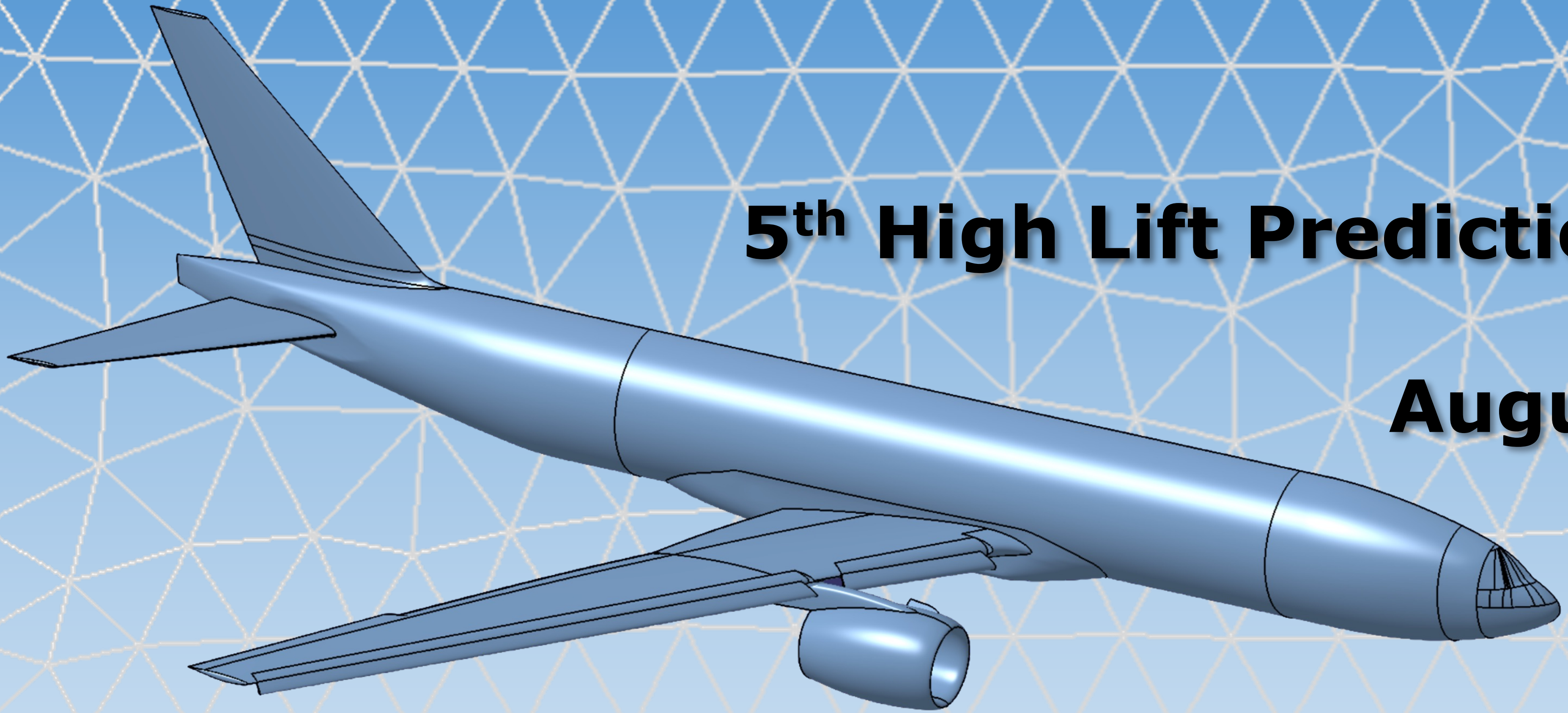
AIAA
SHAPING THE FUTURE OF AEROSPACE



5th High Lift Prediction Workshop

August 2-3, 2024

Adapt Technical Focus Group

Mike Park (Luminary Cloud)

Adapt TFG Introduction

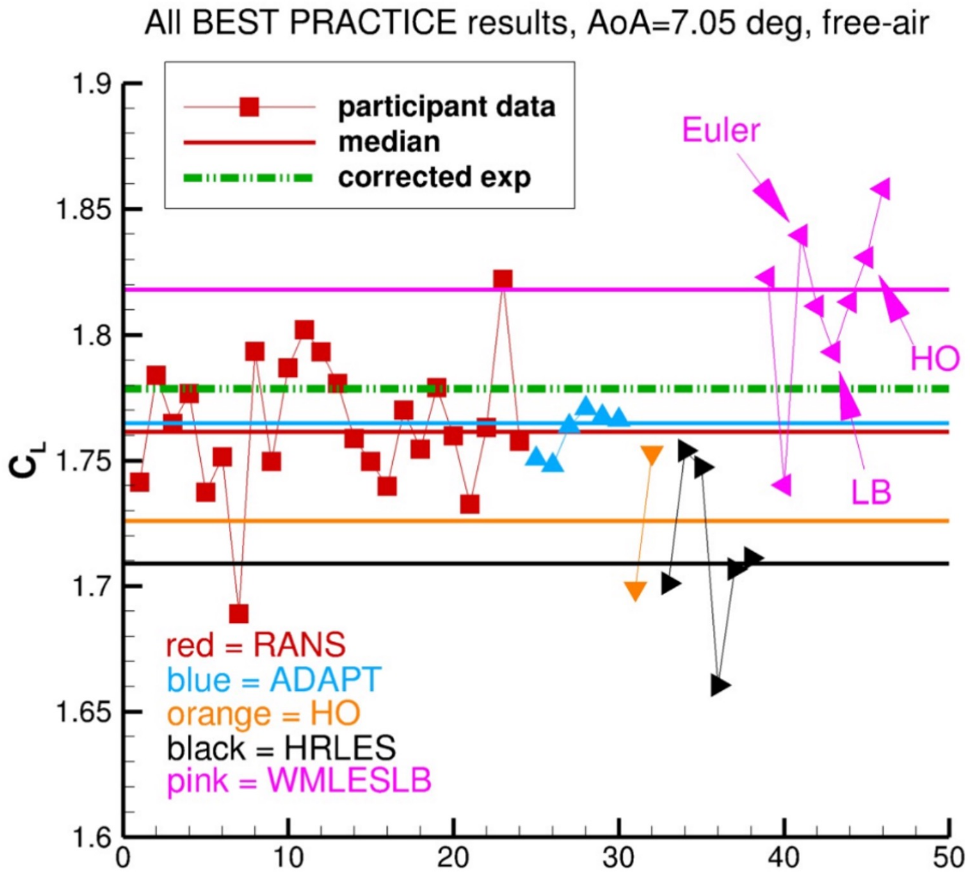
- Verifying methods and model implementations is the primary objective with a goal of controlling RANS meshing influence
- Other sources of uncertainty (e.g., modeling error, wind tunnel corrections, boundary conditions) have less emphasis and can only be quantified when discretization error is controlled and methods are verified
- Share many challenges with the RANS TFG
    - Controlling iterative solver error for separated flows
    - Multiple attractors or stationary points in RANS solutions “multiple solutions”

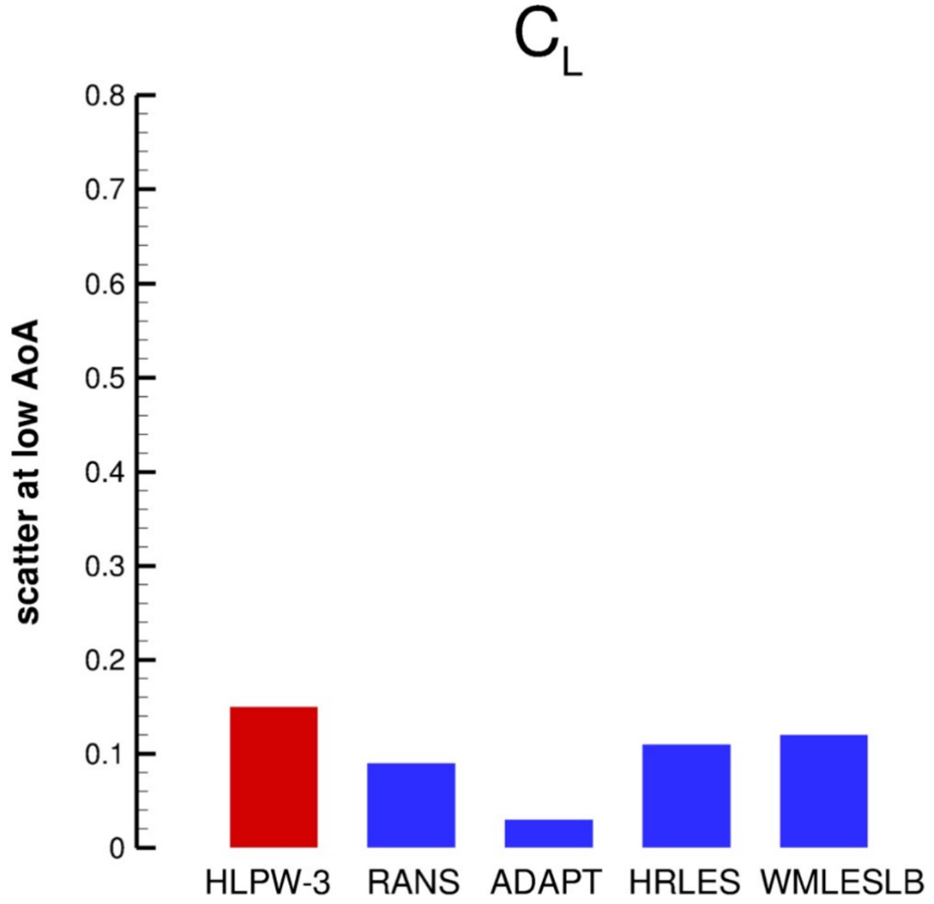
HLPW4 Adapt TFG Context

Mesh Adaptation for RANS TFG

Mesh adaptation reduced scatter

C_L: Results at AoA=7.05 deg

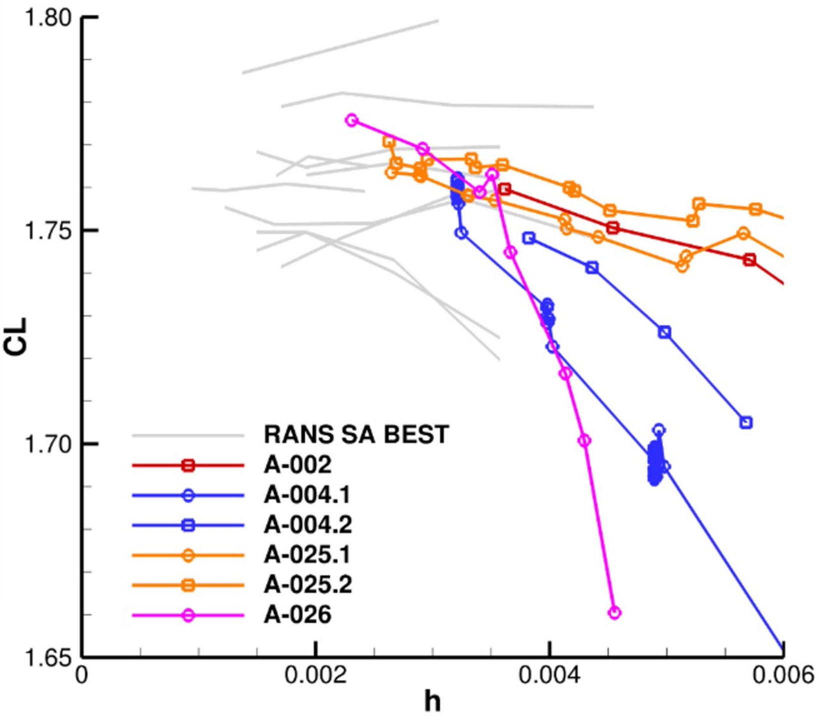


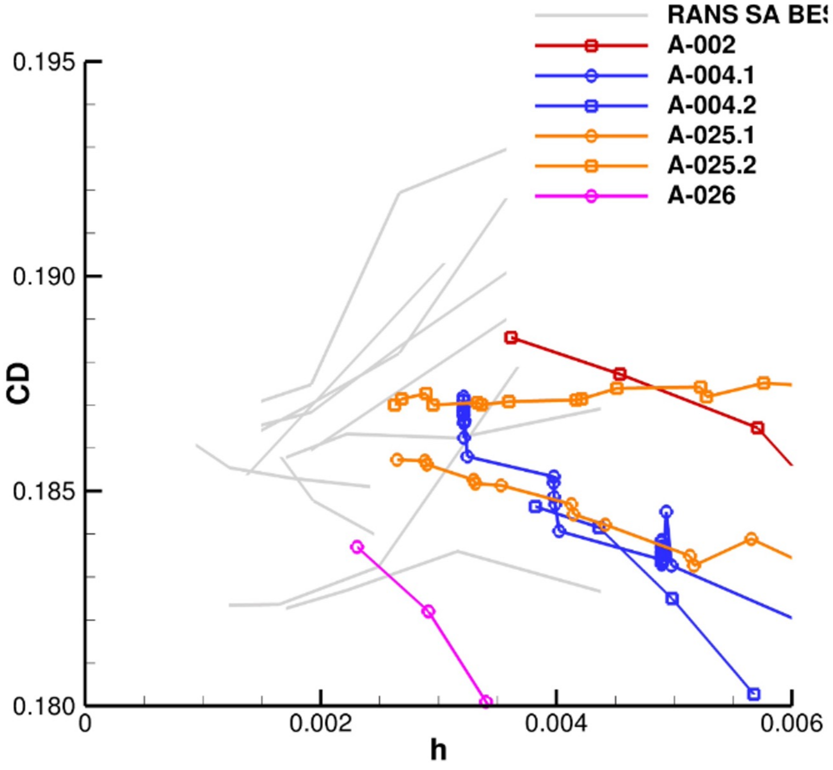


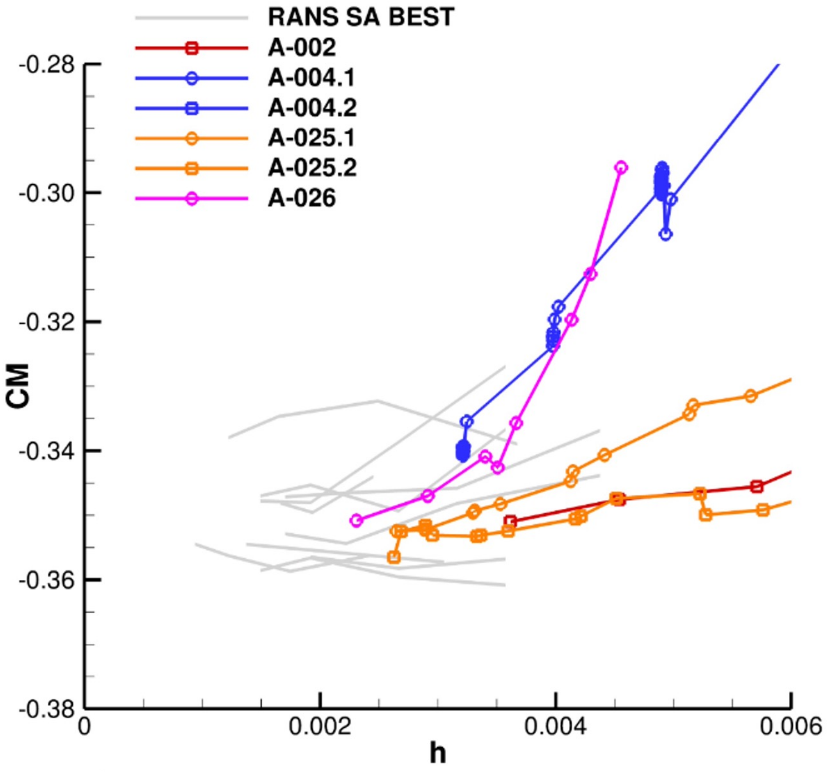
HLPW4 Adapt TFG Context

Mesh adaptation reduced scatter

- Complexity continuation at 7.05° case1b (SA)
  - Includes Fixed RANS FG best practice (SA)







