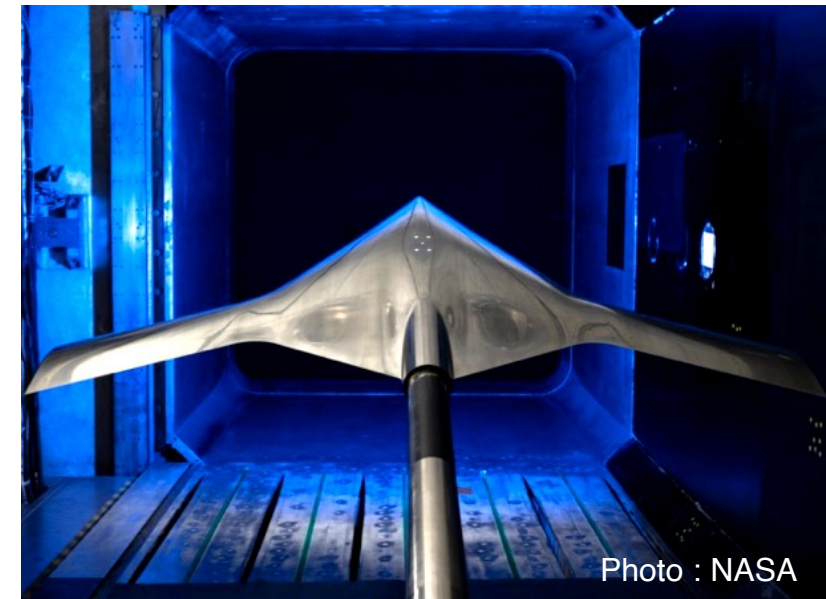


• Focus of results

- Longitudinal aerodynamic force & moment coefficients
 - C_L , C_m , C_D scales removed per project guidelines
- **Mach 0.2, $\beta = 0^\circ$**
 - Transonic results in paper
- SWiFT clean configuration (no trip dots)

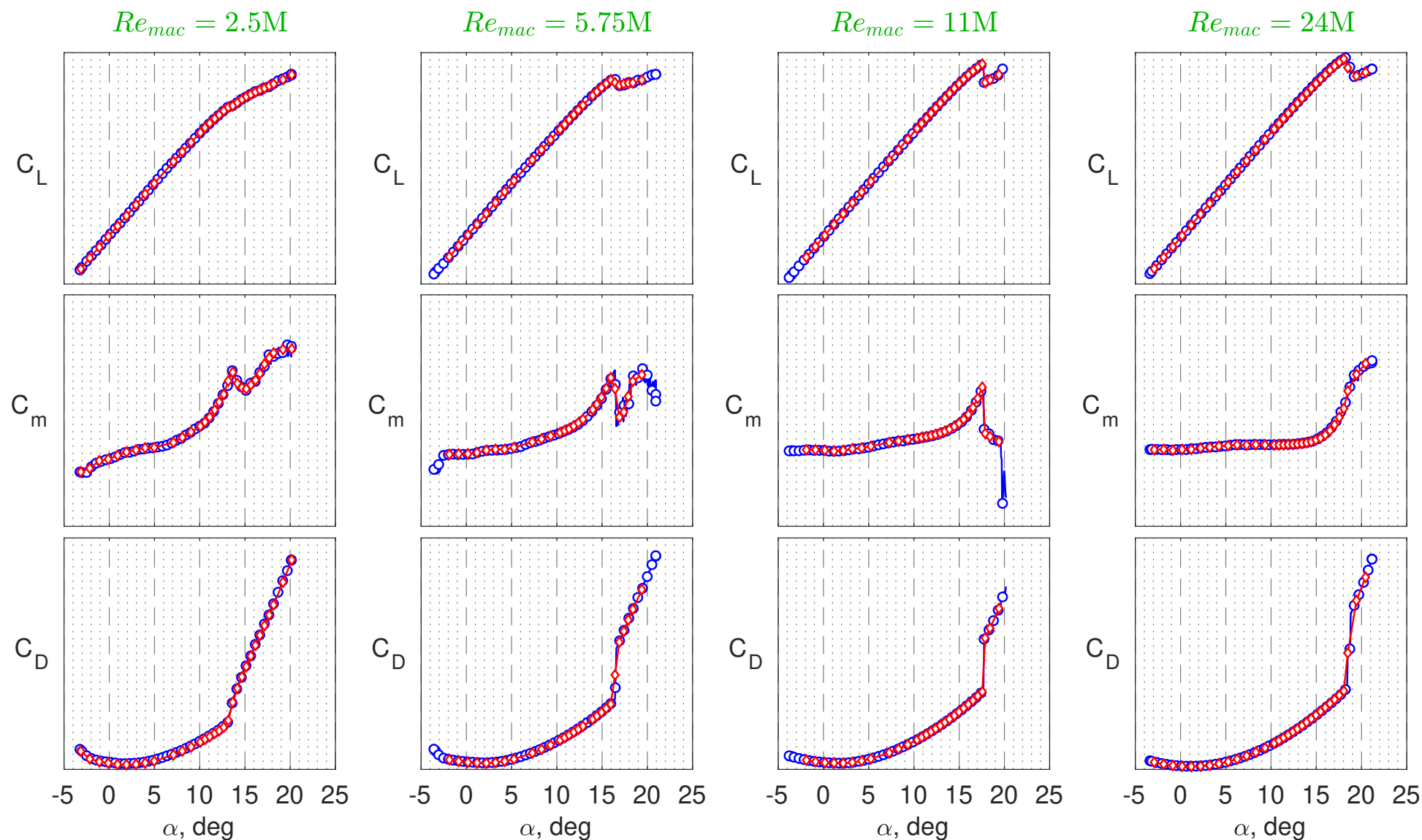
• Data acquisition

- Move-pause polars
 - 8-sec averaged data points at 80 Hz scan rate
- **Continuous sweep** polars
 - 0.1 deg/sec movement rate at 80 Hz scan rate
 - Post-processed for averaged data point every ~ 0.05 deg
 - Capture details around $C_{L,max}$ (pre- and post-stall)
 - Positive (min $\rightarrow$ max) and negative (max $\rightarrow$ min) directions
- Moment reference point (MRP)
 - Chosen to be at low-speed aerodynamic center



Continuous Sweep vs. Move-Pause

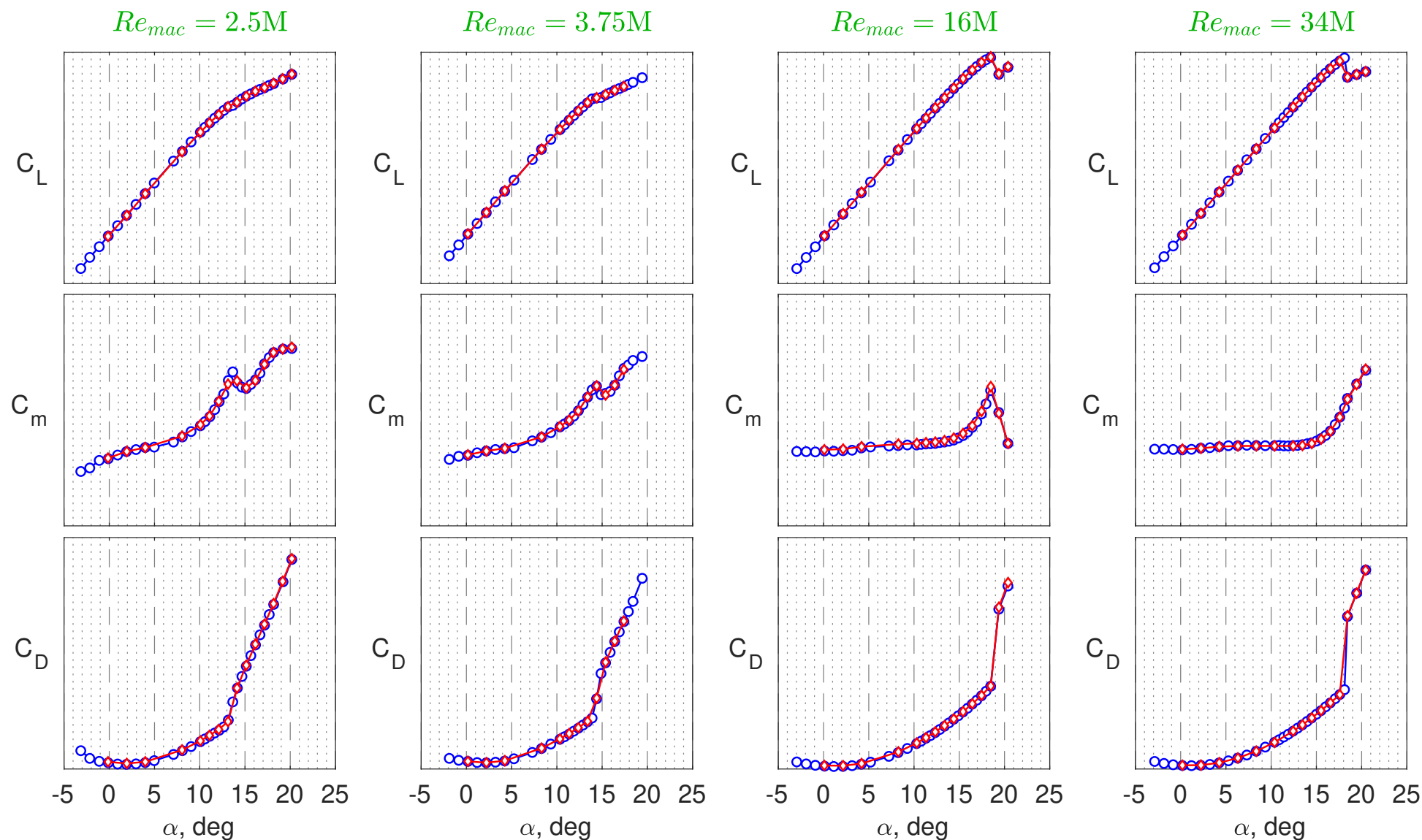
Sweep Type	
○ Continuous	◇ Move-Pause



- Very good comparison at all Re_{mac} conditions
- Provided confidence in quality of continuous sweep data

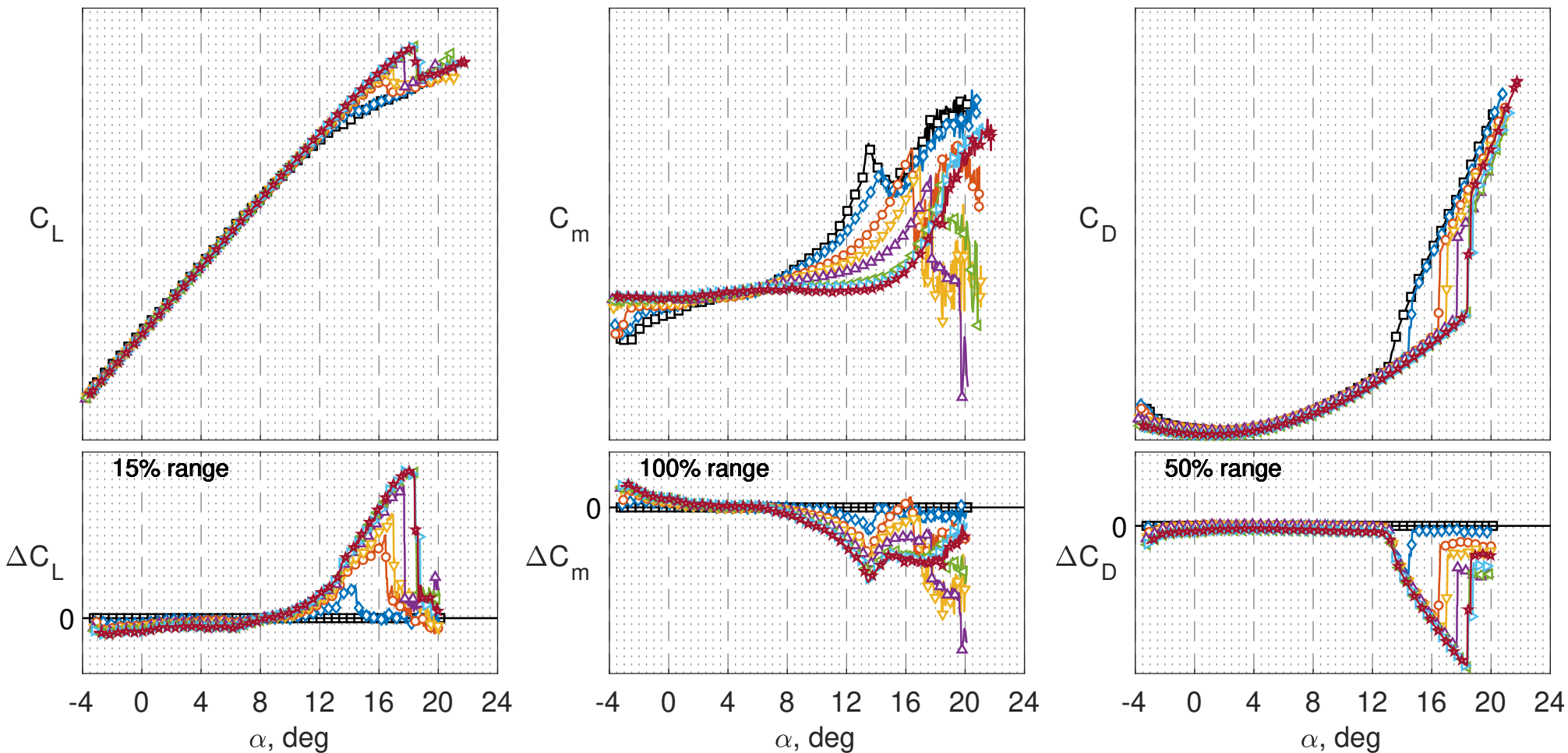
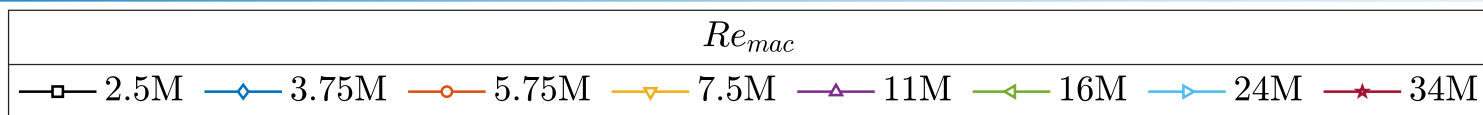
Data Repeatability

Run Type	
○ Standard	◇ Repeat



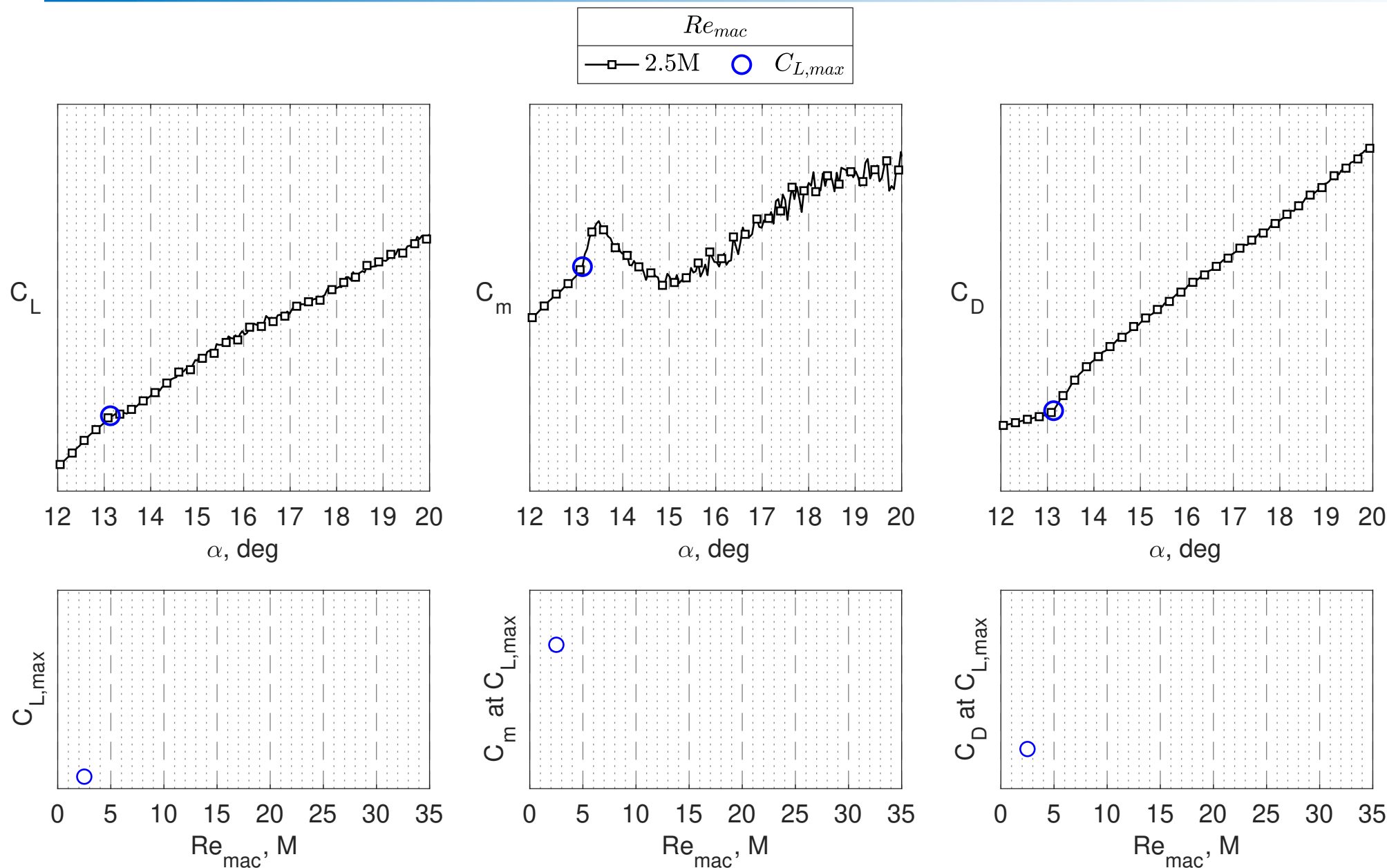
- Very good comparison at all Re_{mac} conditions
- Provided confidence in overall quality and repeatability of entire data set
- Paper also shows comparison to ARA data

Reynolds Number Effects



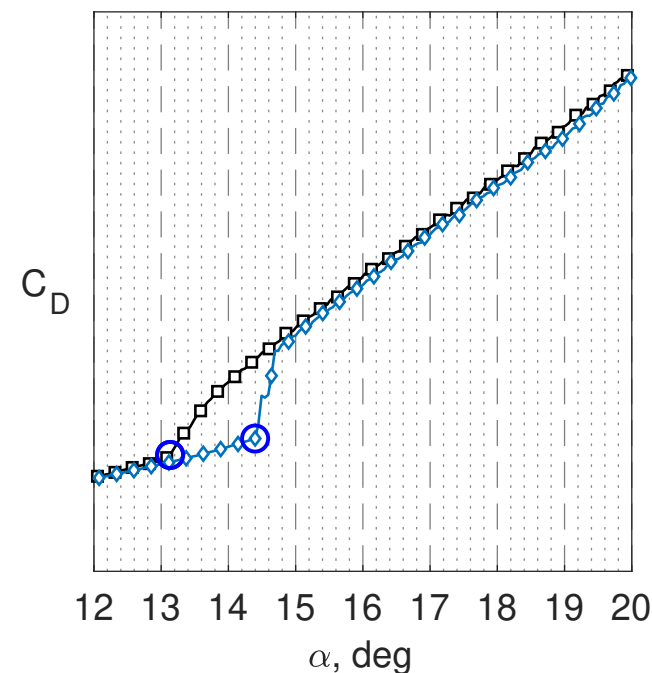
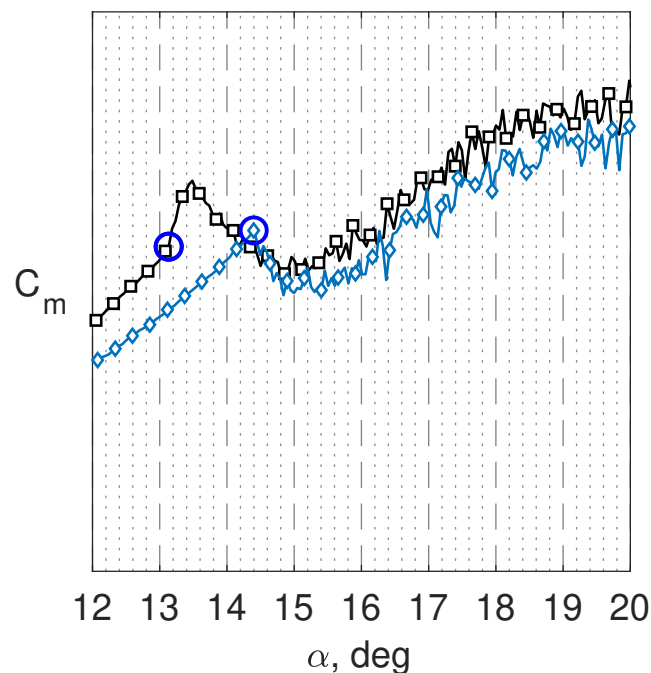
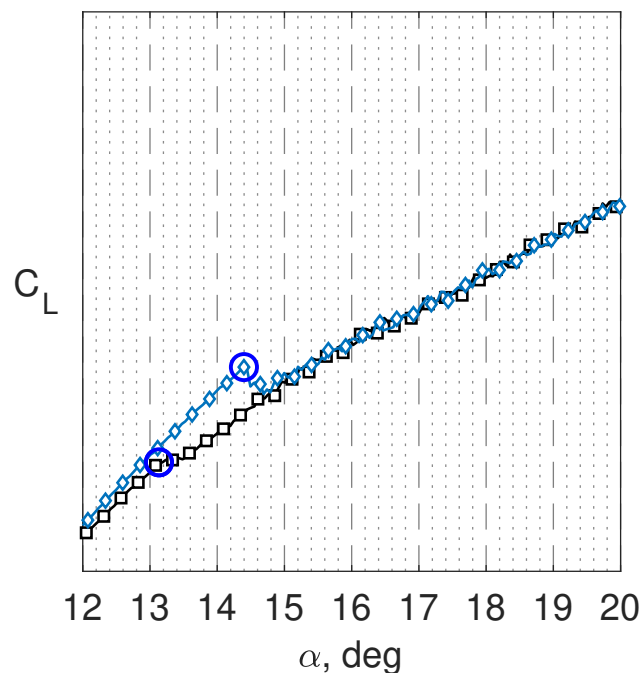
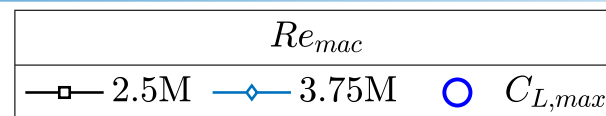
- Increments use $Re_{mac} = 2.5M$ as baseline
- Majority of Reynolds number effects occur for $\alpha > 8^\circ$
- $C_{L,max}$ increases with increasing Re_{mac}
- Stabilizing effect for C_m with increasing Re_{mac}
- Nearly constant C_m up to $\alpha = 12^\circ$ at $Re_{mac} = 34M$