$h = N^{-1/3}$

Adapt TFG Key Questions (KQs)

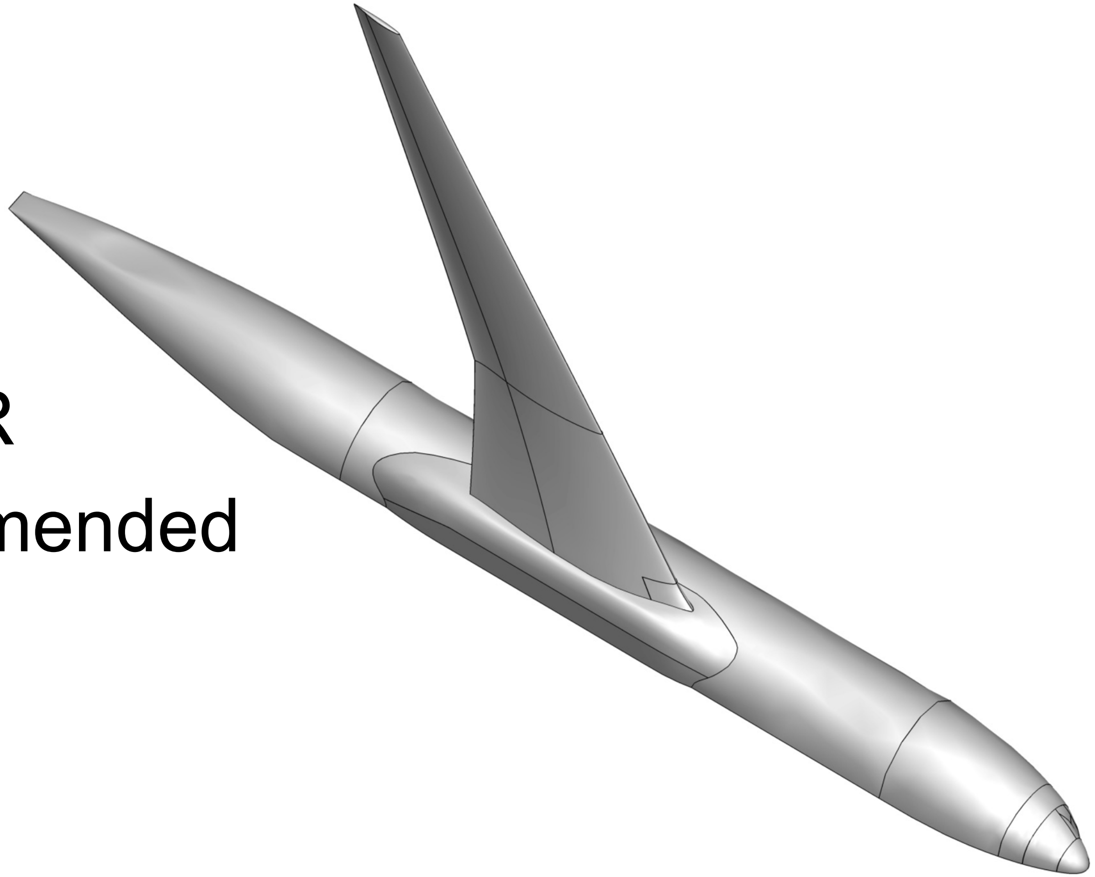
#	Key Question
1	Can adaptive mesh convergence be achieved on the CRM-HL Wing-Body to verify implementations?
2	Can adaptive mesh refinement identify consistent trends due to increasing geometric complexity across the angle of attack range?
3	Can adaptive mesh refinement resolve Reynolds number trends in integrated forces, moment, and separation patterns across the angle of attack range?
4	Where can mesh adapted RANS contribute to prediction of high-lift flow physics?

Compiled technical results

- From all participants that provided data (forces, moment, surface flow visualization, etc., as available and appropriate)
- Approximate mesh control volume counts are in legend
  - The minimum count is quoted when the count varied over the submission
- Corresponding RANS TFG submissions shown in light gray

Test Case 1 Description

- CRM-HL-WB
- Mach number 0.20
- Chord Reynolds number 5.6 x 10^6
- Angle of attack 11°
- Reference static temperature 521 °R