Reynolds Number Effects on $C_{L,max}$

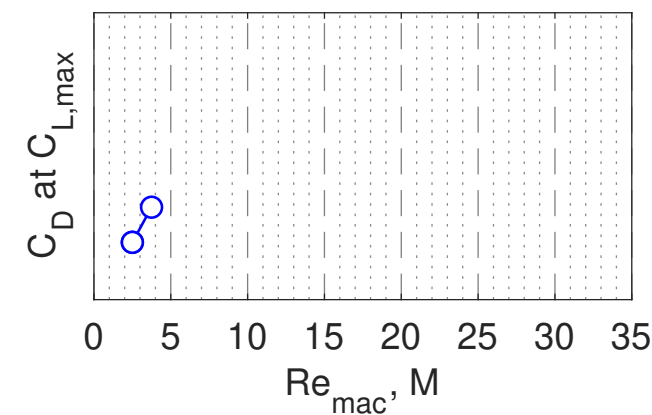
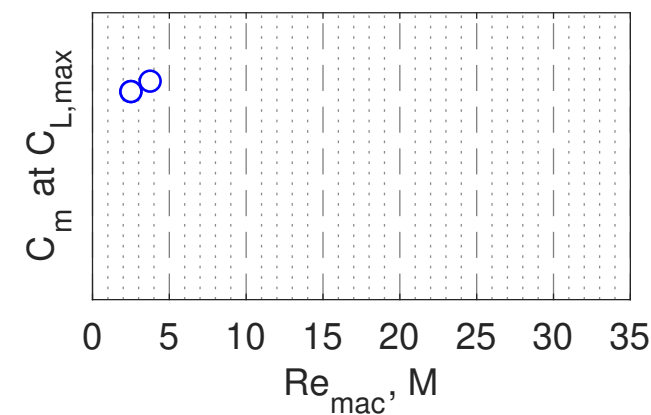
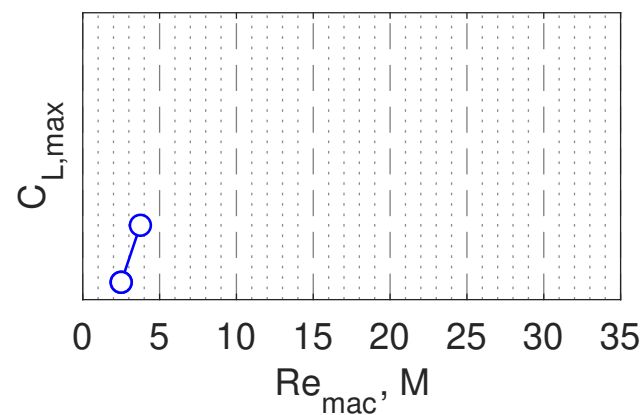


- Identify critical C_L point where there is change in behavior
- Critical C_L point sometimes coincides with $C_{L,max}$ and sometimes not
 - $C_{L,max}$ term used in rest of slides
- Use break in C_D curve to identify point (most consistent)

Reynolds Number Effects on $C_{L,max}$

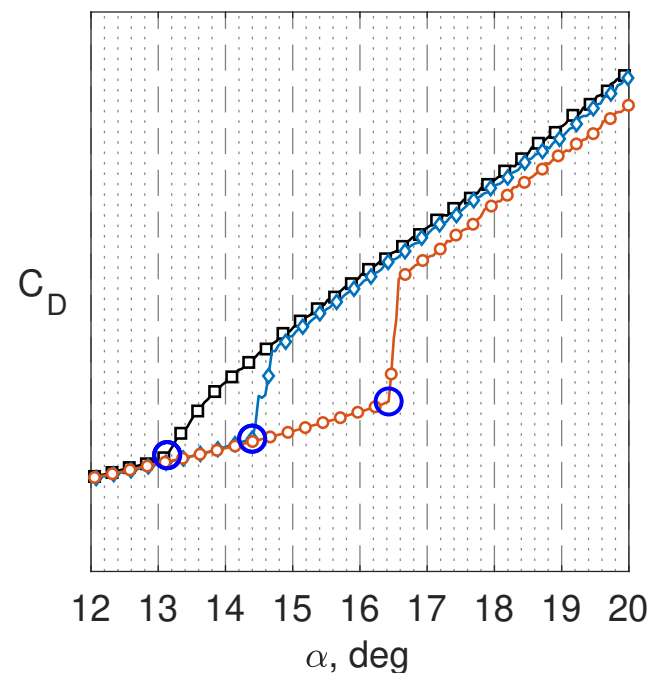
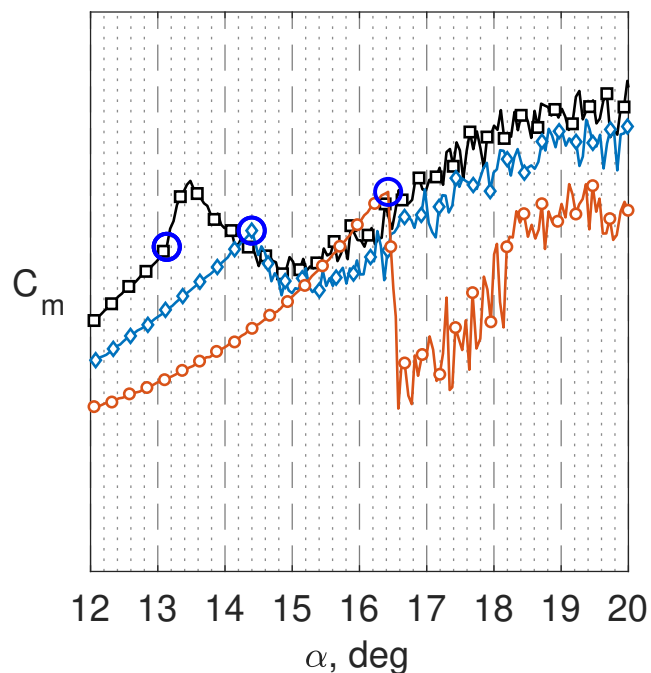
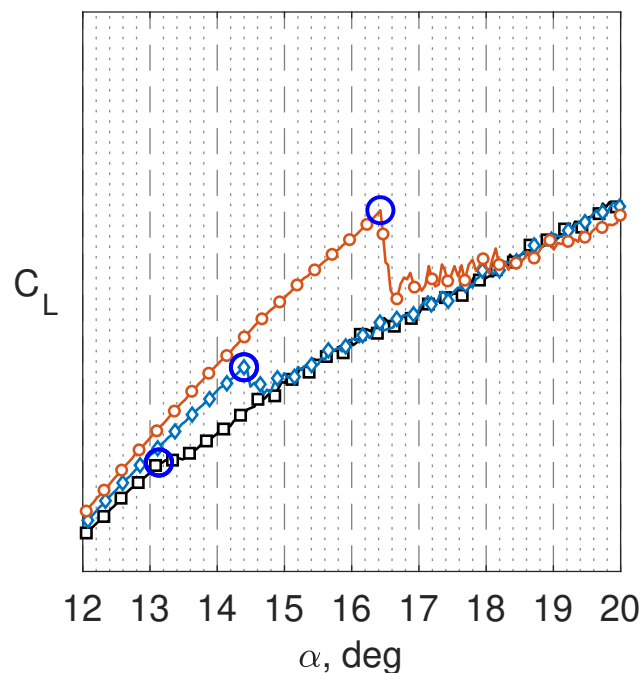


- Increase in $C_{L,max}$
- Slightly more defined stall observed
- Break in C_L , C_m , C_D curves coincide with each other

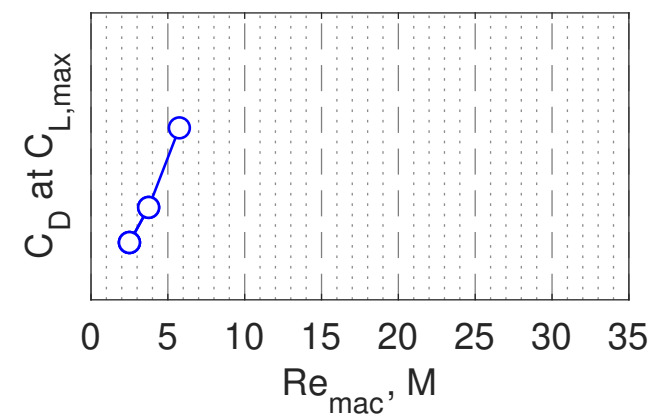
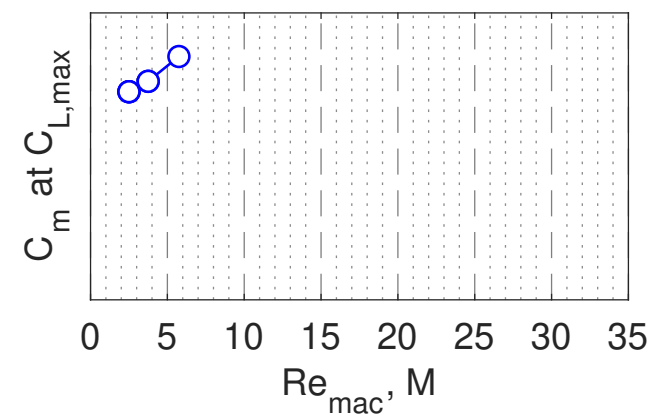
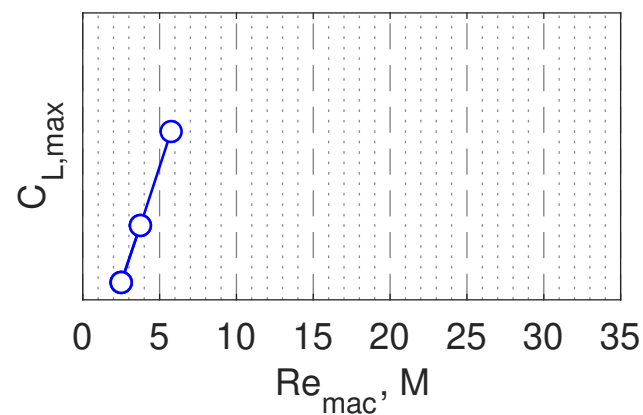