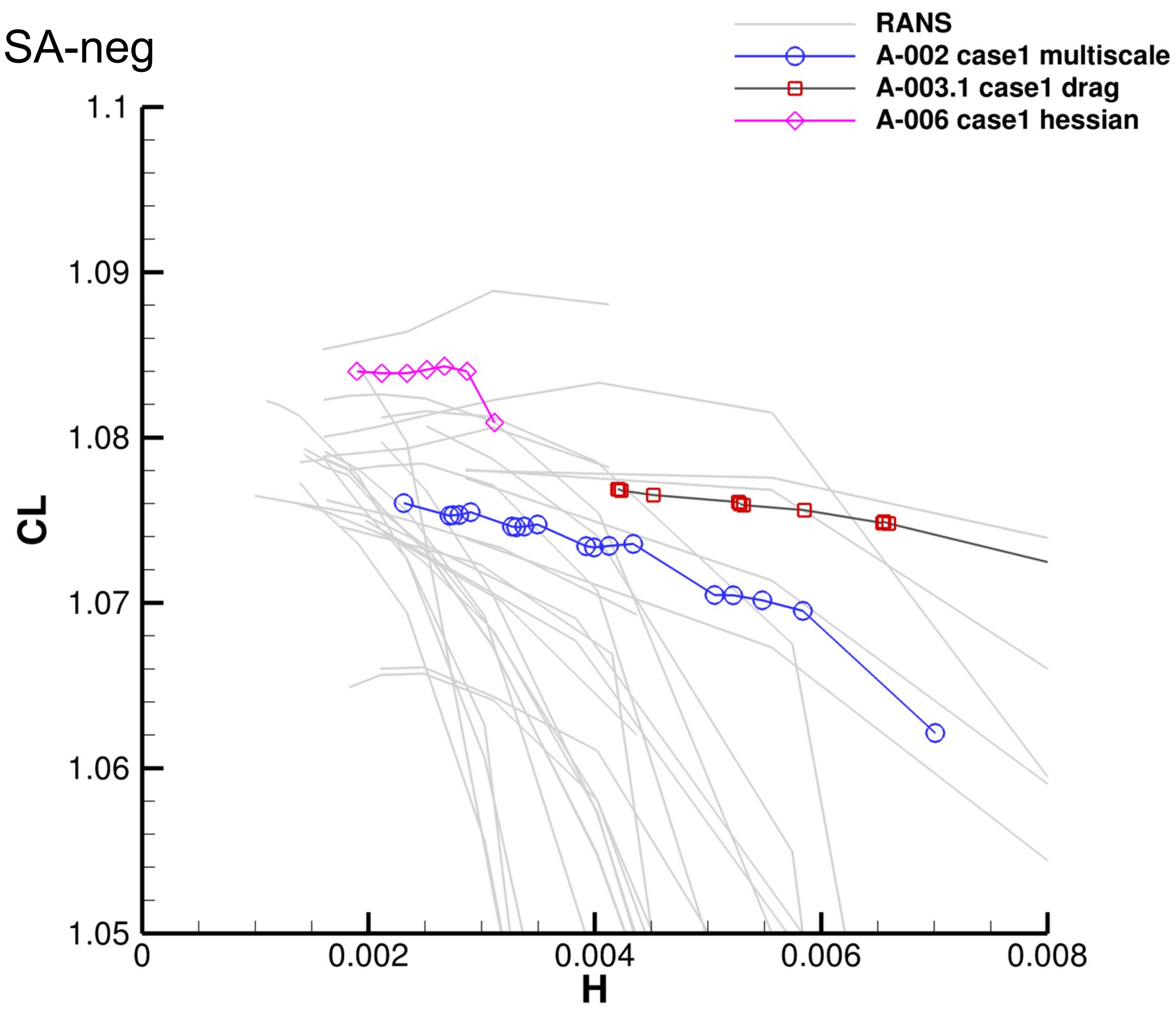


SA-neg-QCR2000-R(Crot=1) is recommended

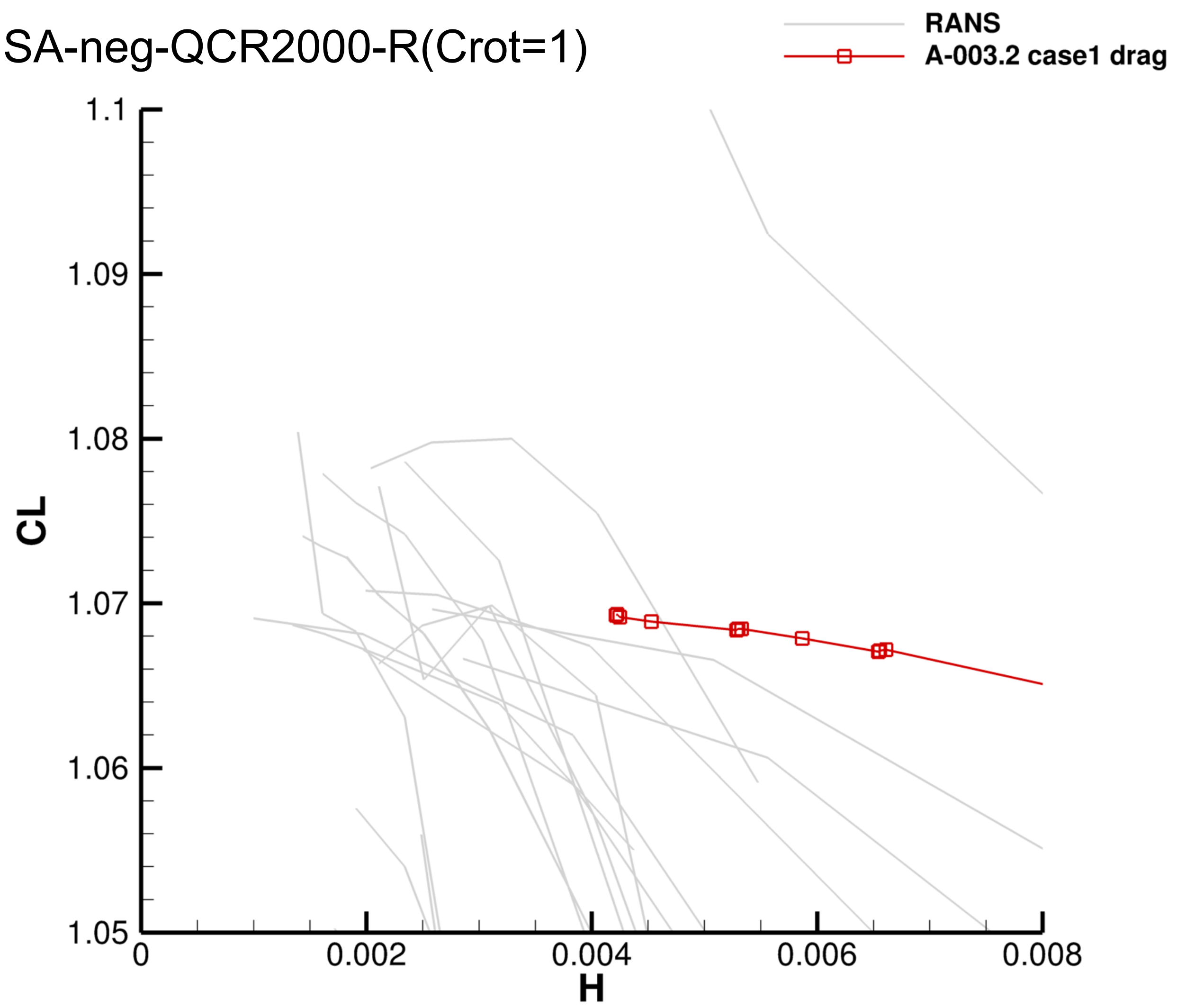
SA-neg is also of interest

Test Case 1 Lift

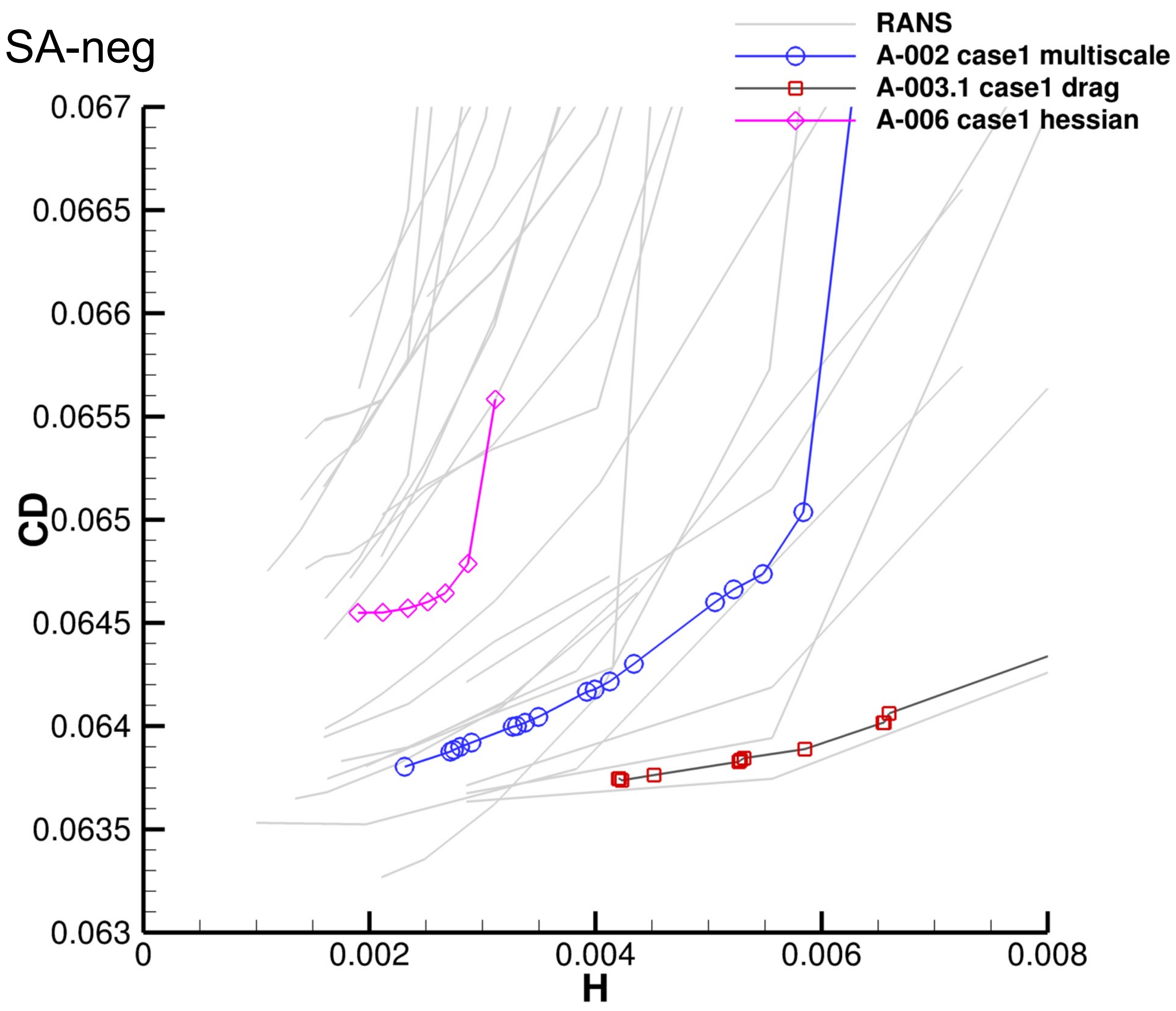
SA-neg

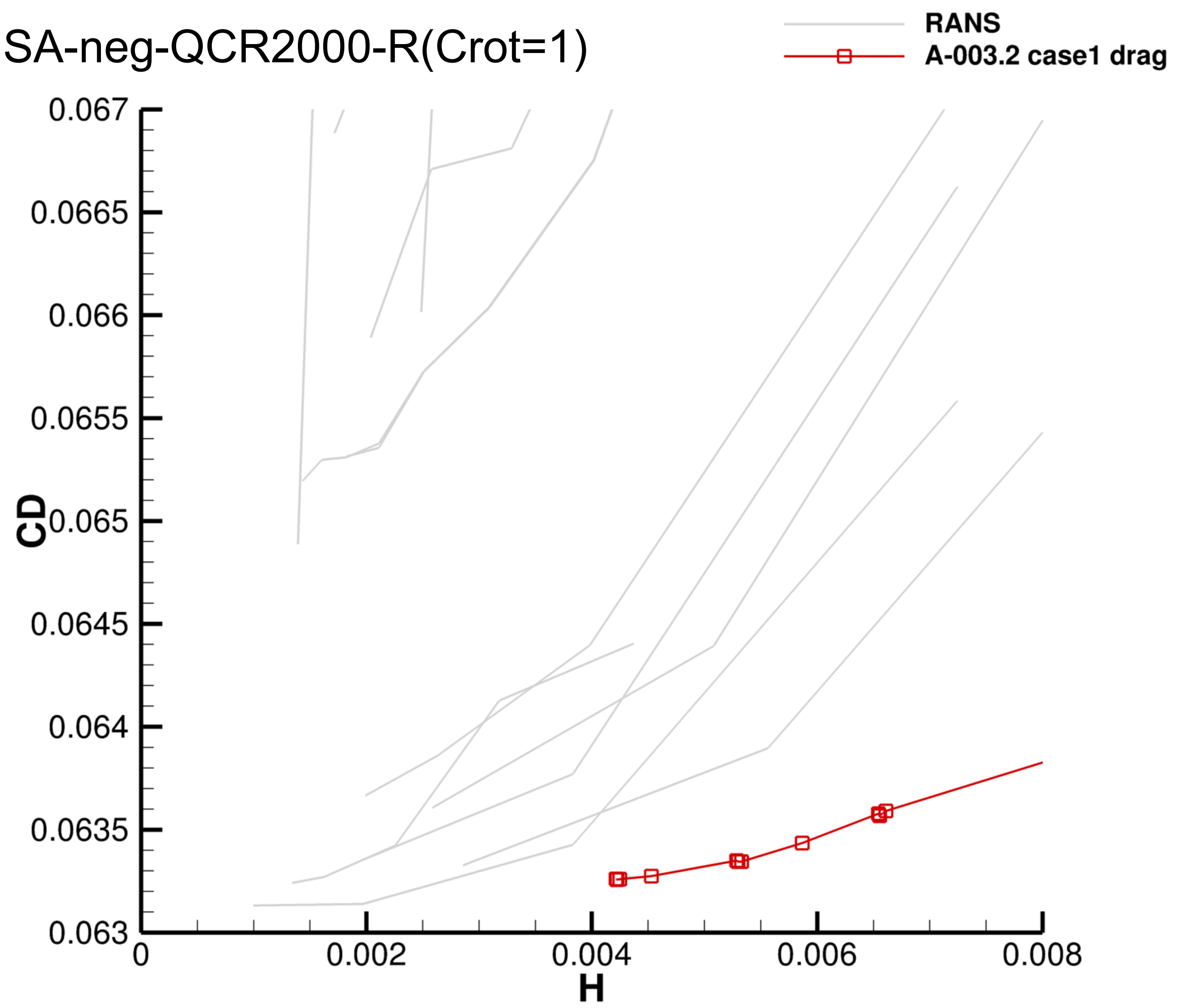


SA-neg-QCR2000-R(Crot=1)