Reynolds Number Effects on $C_{L,max}$

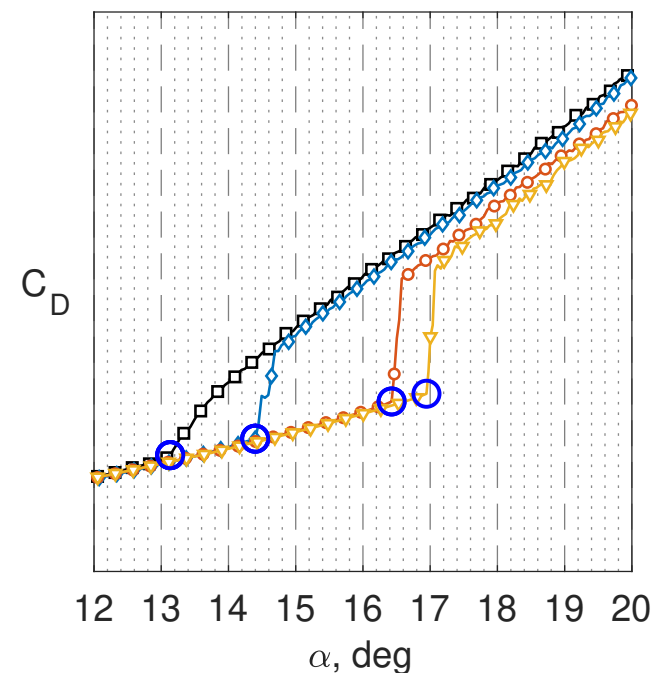
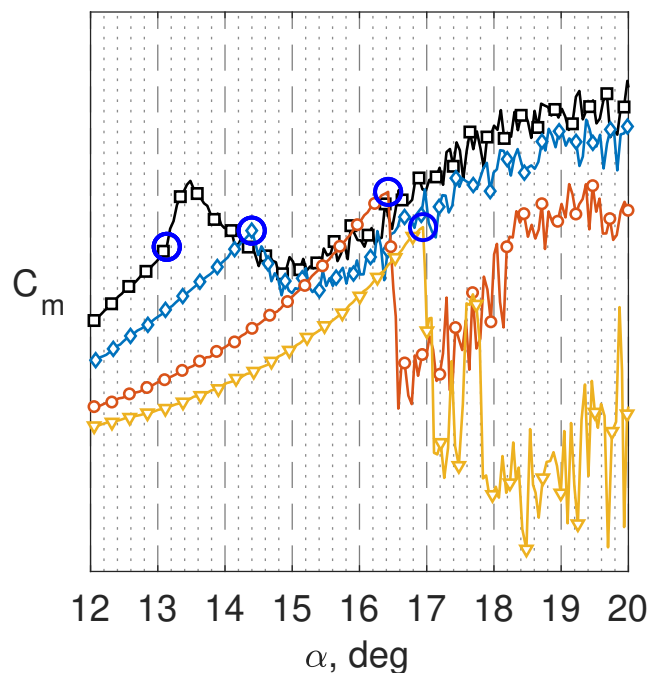
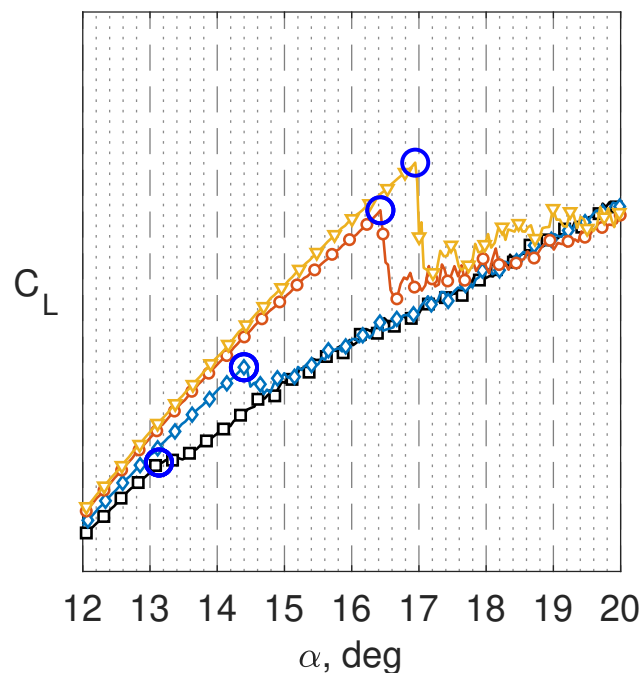
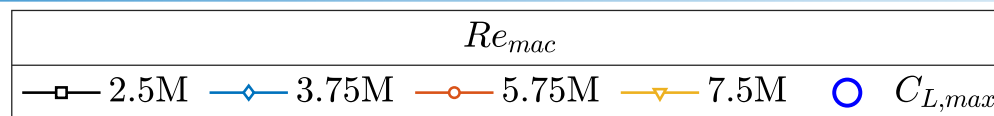
Re_{mac}			
—□—	—◇—	—○—	○ $C_{L,max}$
2.5M	3.75M	5.75M	



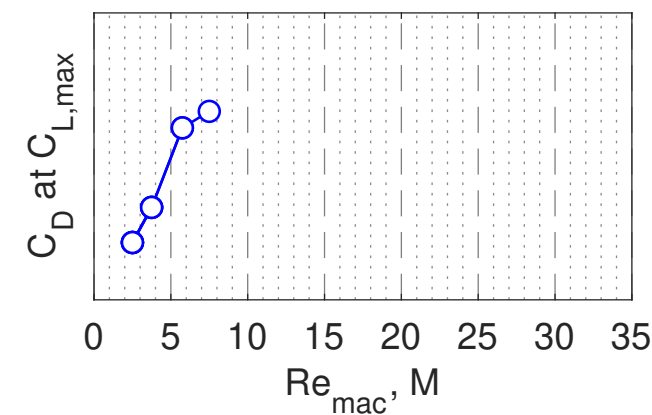
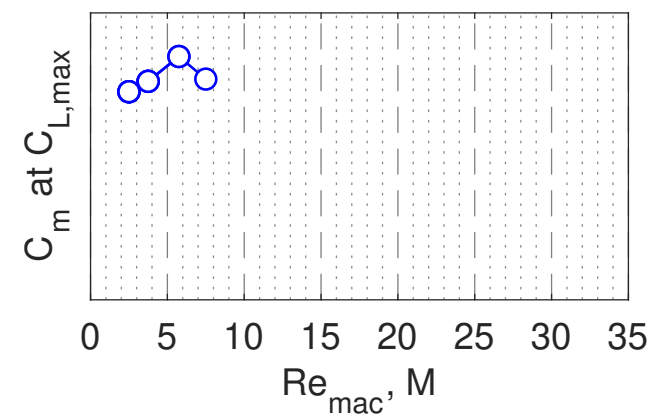
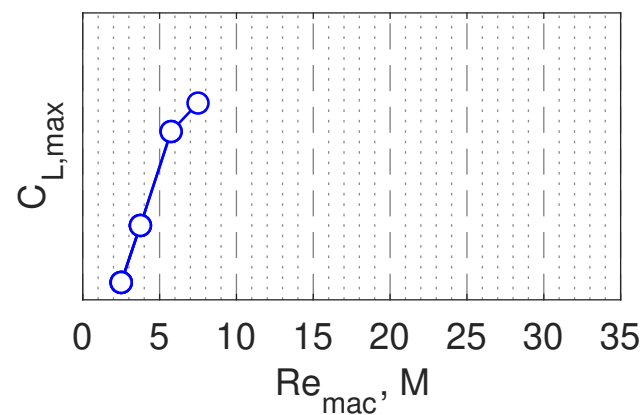
- Large increase in $C_{L,max}$
- More abrupt stall observed with large gradients over small α range



Reynolds Number Effects on $C_{L,max}$

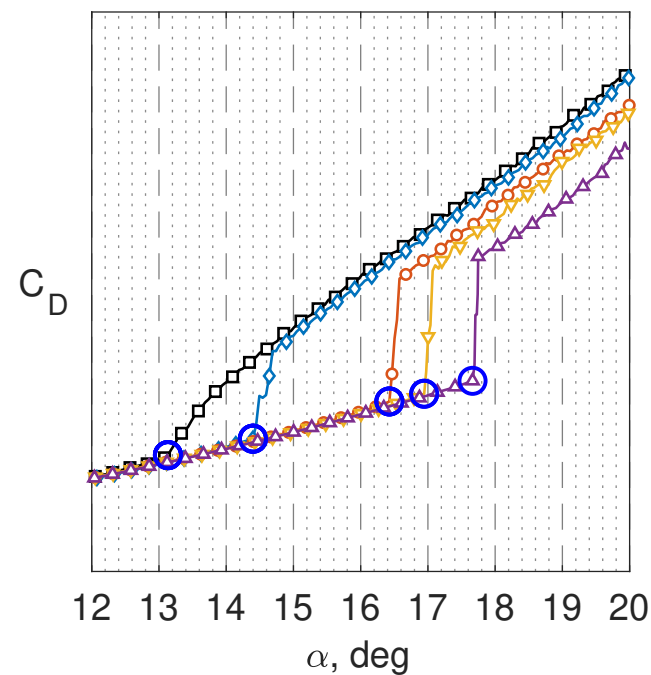
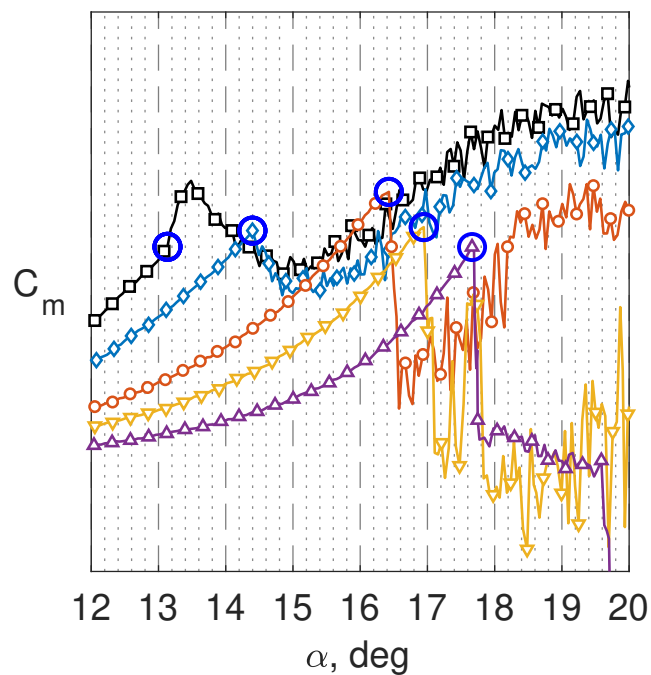
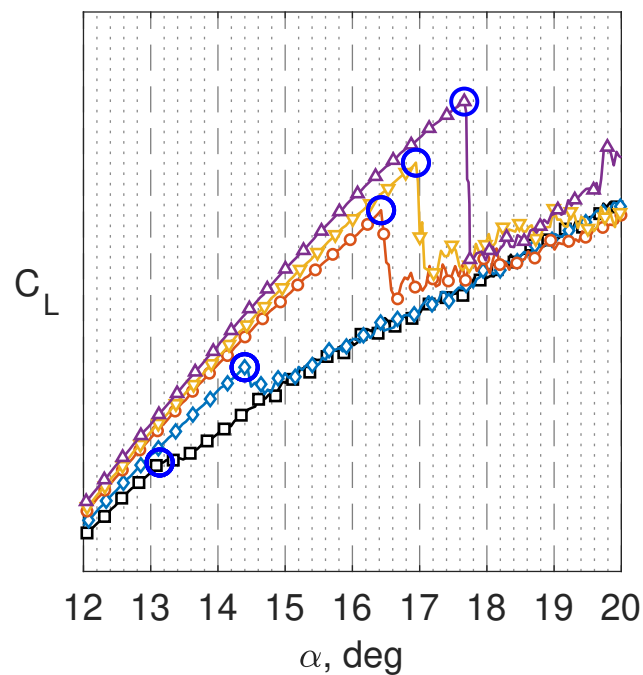


- Continued increase in $C_{L,max}$ but at a reduced rate
- Stall shows even larger gradients over smaller α range
- C_m break value starts to decrease

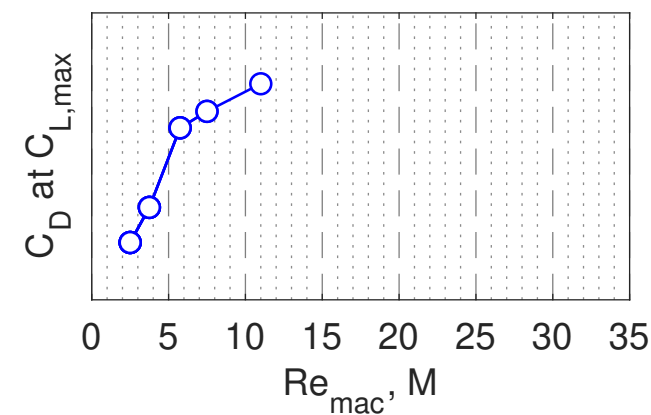
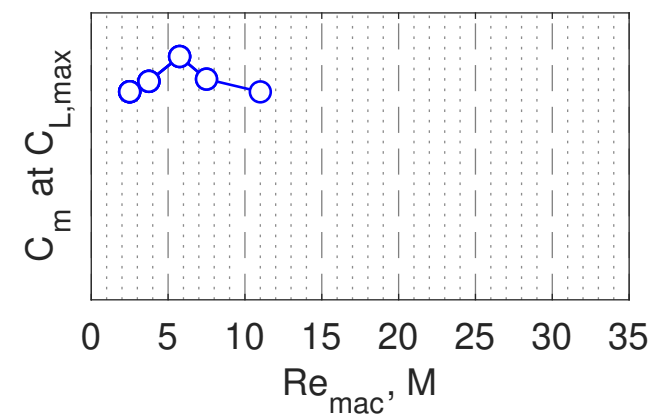
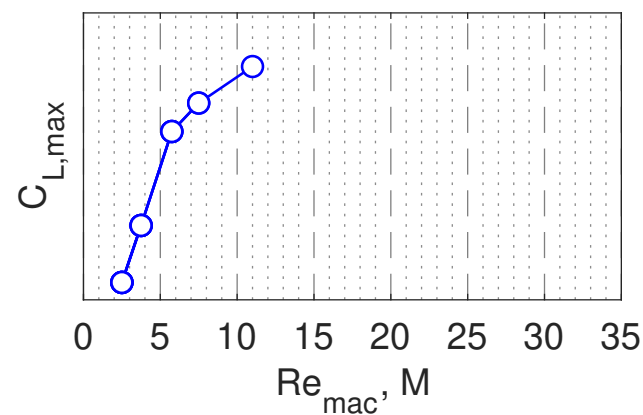


Reynolds Number Effects on $C_{L,max}$

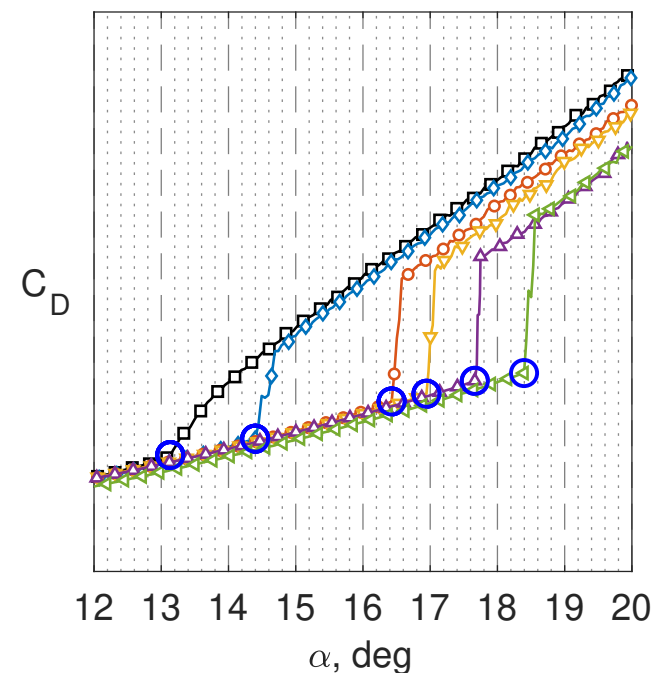
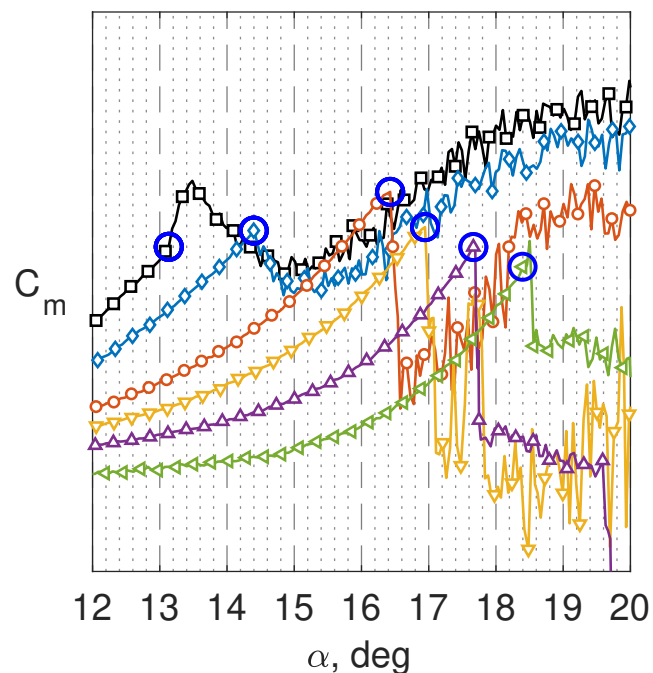
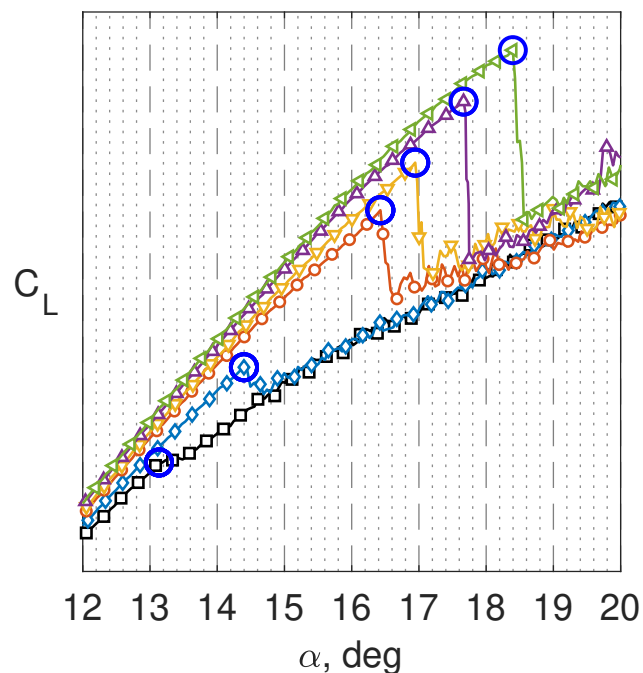
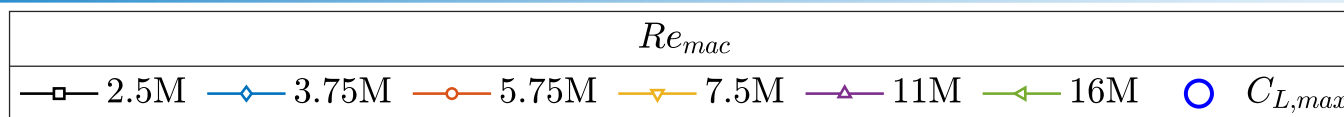
Re_{mac}					
—□—	—◇—	—○—	—▽—	—△—	○ $C_{L,max}$
2.5M	3.75M	5.75M	7.5M	11M	