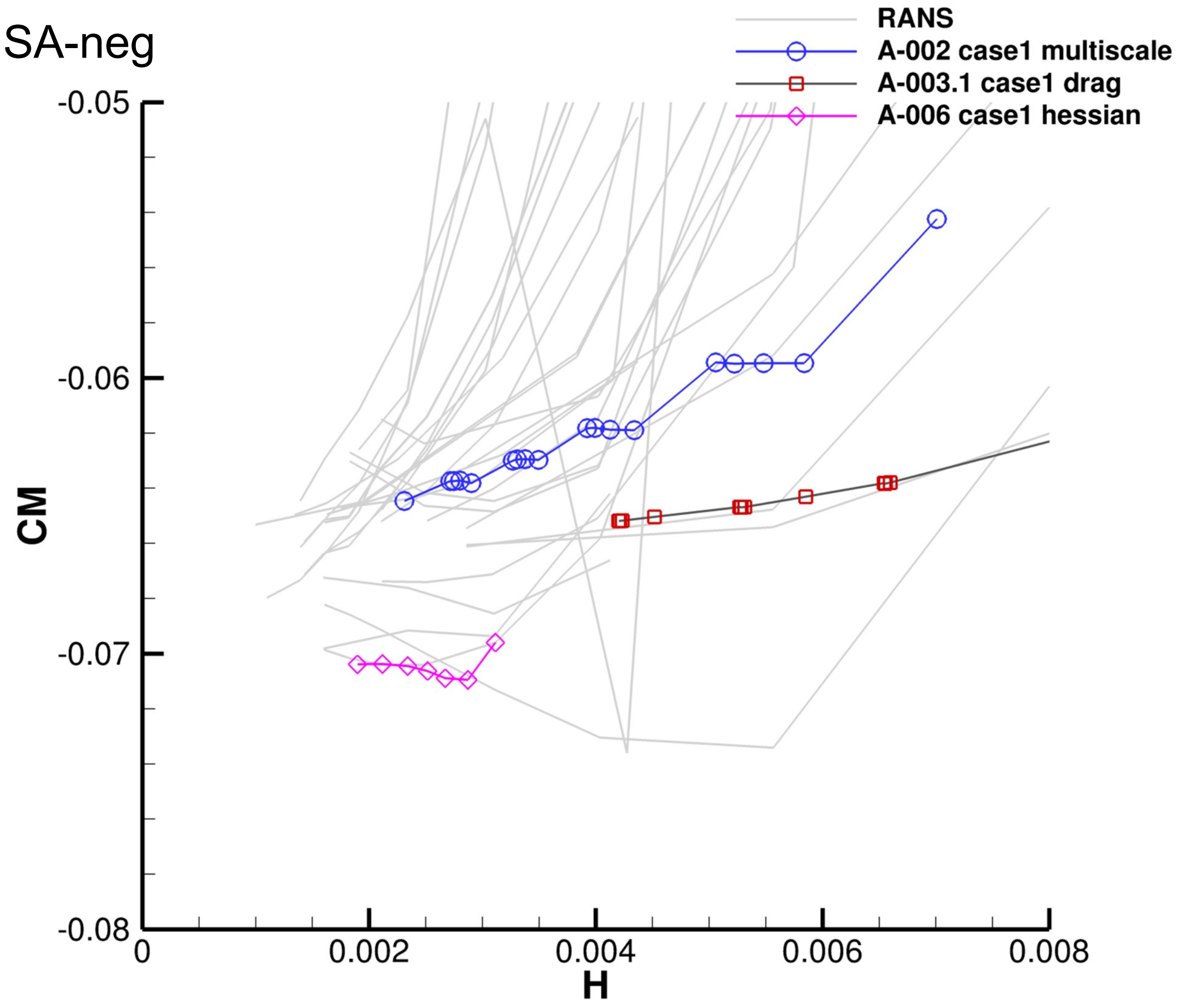
Test Case 1 Drag



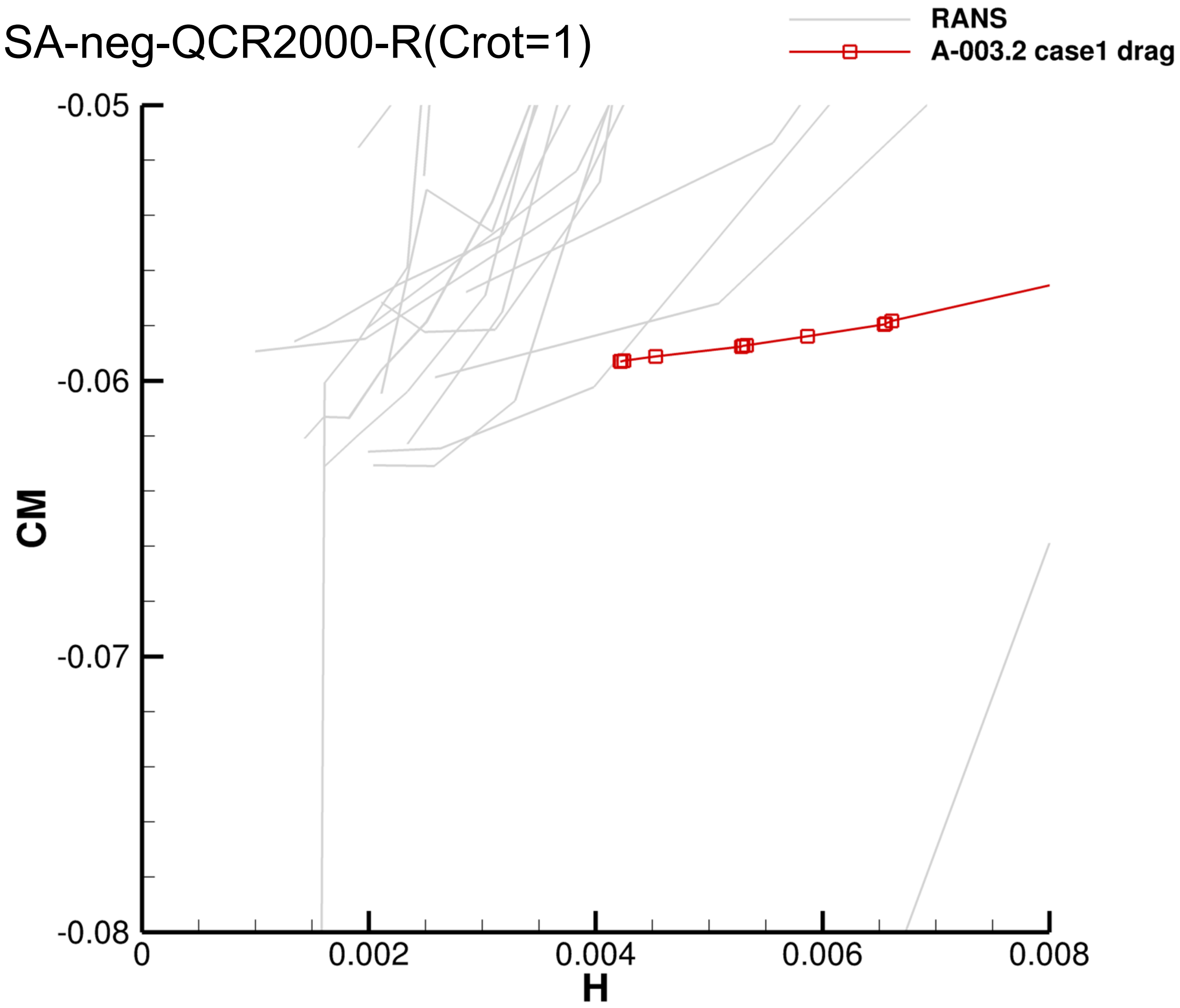


Test Case 1 Pitching Moment

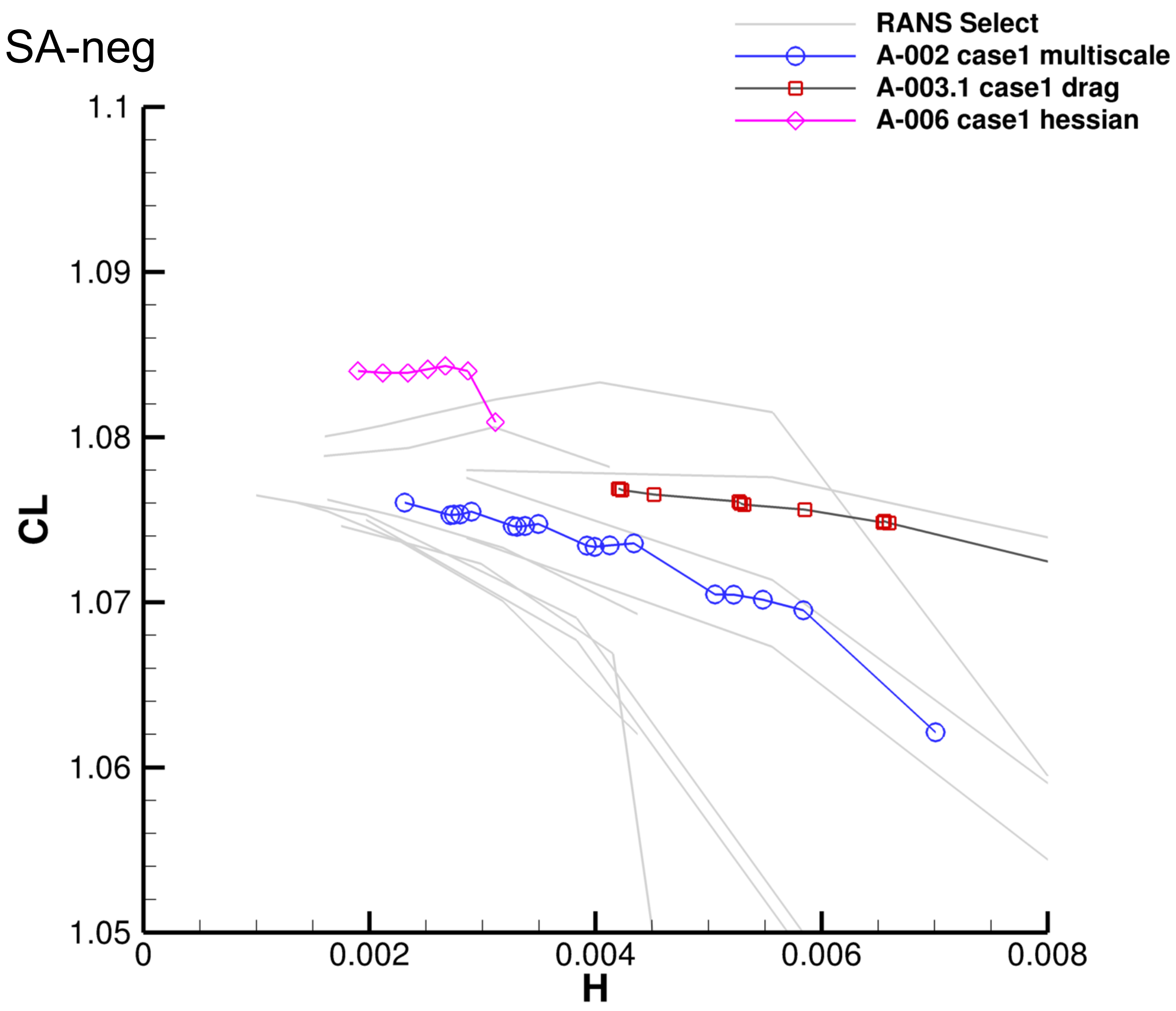
SA-neg

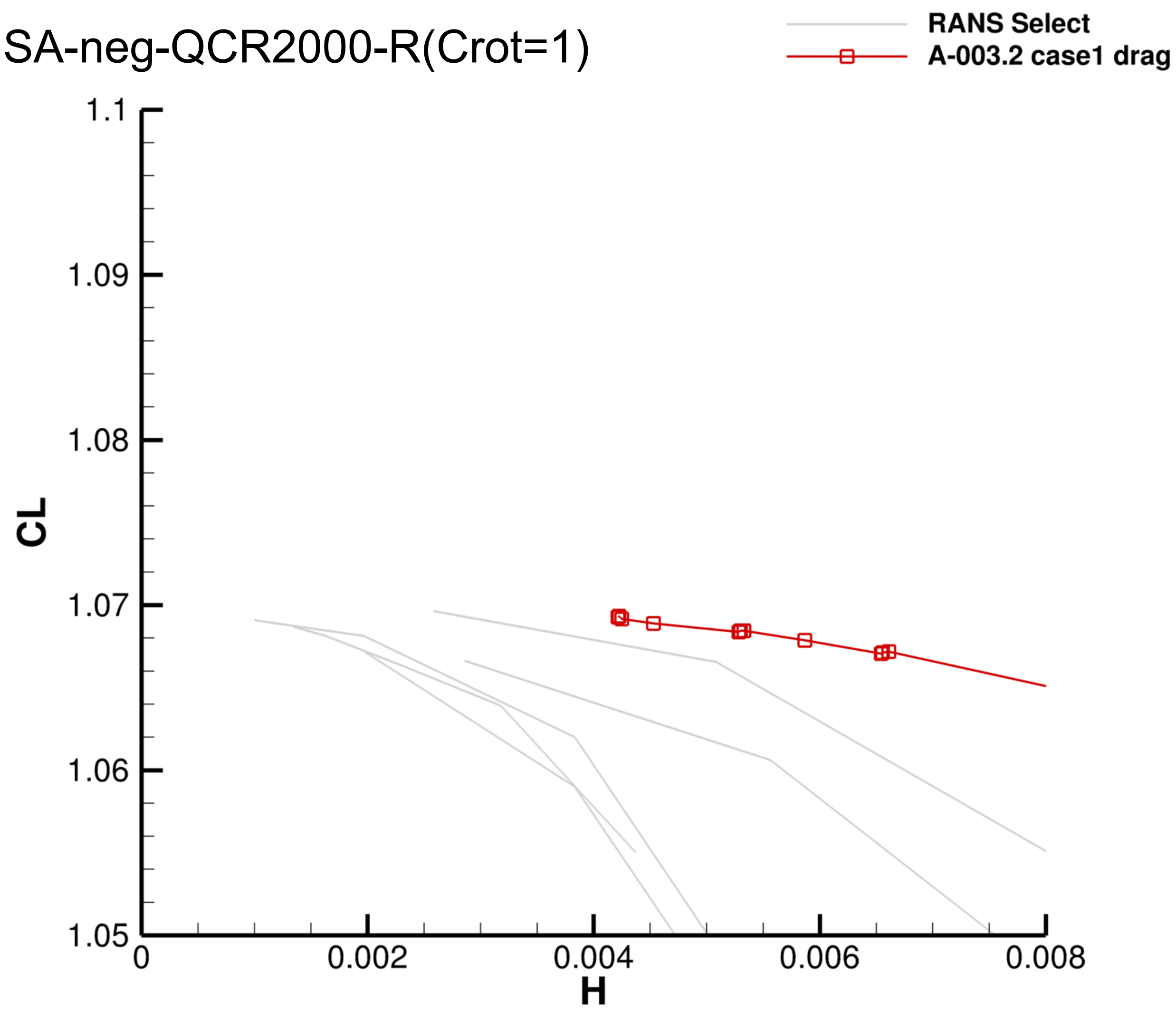


SA-neg-QCR2000-R(Crot=1)