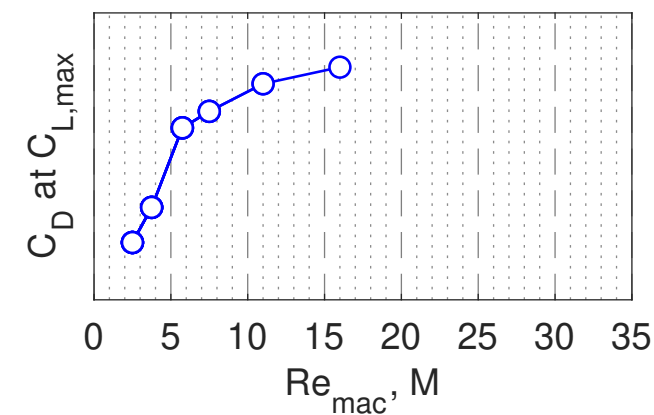
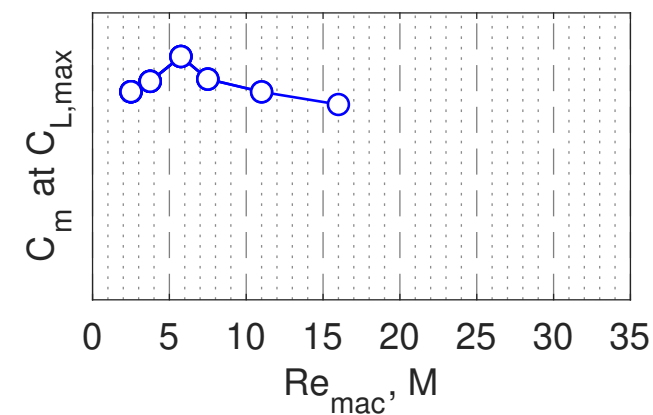
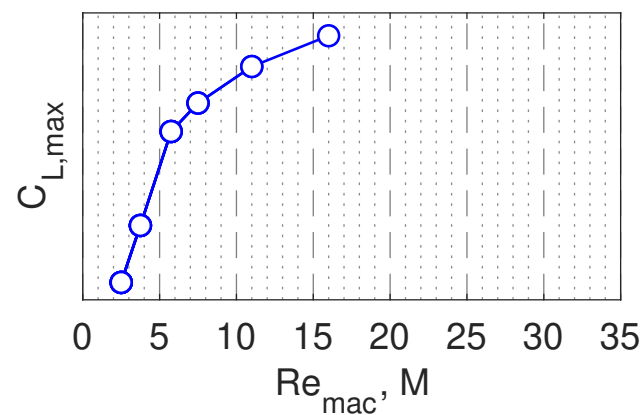
- Trend continues



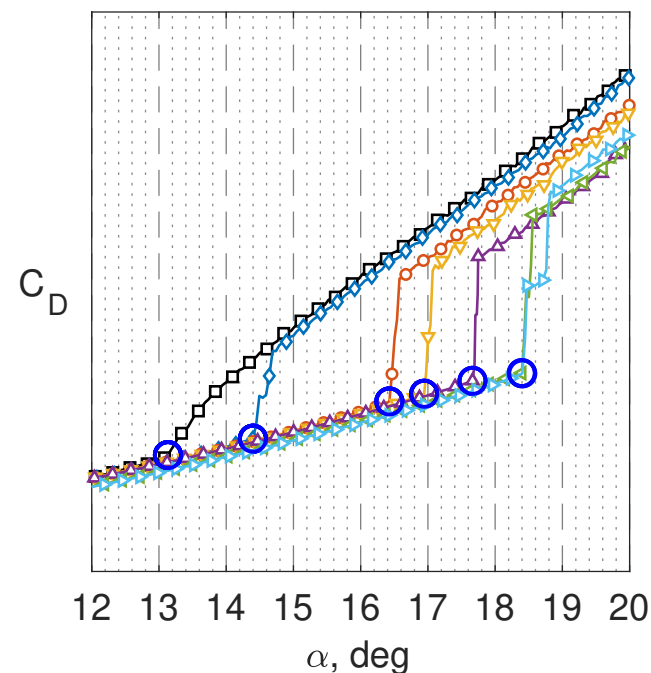
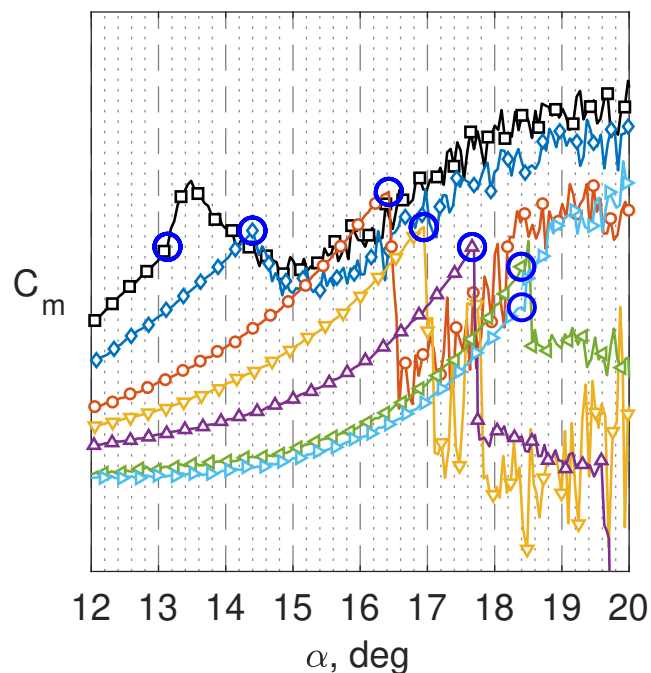
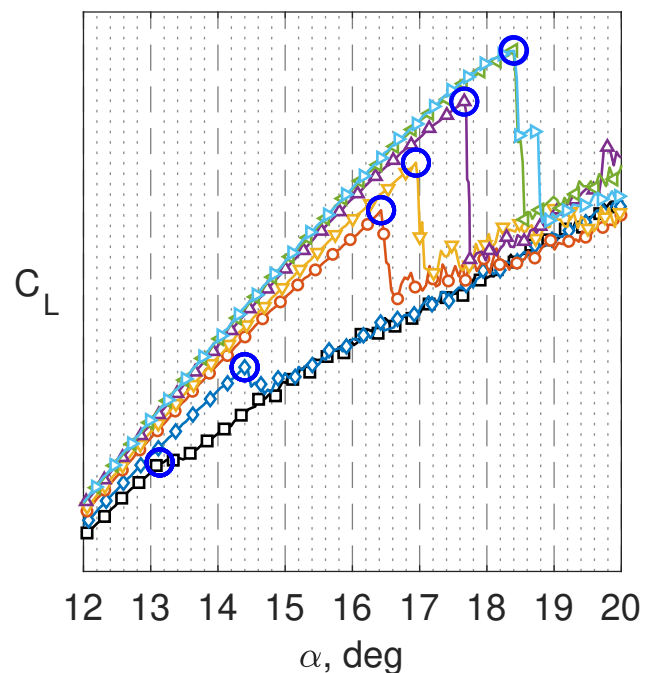
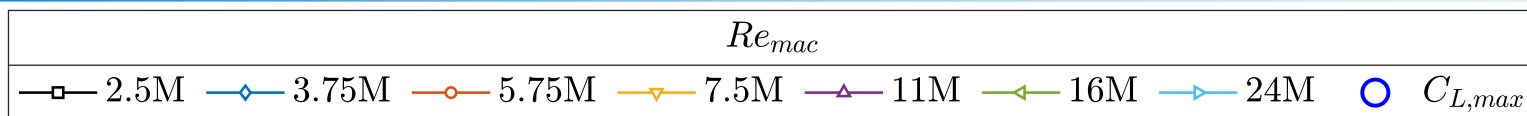
Reynolds Number Effects on $C_{L,max}$



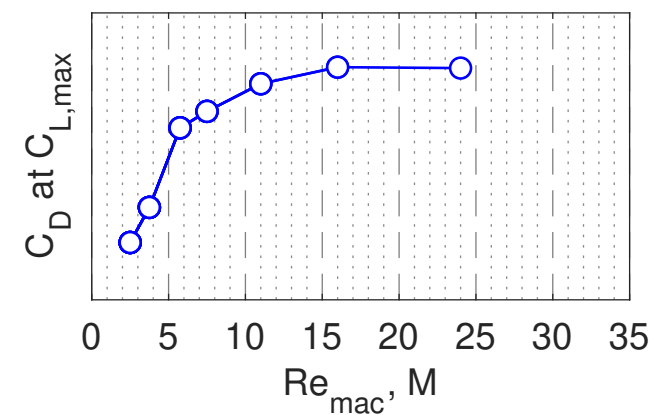
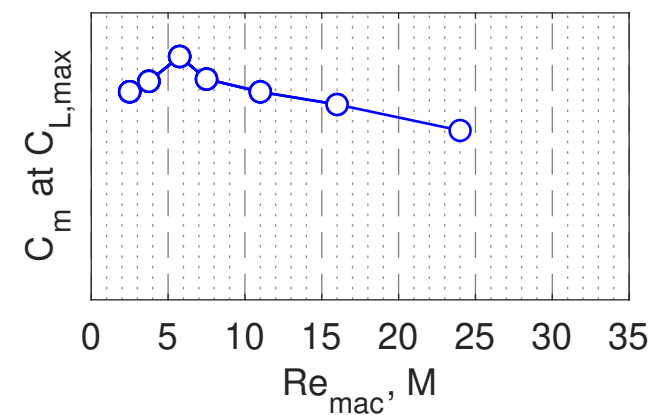
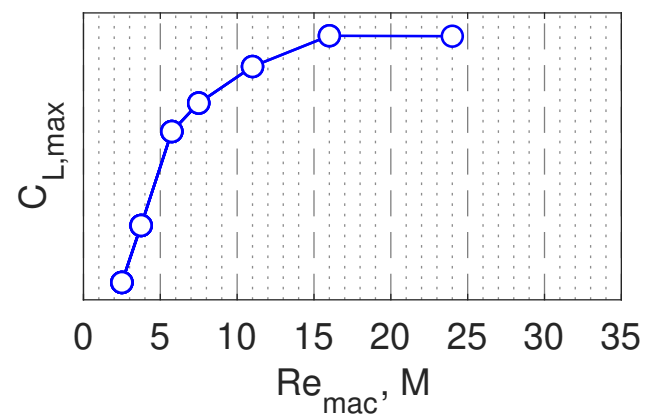
- Trend continues