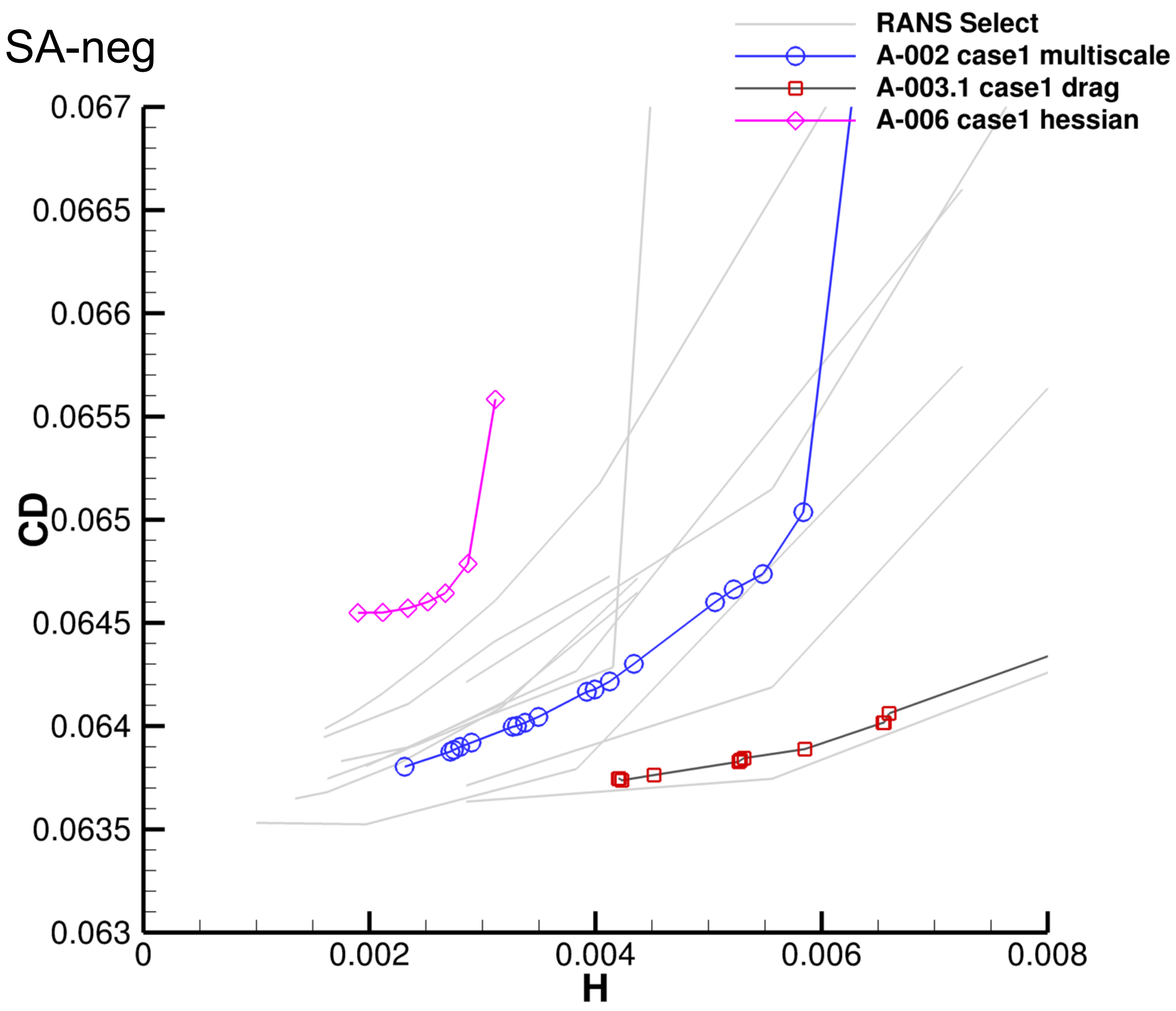


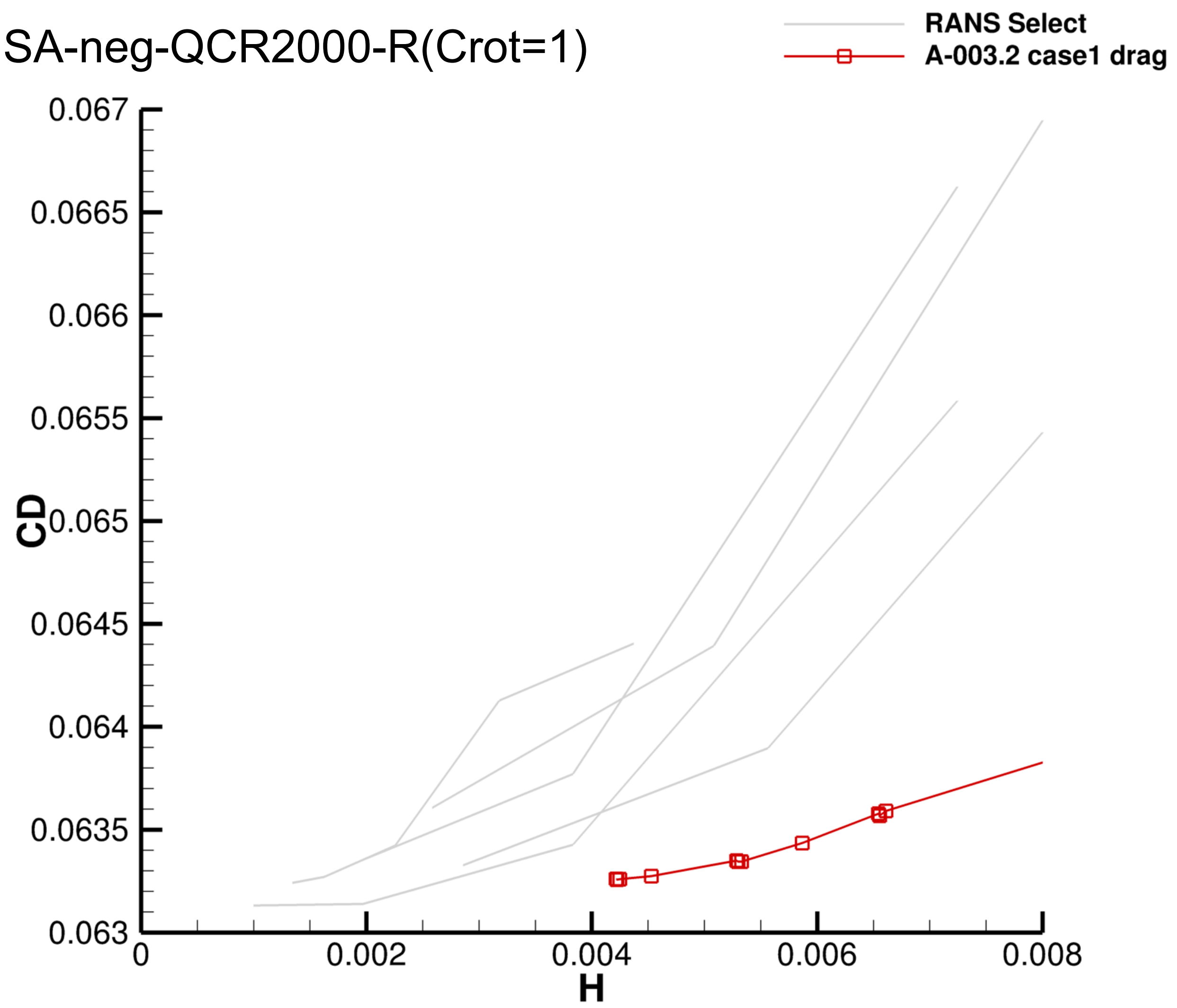
Test Case 1 Lift



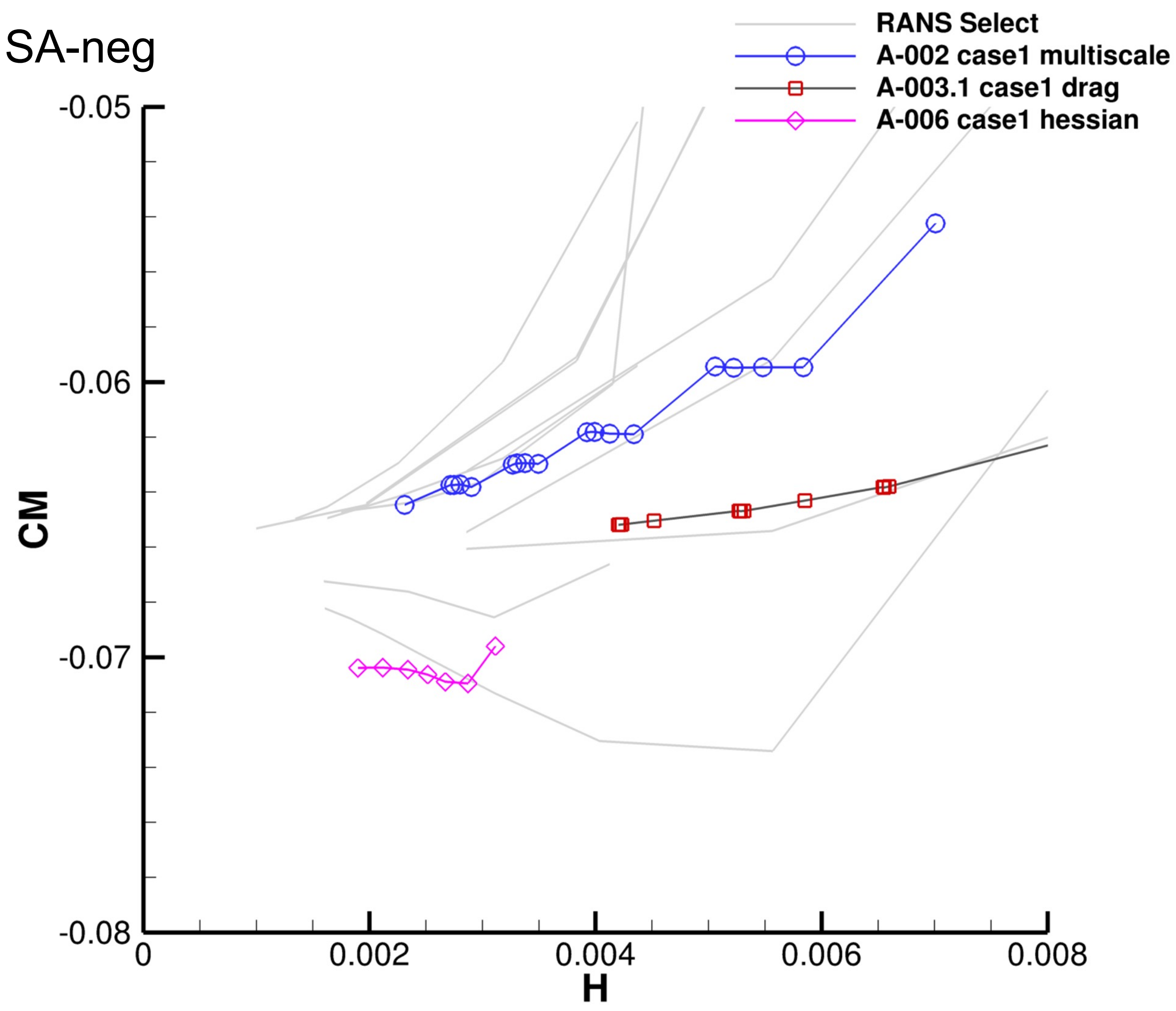


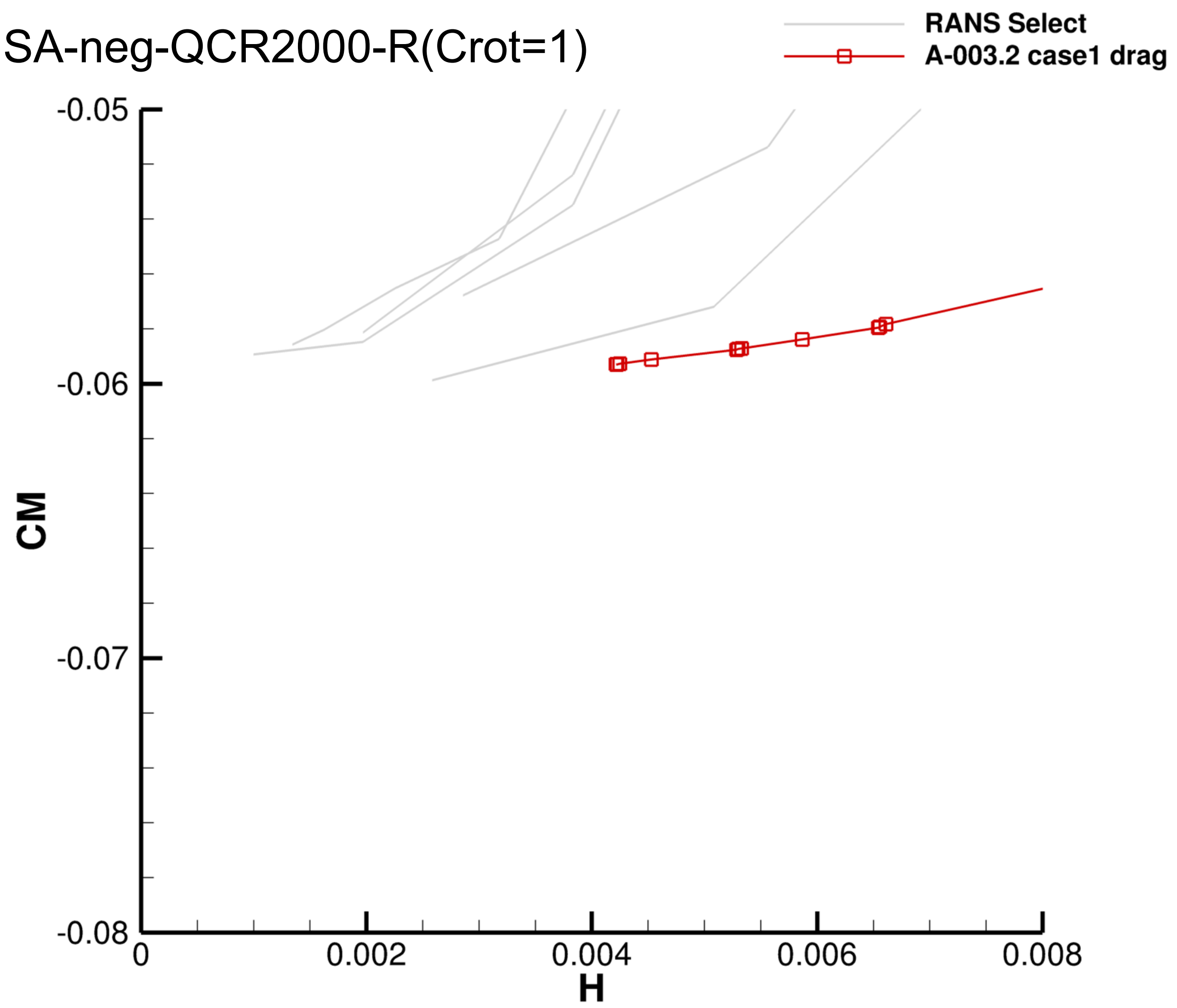
Test Case 1 Drag



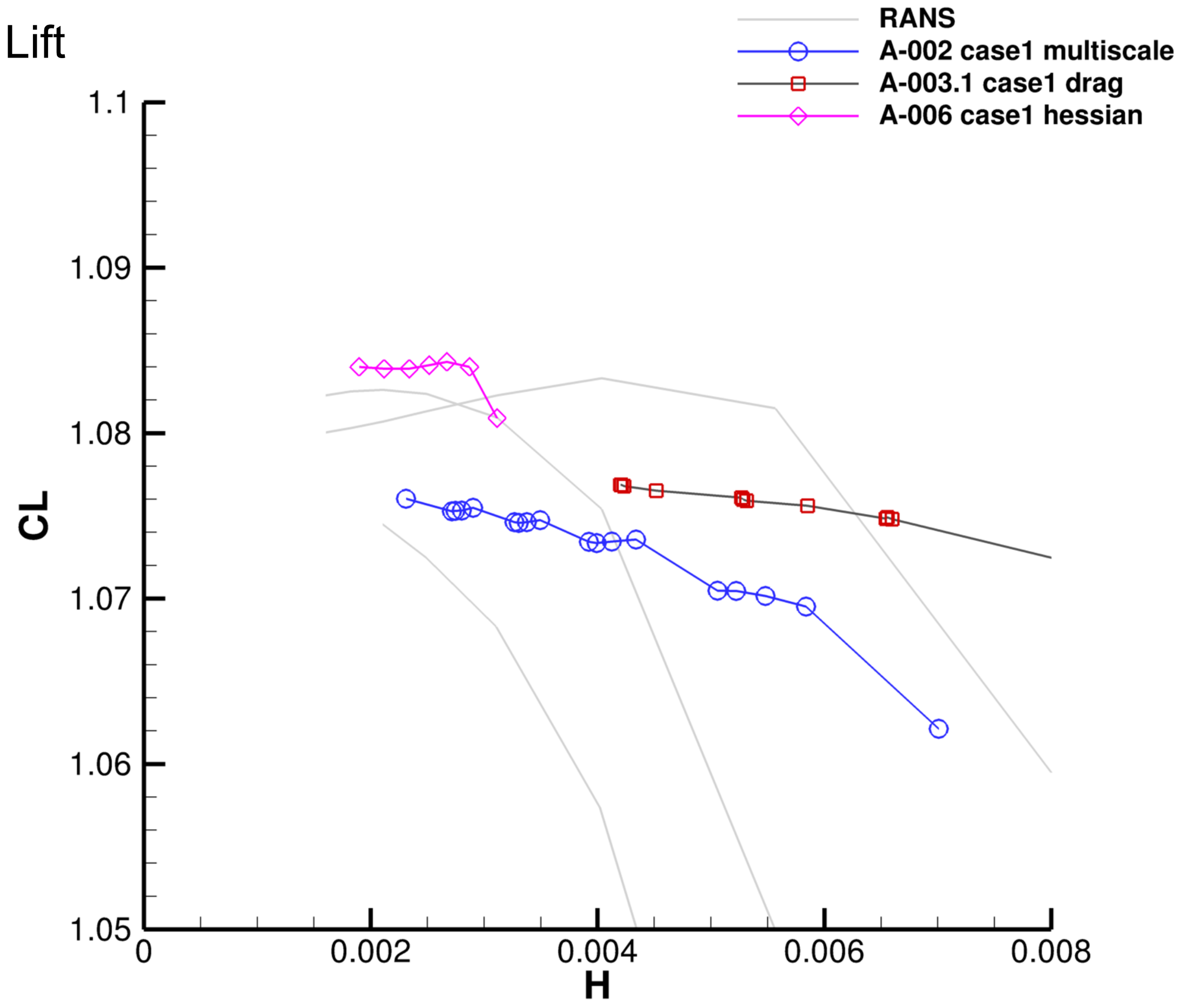


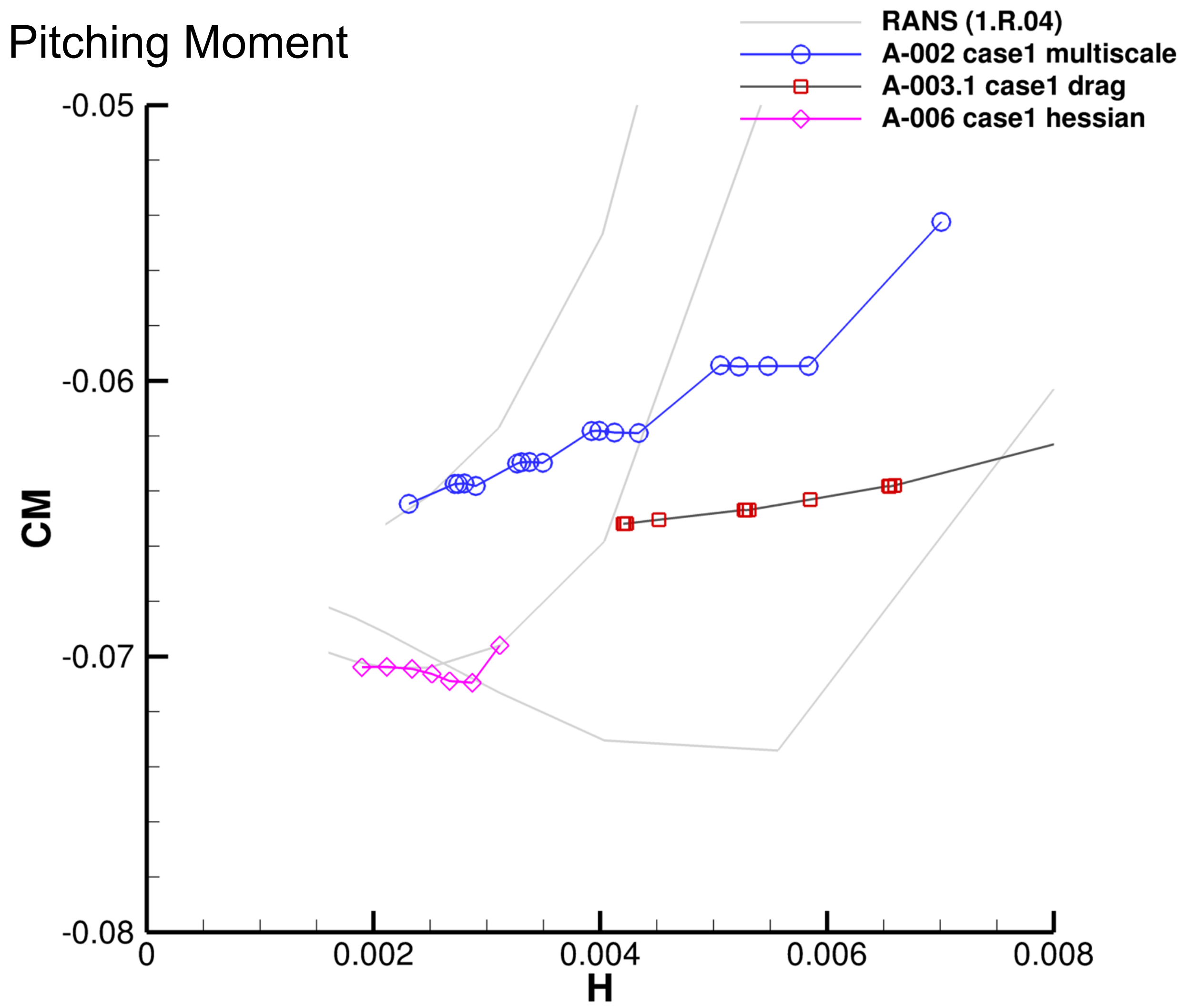
Test Case 1 Pitching Moment





Test Case 1 SA Influence of 1.R.04 Base Mesh





Case 1 Summary

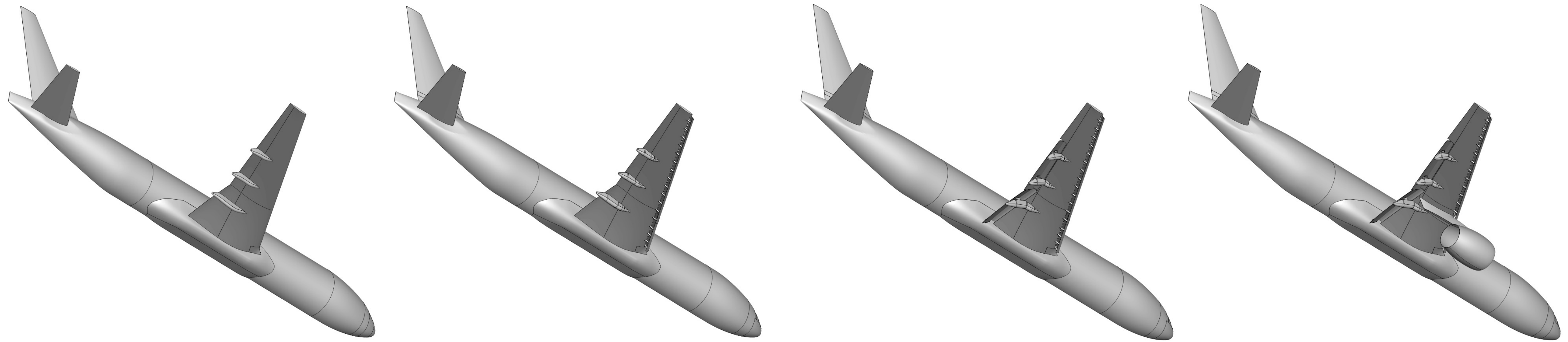
Can adaptive mesh convergence be achieved on the CRM-HL Wing-Body to verify implementations?

- Adapted mesh solution forces and moment are consistent with RANS TFG submissions for SA and SA-QCR2000-R(Crot=1) turbulence models
- Goal-based drag metric approached fine-mesh result with less degrees of freedom
- A-006 used the workshop 1.R.04 mesh as a base mesh and refined volume without surface adaptation, which trended toward 2 of 3 1.R.04 RANS TFG submissions
- A-002 and A-003.1 used remeshing in the volume and on the surface
  - Approached similar force and moment values to the RANS Select submissions

Test Case 2 Description

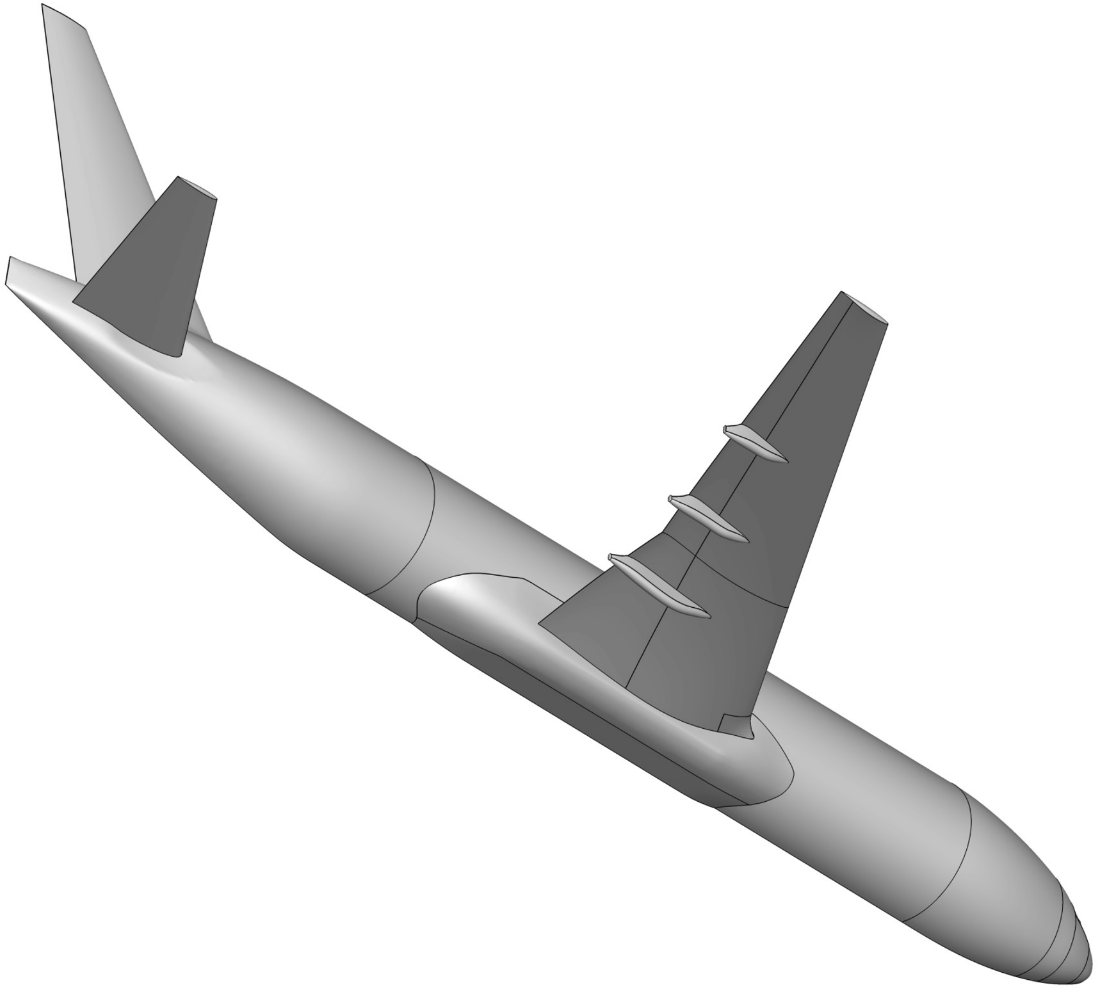
- Mach number 0.20
- Chord Reynolds number
  - 5.6 x 10^6 (subcase 2.1)
  - 5.9 x 10^6 (subcases 2.2 - 2.4)
- Reference static temperature 518.67 °R

2.1: CRM-HL-WBHV | 2.2: ONERA_LRM-WBSHV | 2.3: ONERA_LRM-WBSFHV | 2.4: ONERA_LRM-LDG-HV



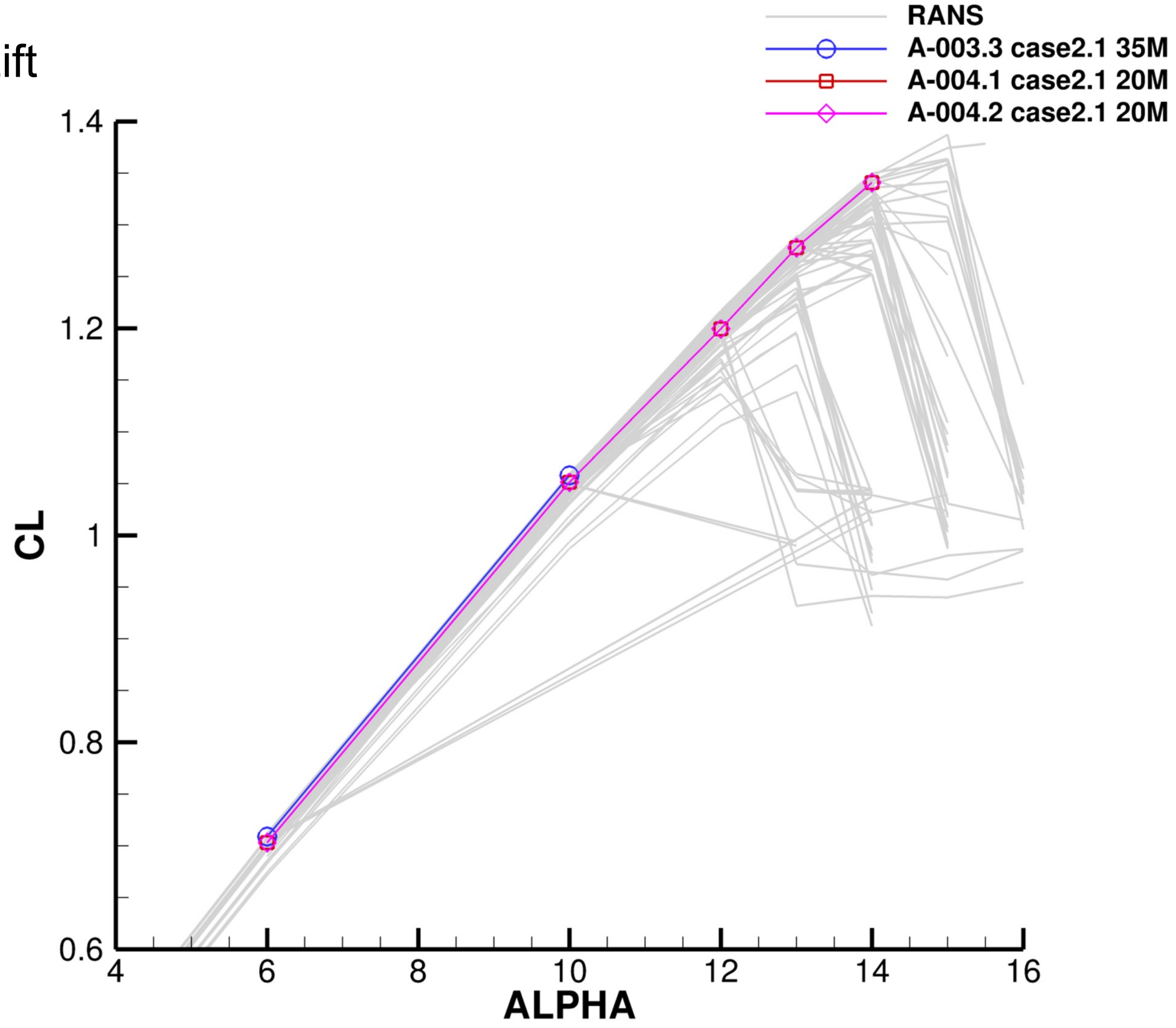
Test Case 2.1

- CRM-HL-WBHV Clean wing with flap fairings

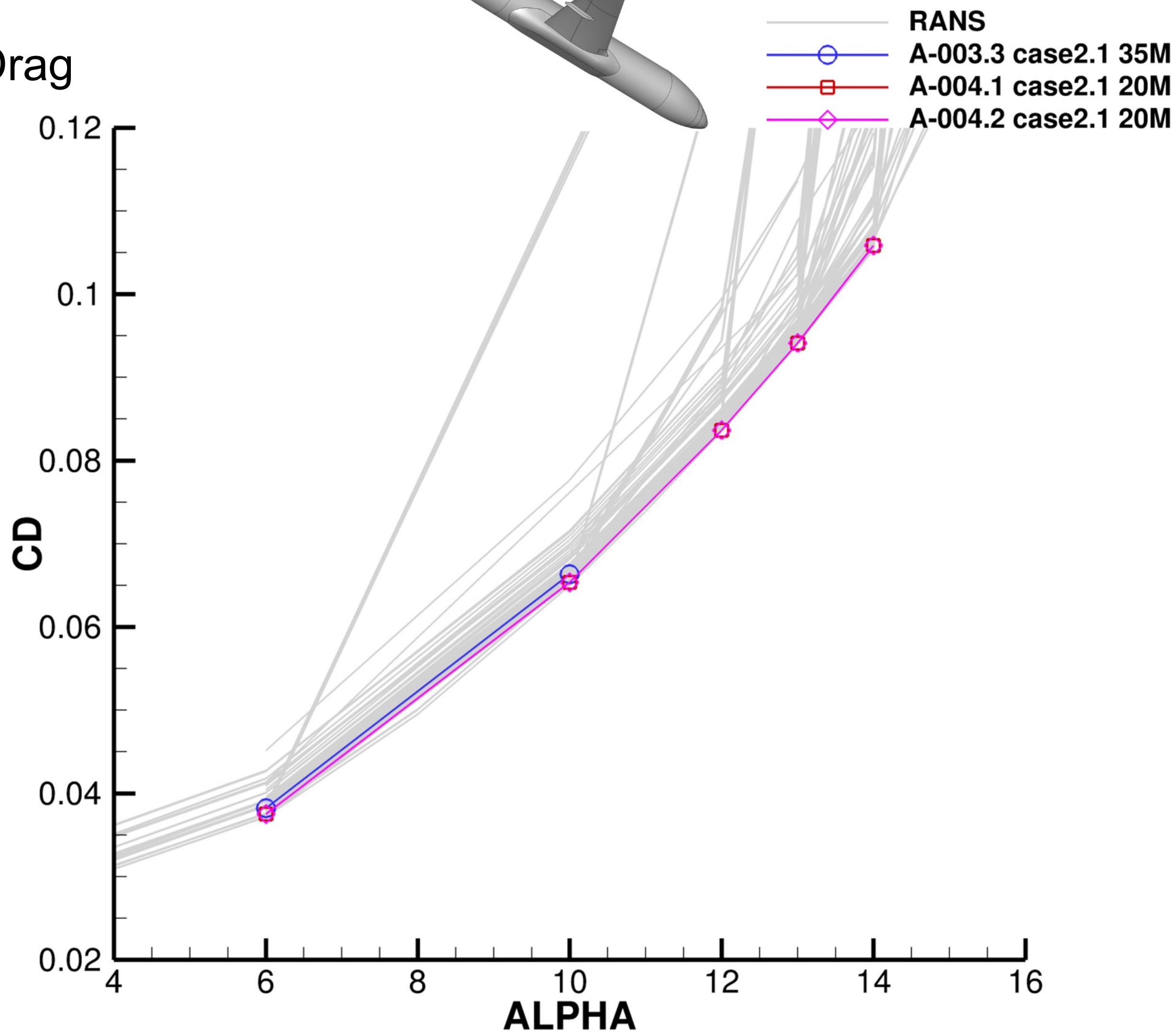


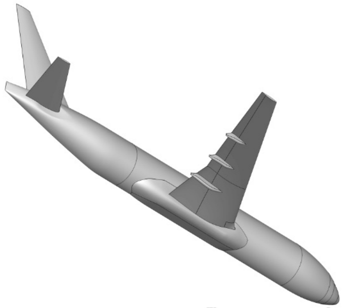
Test Case 2.1

Lift

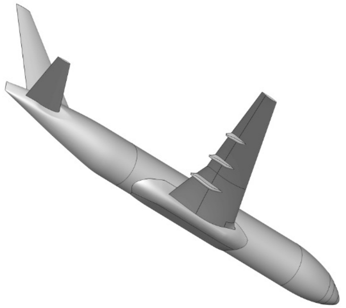


Drag





Test Case 2.1



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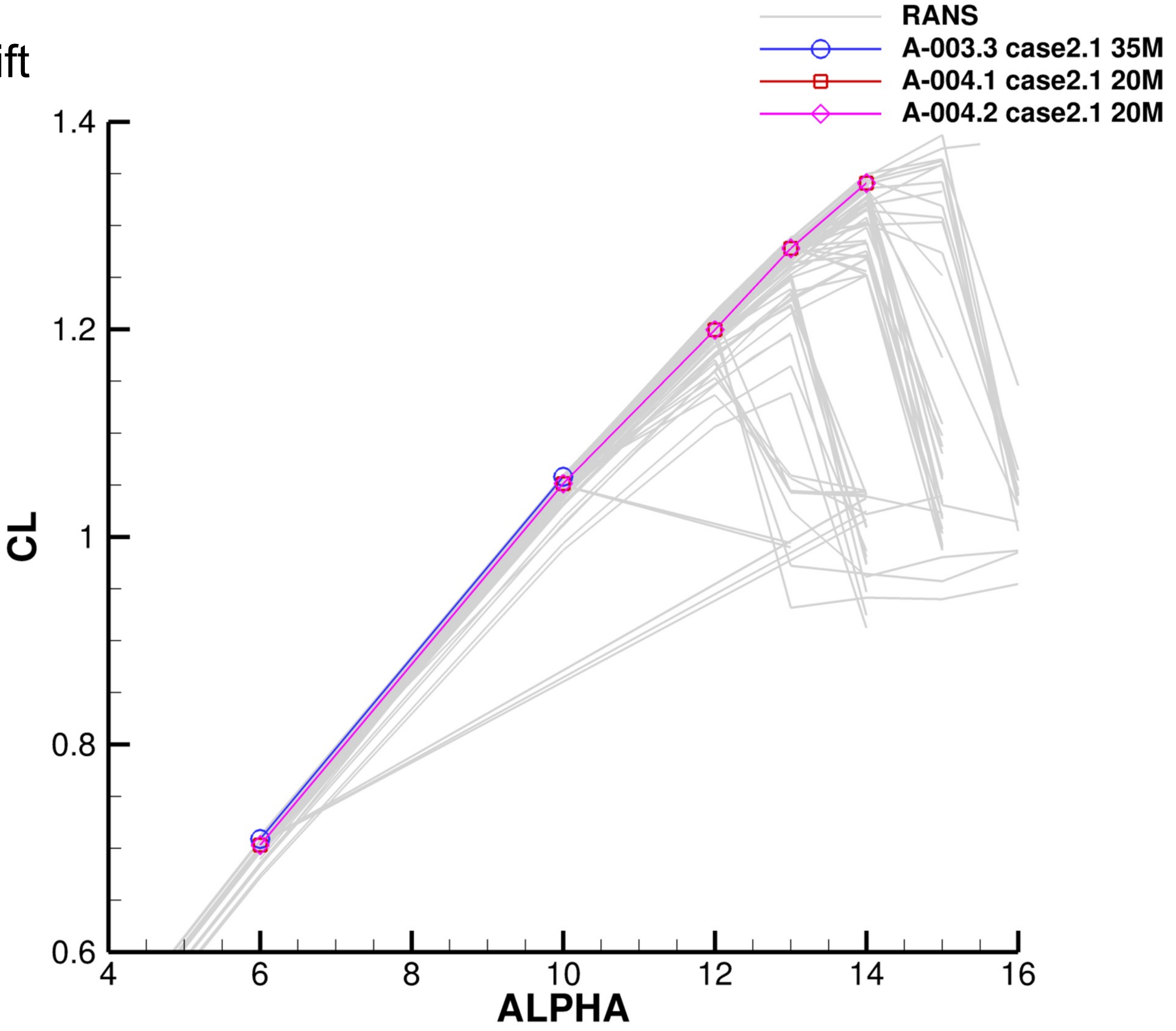
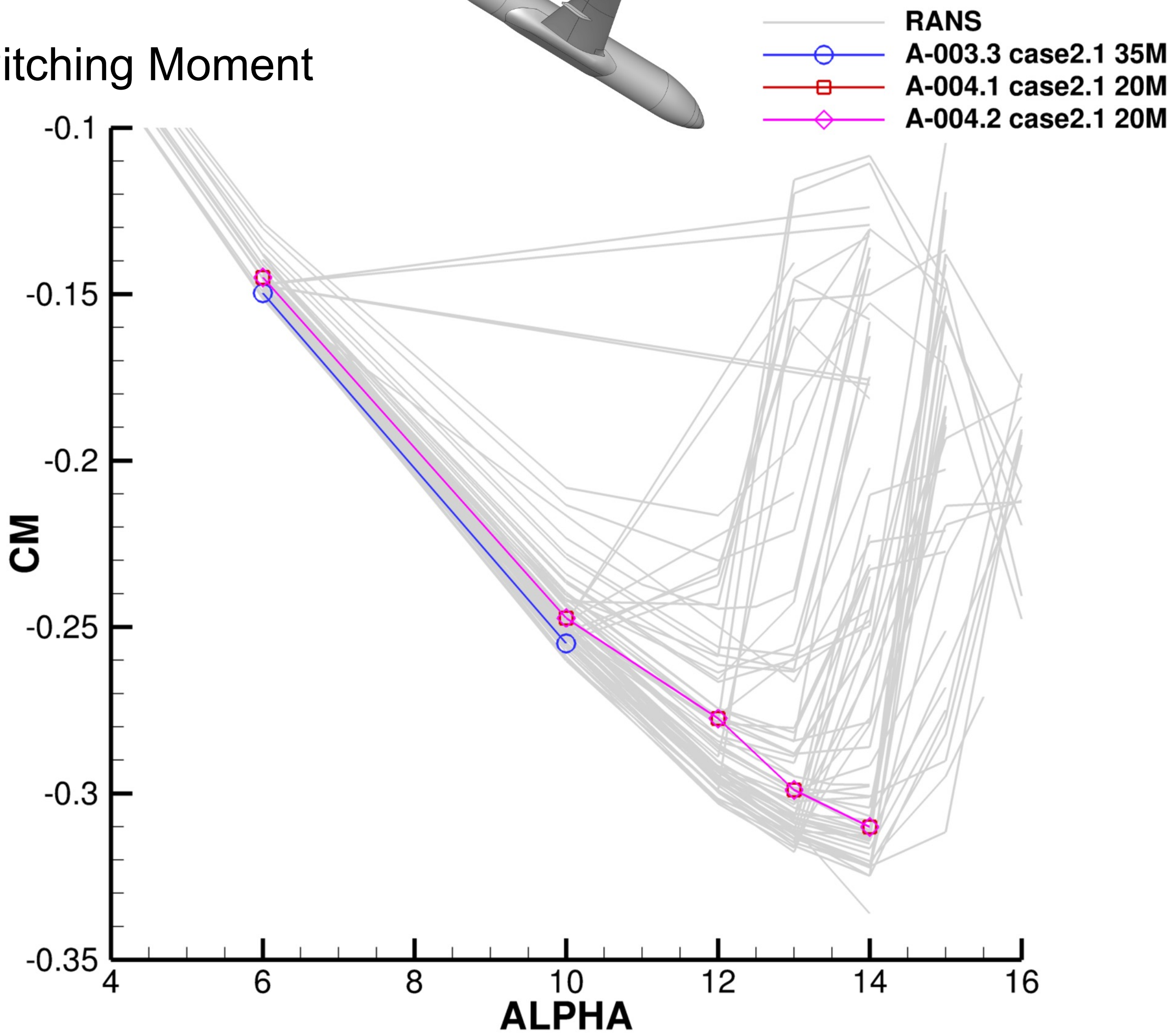
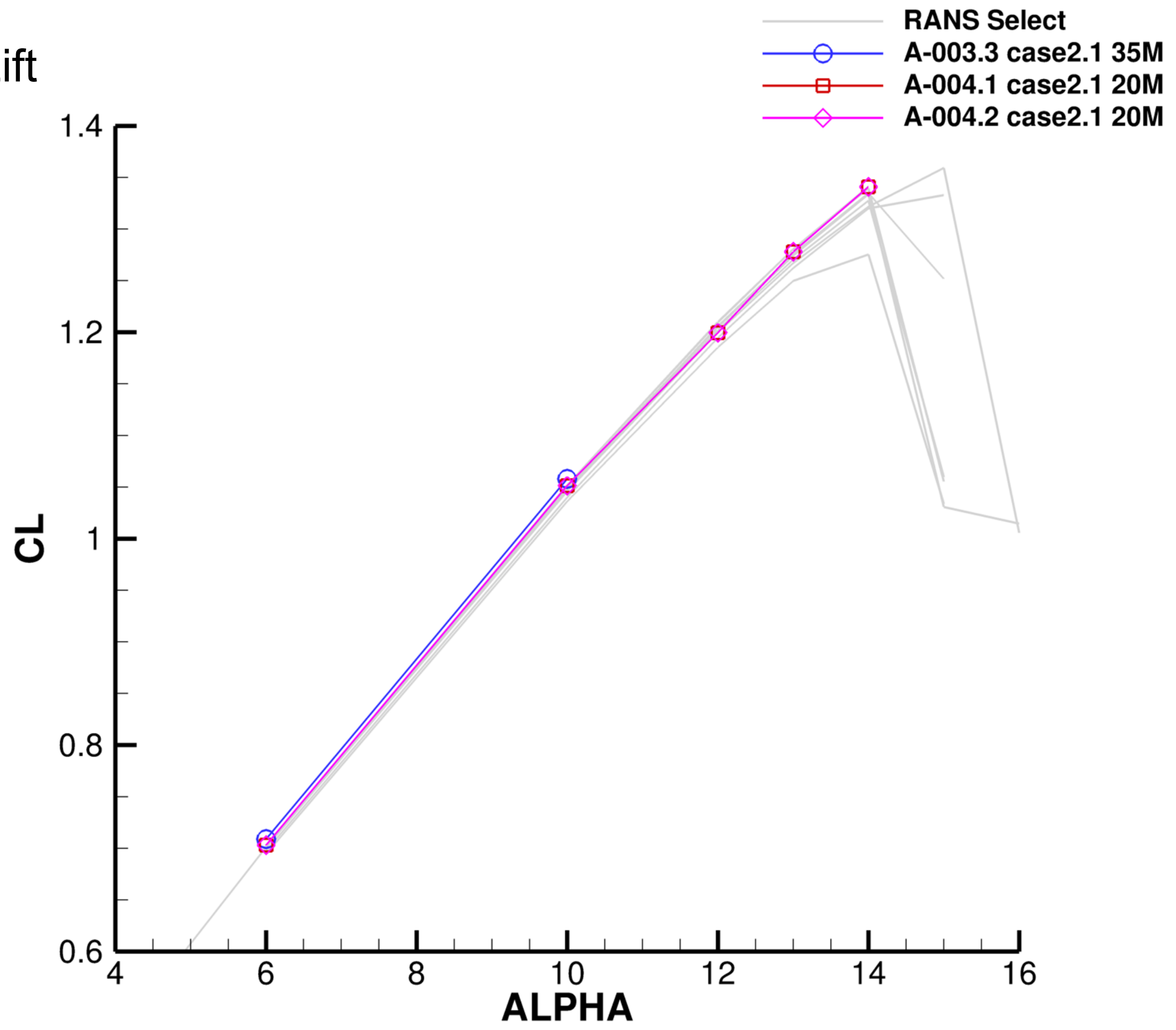