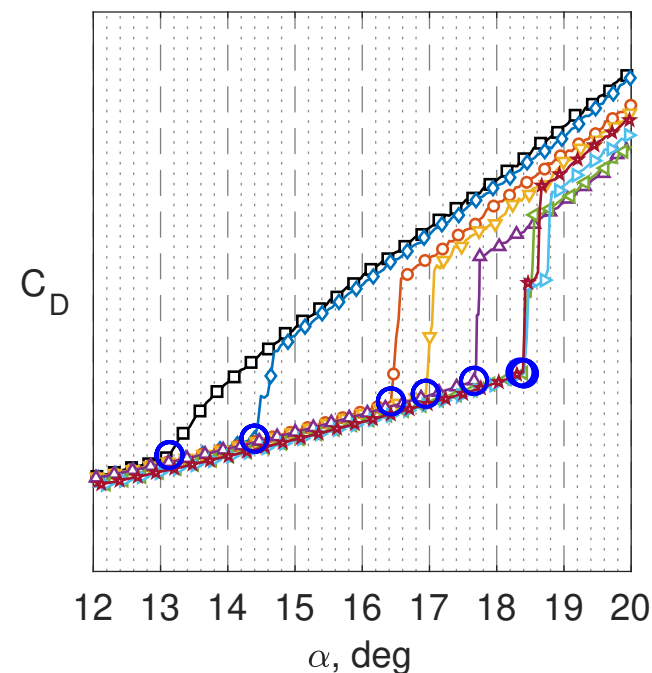
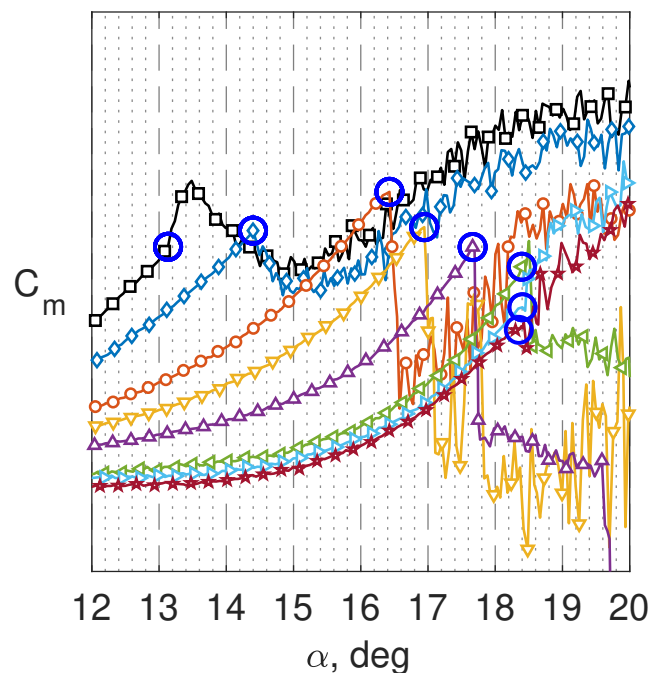
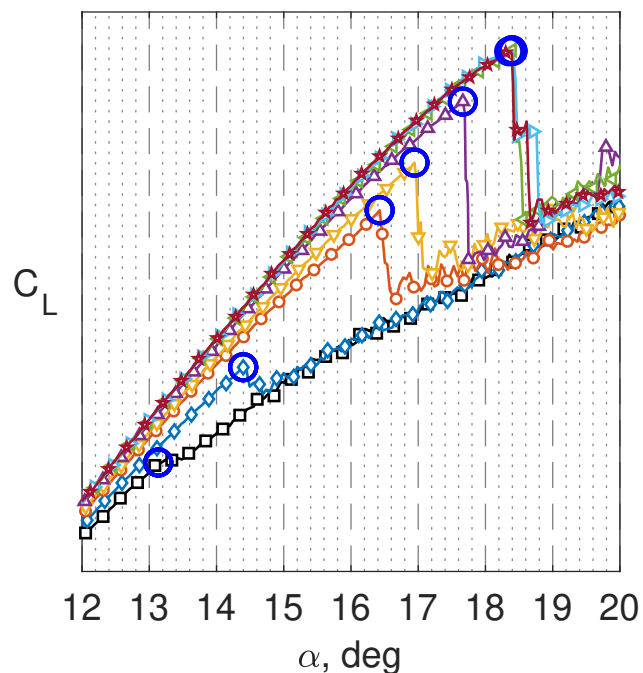
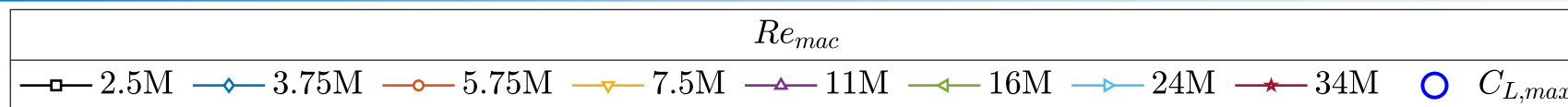
Reynolds Number Effects on $C_{L,max}$



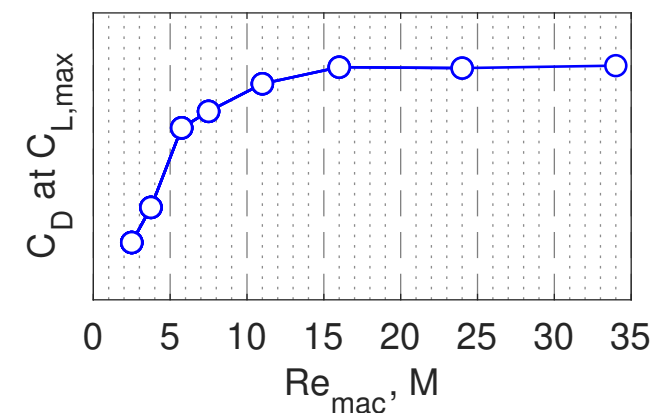
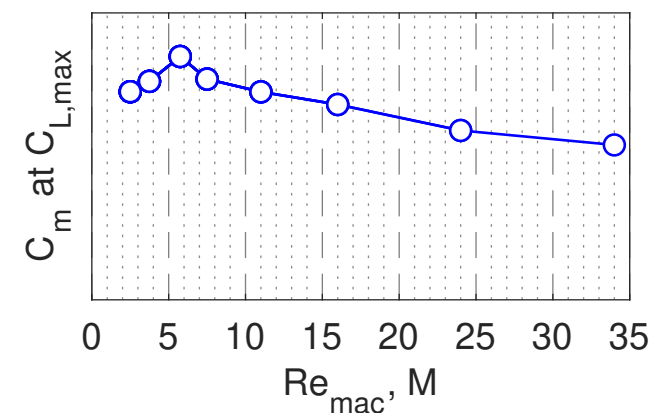
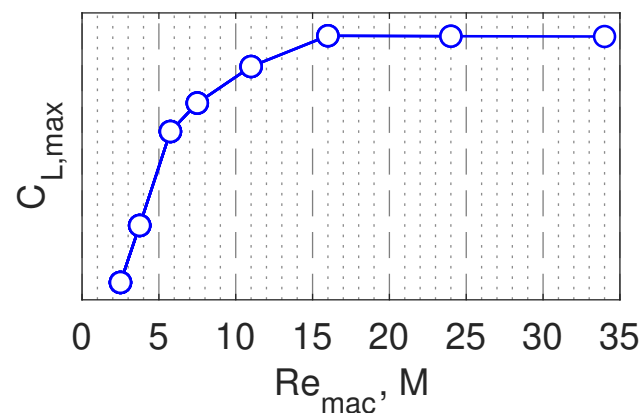
- No further increase in $C_{L,max}$
- Double stall observed
 - One wing stalls before the other
- No observed C_m break



Reynolds Number Effects on $C_{L,max}$

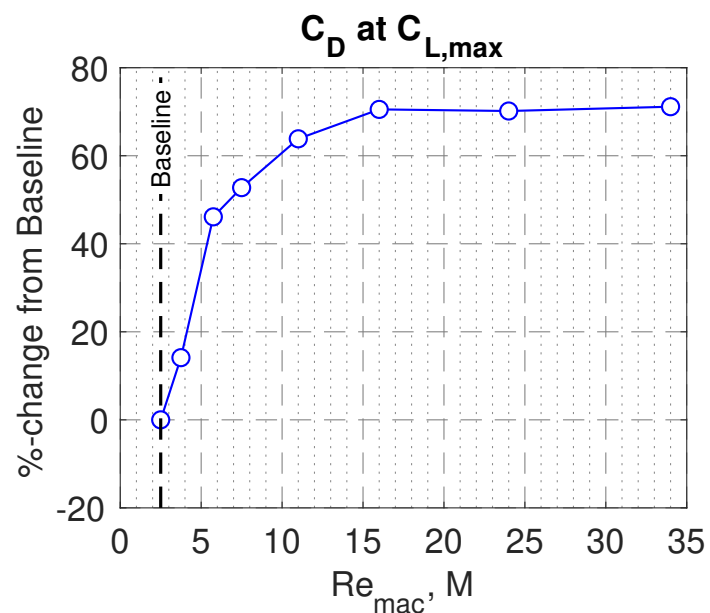
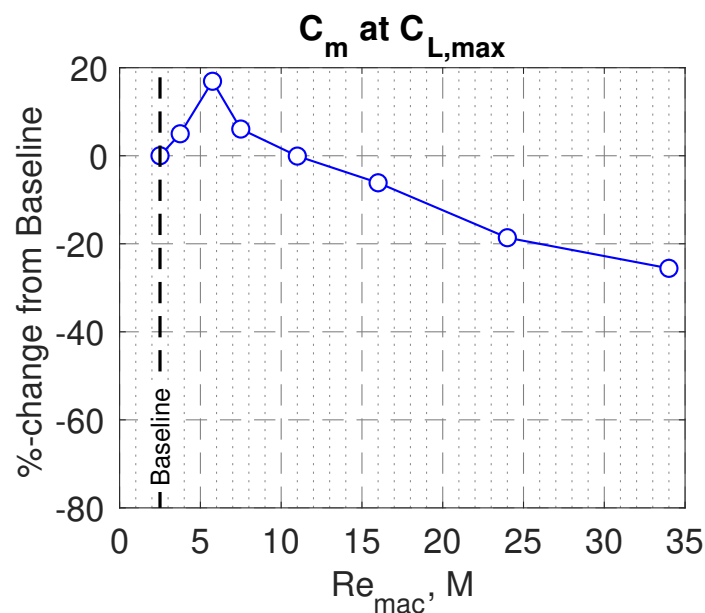
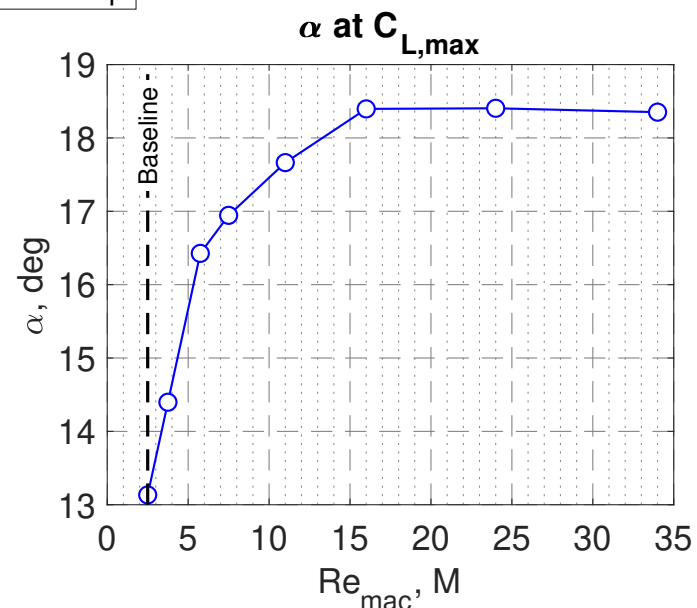
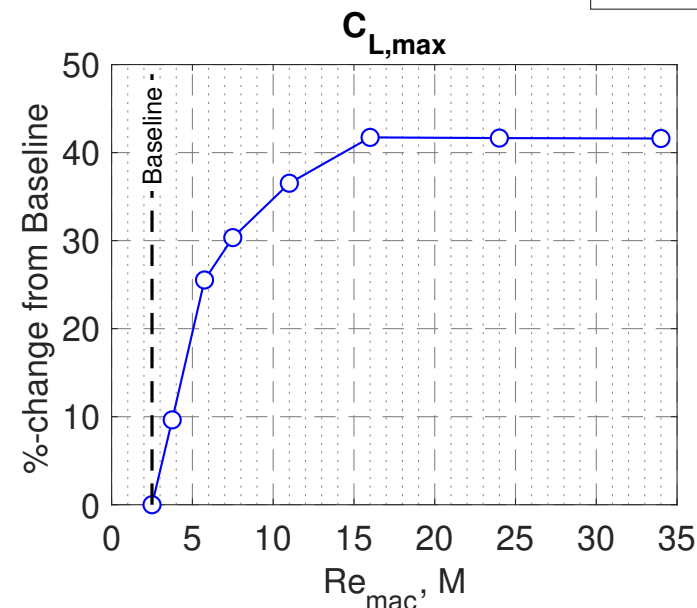