Pitching Moment



Test Case 2.1

Lift



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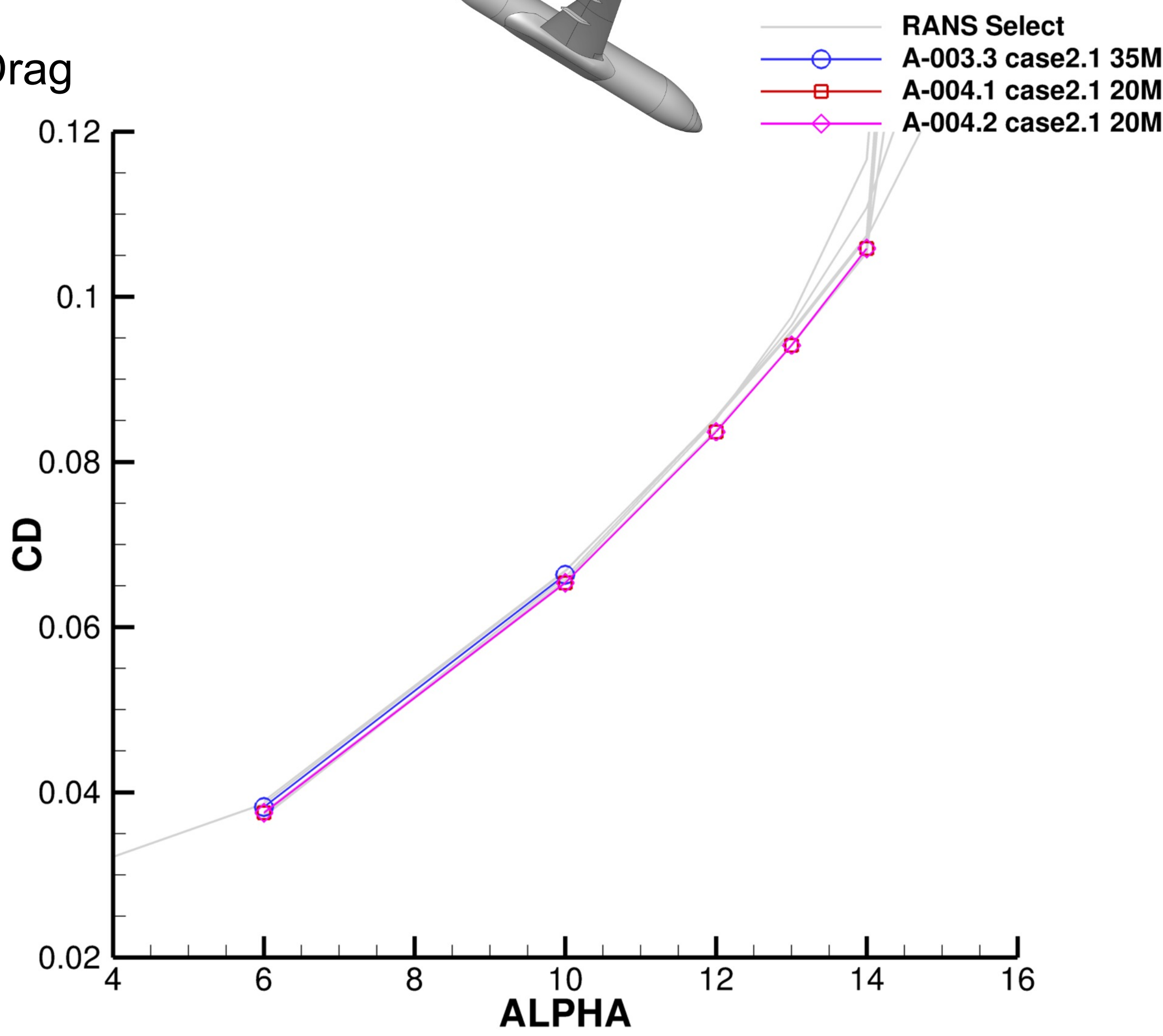
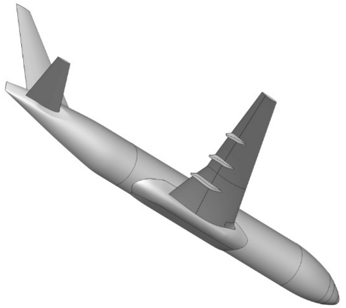
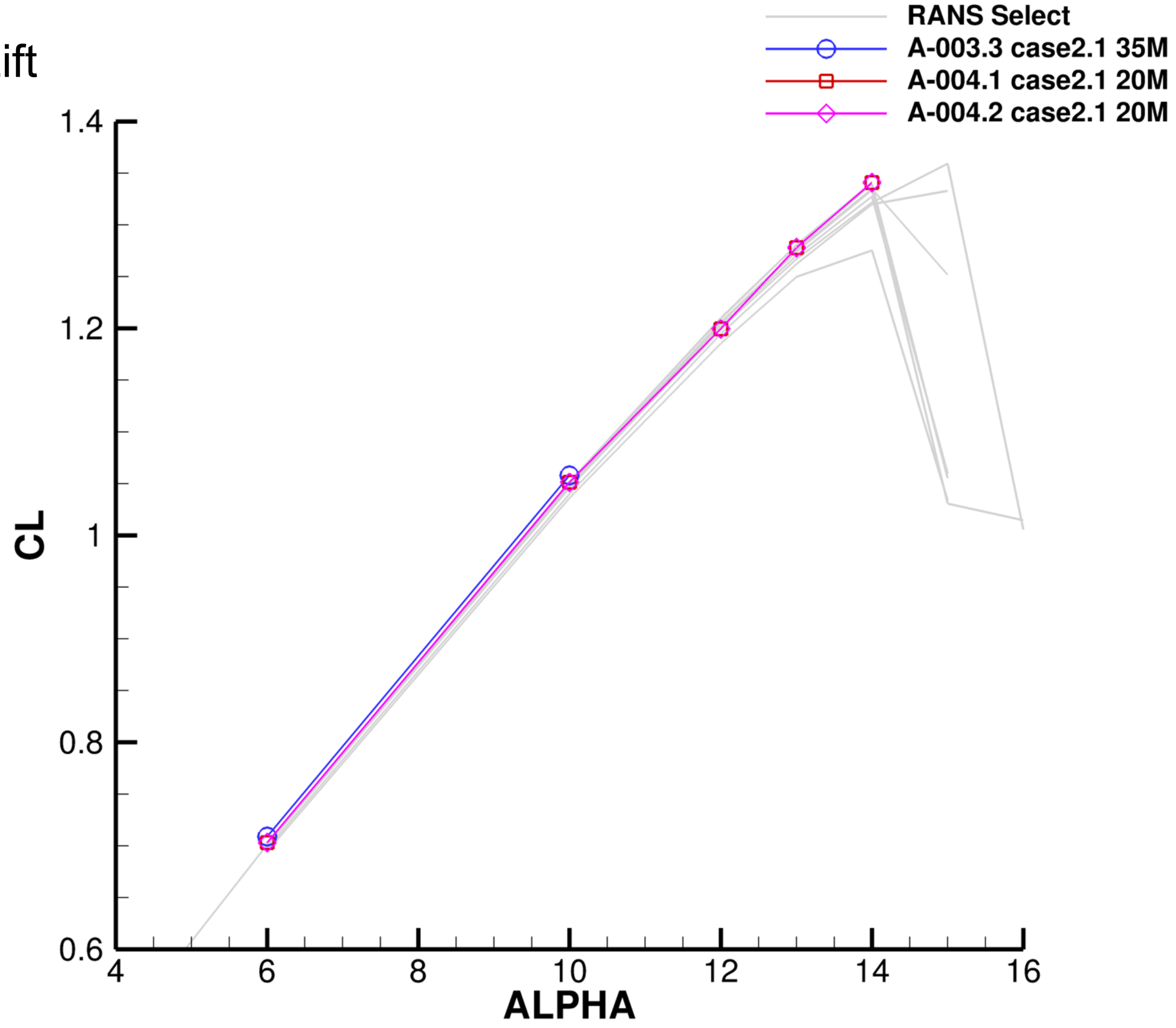