- Again, no increase in $C_{L,max}$
- Again, double stall observed
- Again, no observed C_m break



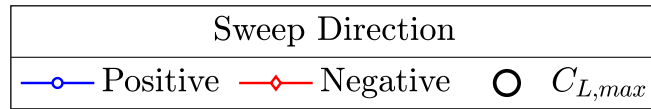
Reynolds Number Effects on $C_{L,max}$

—○— Positive Sweep



- $C_{L,max}$ increased by over 40% from baseline
- $C_{L,max}$ angle of attack increased from $\alpha = 13^\circ$ to over 18°
- C_m at $C_{L,max}$ decreased by over 20%
- Highlights the need for high Reynolds number testing
 - Earlier in design cycle in addition to final configuration validation

Hysteresis effects

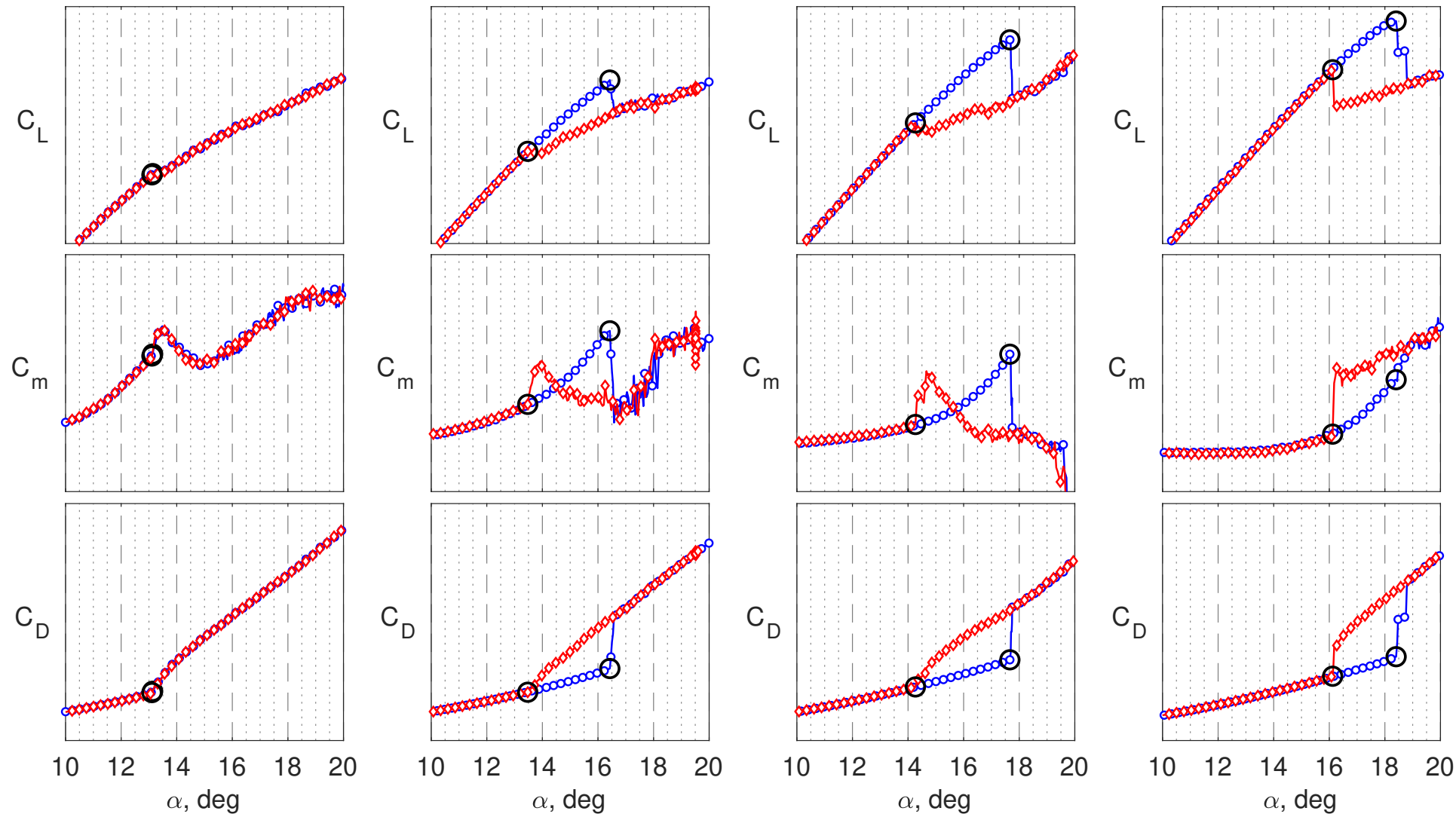


$Re_{mac} = 2.5M$

$Re_{mac} = 5.75M$

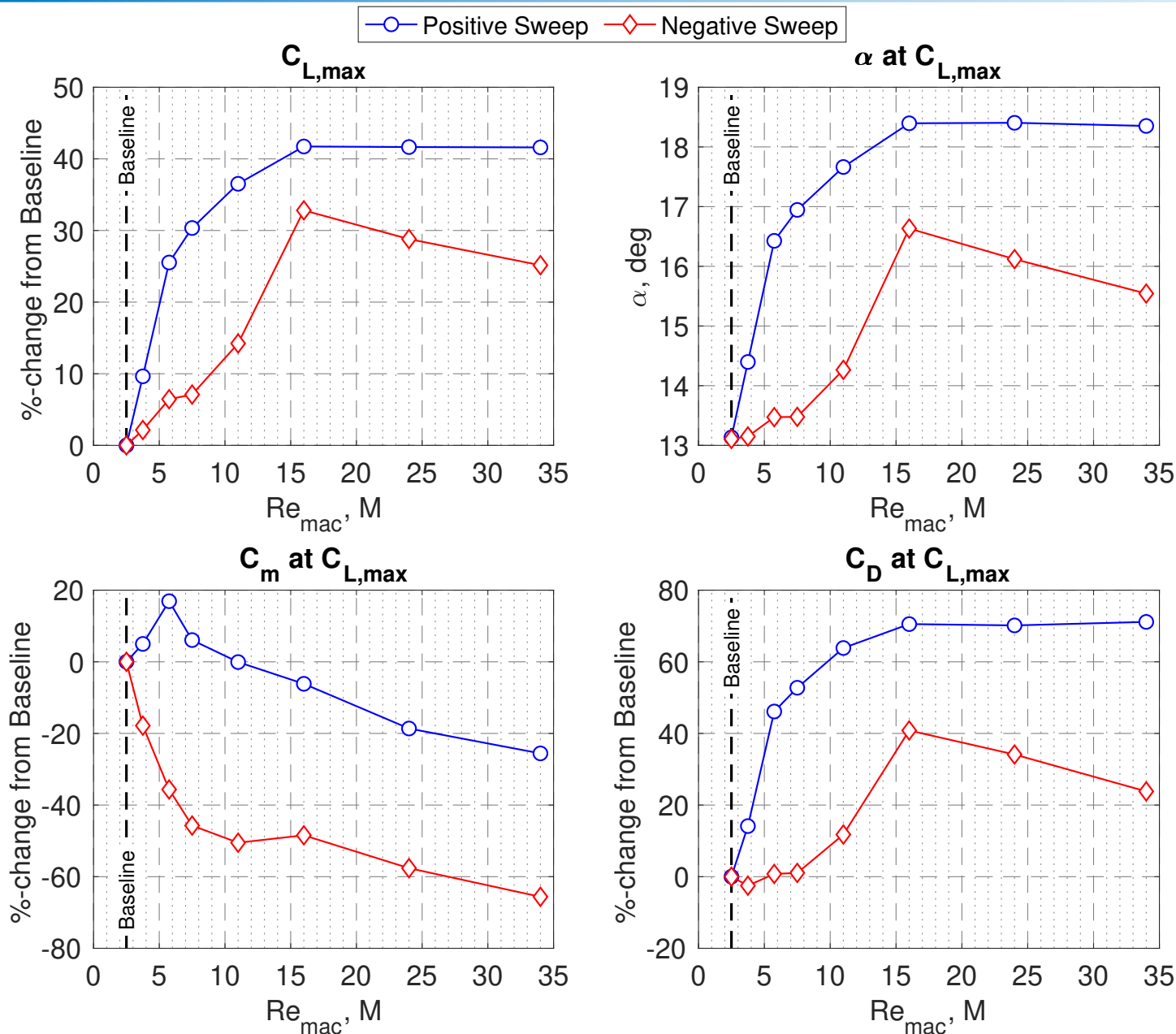
$Re_{mac} = 11M$

$Re_{mac} = 24M$



- No hysteresis effects seen at baseline of $Re_{mac} = 2.5M$
- Significant hysteresis effects seen at all other Re_{mac}

Hysteresis effects



- $C_{L,max}$ for negative sweep polars were 10% to 25% lower than positive sweep polars
- $C_{L,max}$ angle of attack decreased by 1.5° to 3.5°
- Could have implications in vehicle design for determining maximum usable incidence and lift
- Could also be important for low-speed controllability and maneuvering

- **SWiFT high Reynolds number experiment in National Transonic Facility**
 - Capstone experiment for NATO STO AVT-298 research task group
 - Investigate Reynolds number effects on low-speed S&C characteristics
 - Relevant for BWB / HWB / UCAV configurations
- **Data quality**
 - Continuous sweep data compared very well to move-pause data
 - Data repeatability was very good
- **Reynolds number effects on $C_{L,max}$ at Mach 0.2**
 - $C_{L,max}$ value increased by over 40% from $Re_{mac} = 2.5M$ to $34M$
 - $C_{L,max}$ angle of attack increased from $\alpha = 13^\circ$ to over 18° over same Re_{mac} range
- **Hysteresis effects**
 - Significant hysteresis effects observed for all Re_{mac} conditions except baseline at $2.5M$
 - Lower $C_{L,max}$ value and angle of attack could affect maximum usable incidence and lift
- **Companion paper discussing surface pressure results**
 - David Chan, et al., “Surface Pressure Results for the NATO AVT-298 SWiFT Configuration in the National Transonic Facility”, Thur. 1:40PM, APA-75, Bayhill 30

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