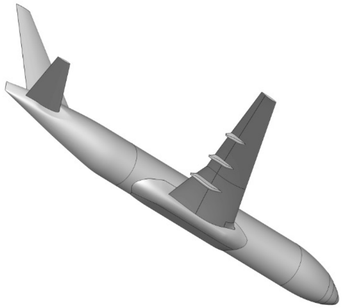


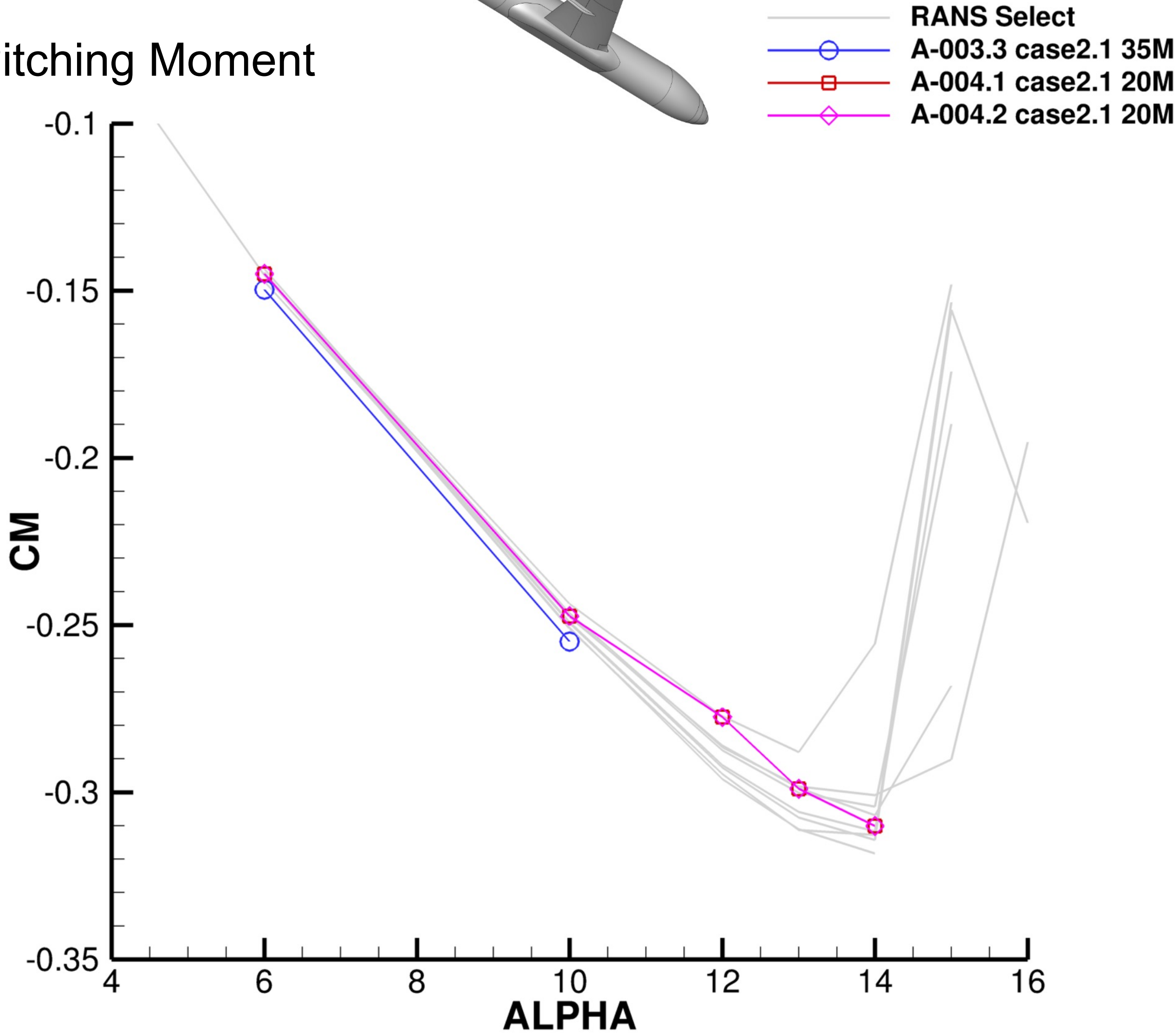
Test Case 2.1

Lift



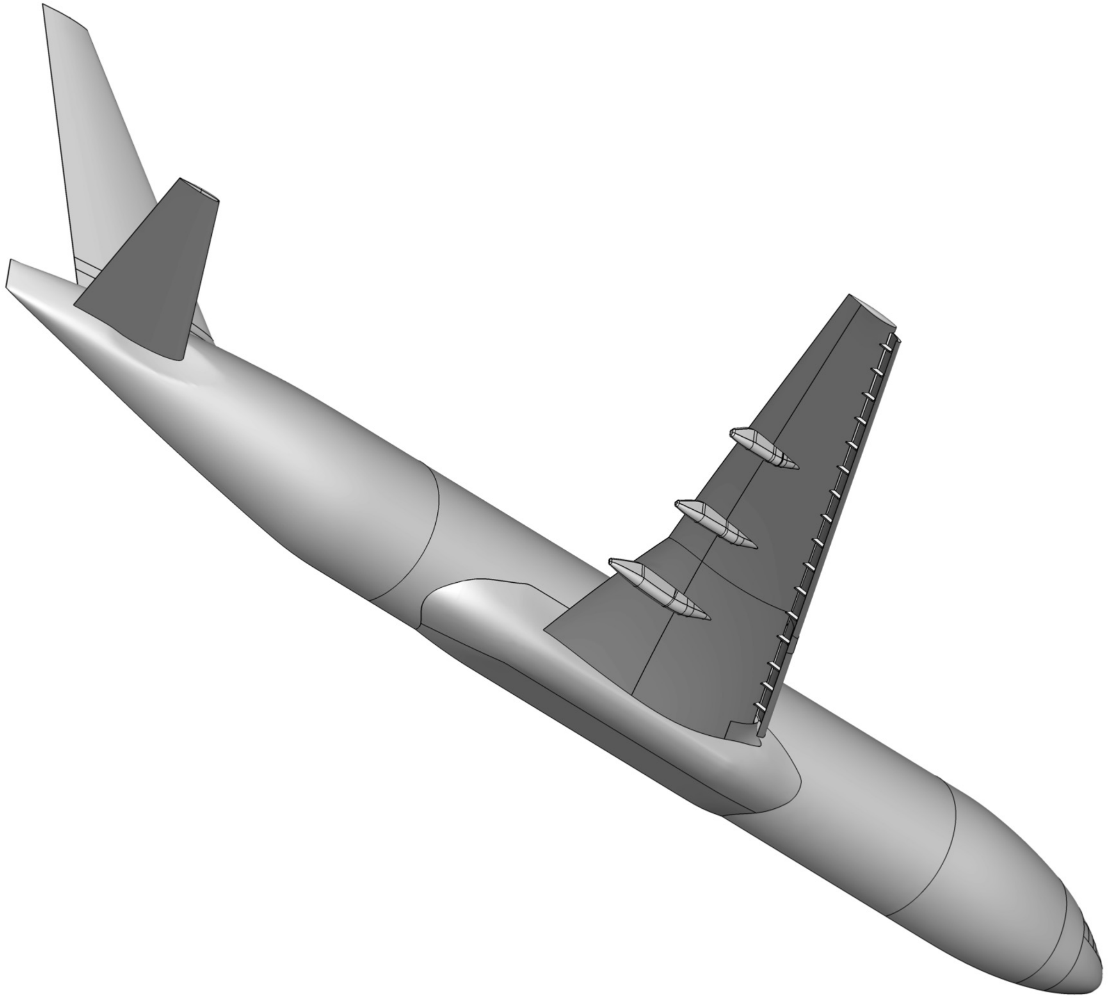
Pitching Moment



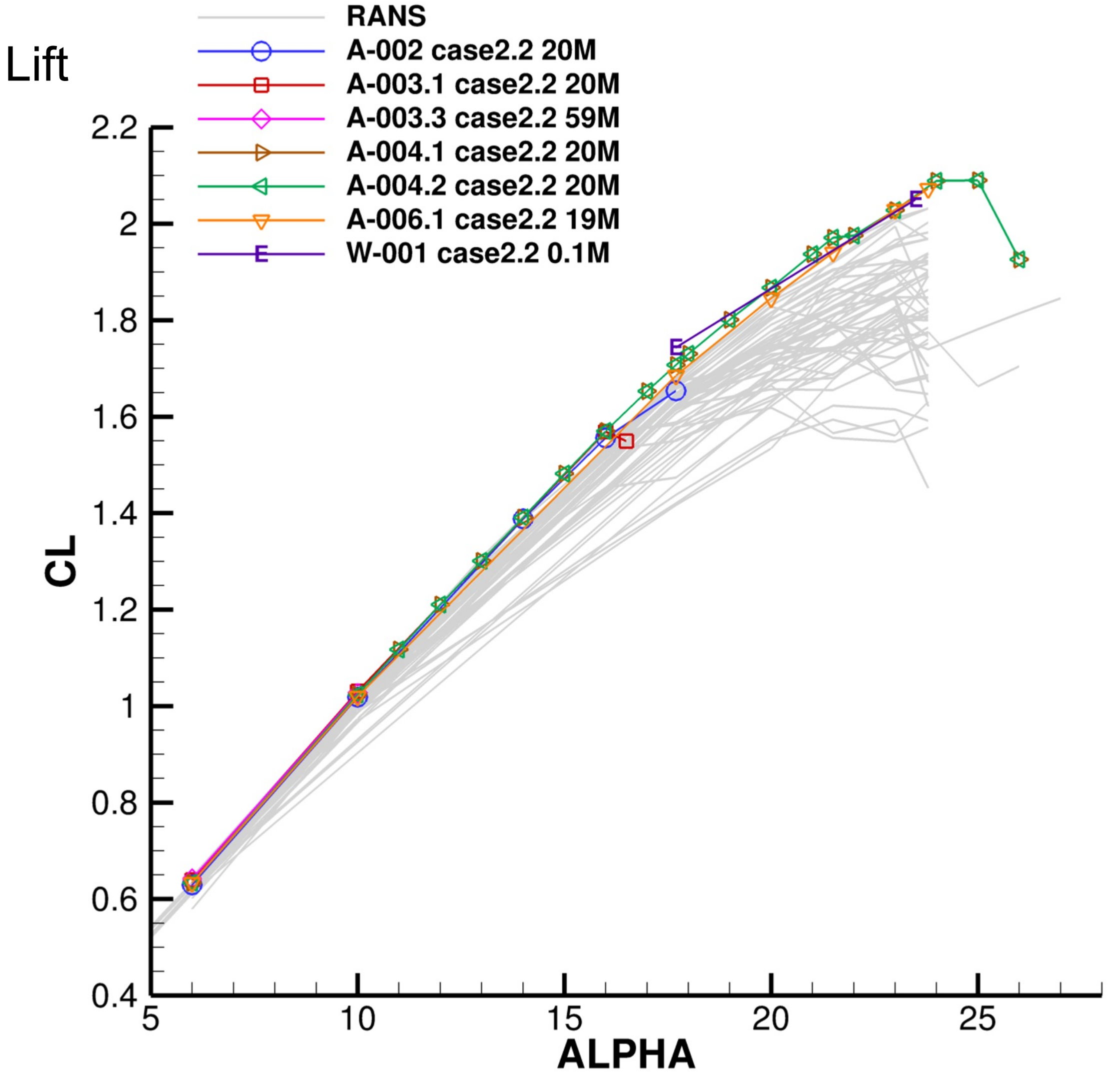


Test Case 2.2

- ONERA_LRM-WBSHV adds full-span slat



Test Case 2.2


Lift
RANS
A-002 case2.2 20M
A-003.1 case2.2 20M
A-003.3 case2.2 59M
A-004.1 case2.2 20M
A-004.2 case2.2 20M
A-006.1 case2.2 19M
W-001 case2.2 0.1M
CL
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
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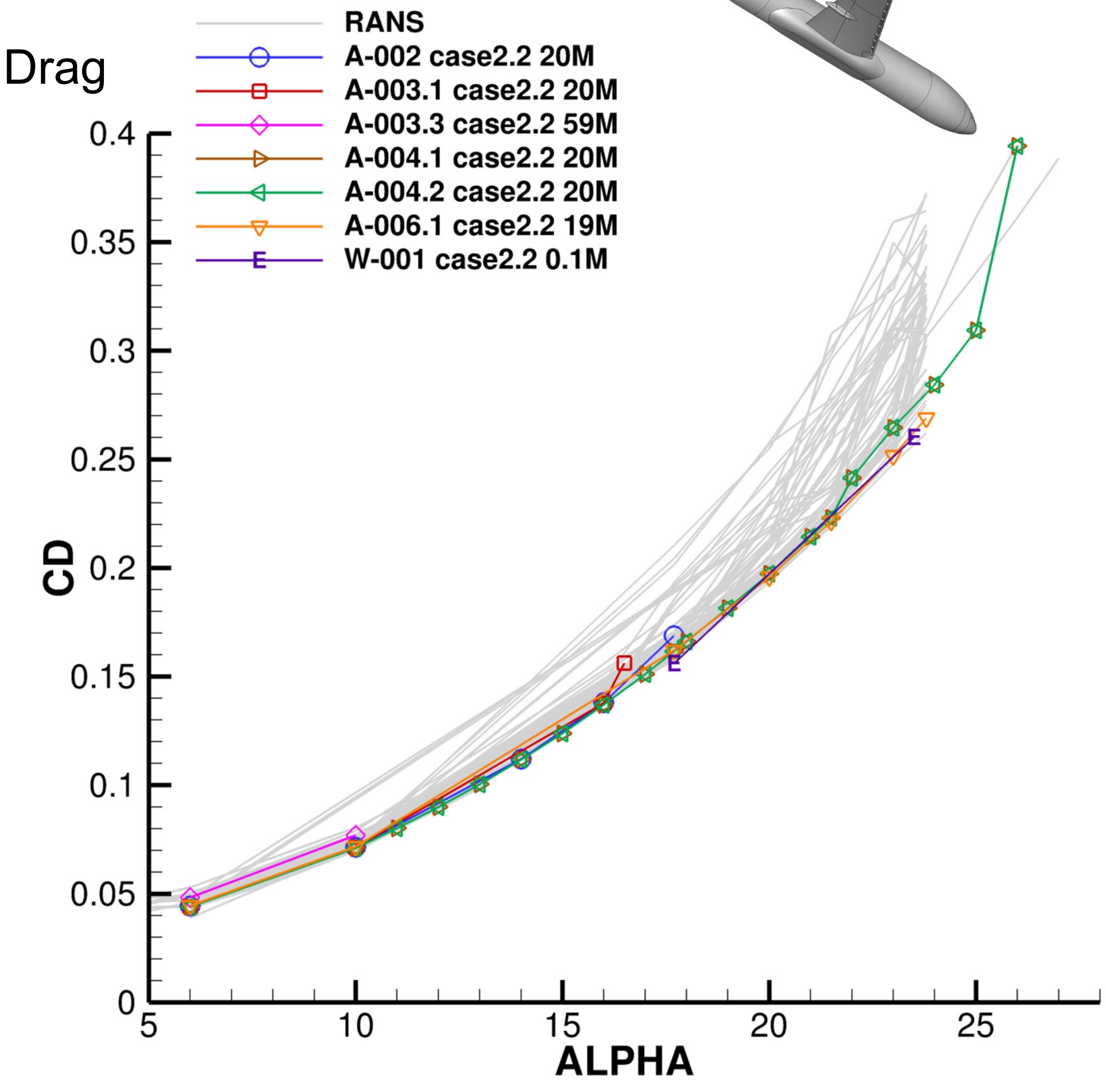
2.2
5
10
15
20
25
ALPHA


Drag
RANS
A-002 case2.2 20M
A-003.1 case2.2 20M
A-003.3 case2.2 59M
A-004.1 case2.2 20M
A-004.2 case2.2 20M
A-006.1 case2.2 19M
W-001 case2.2 0.1M
CD
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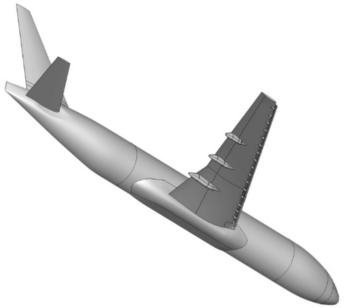
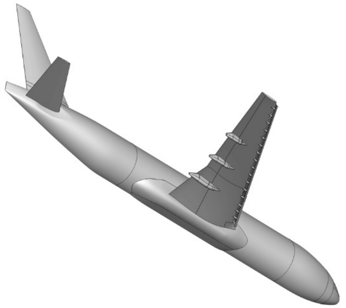
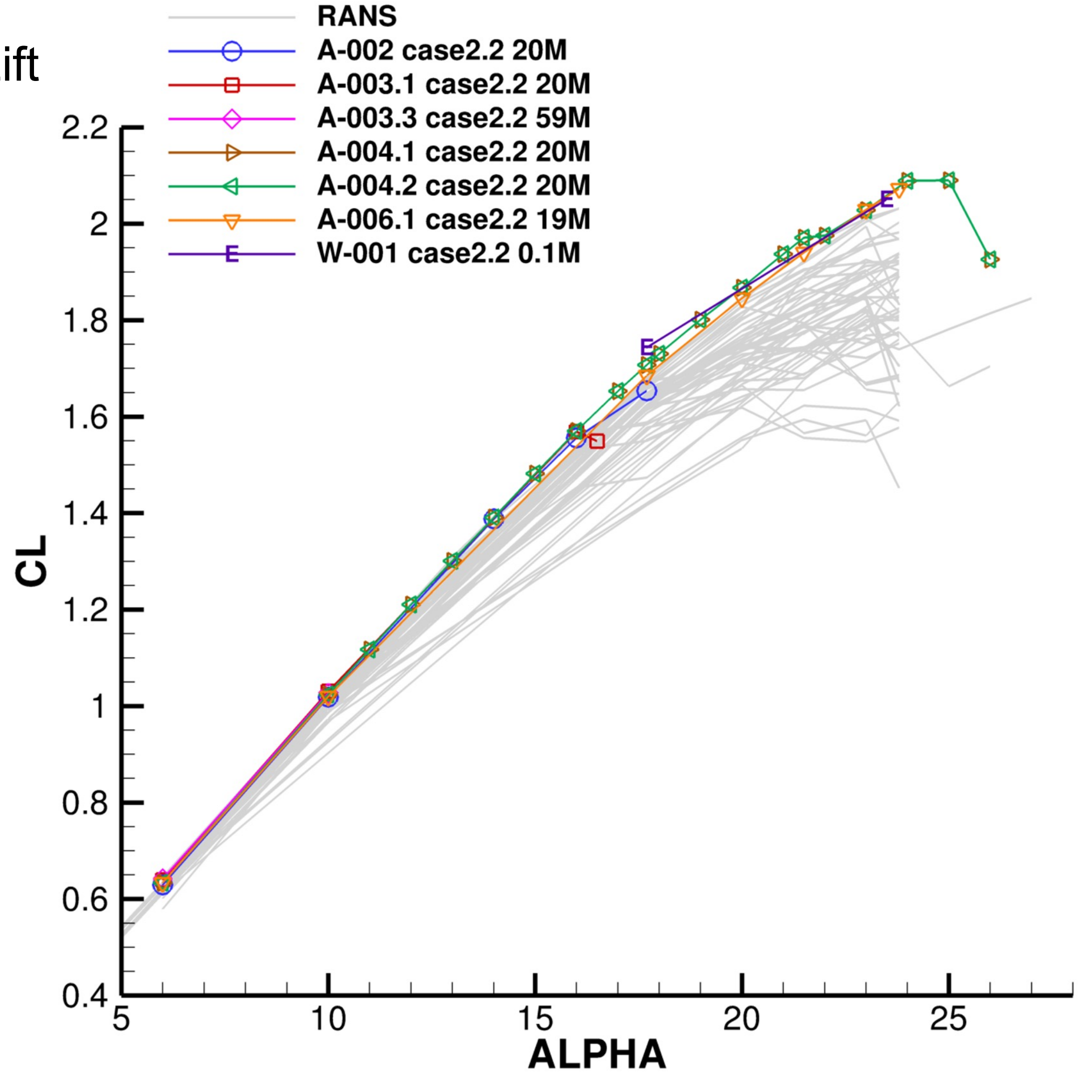
ALPHA



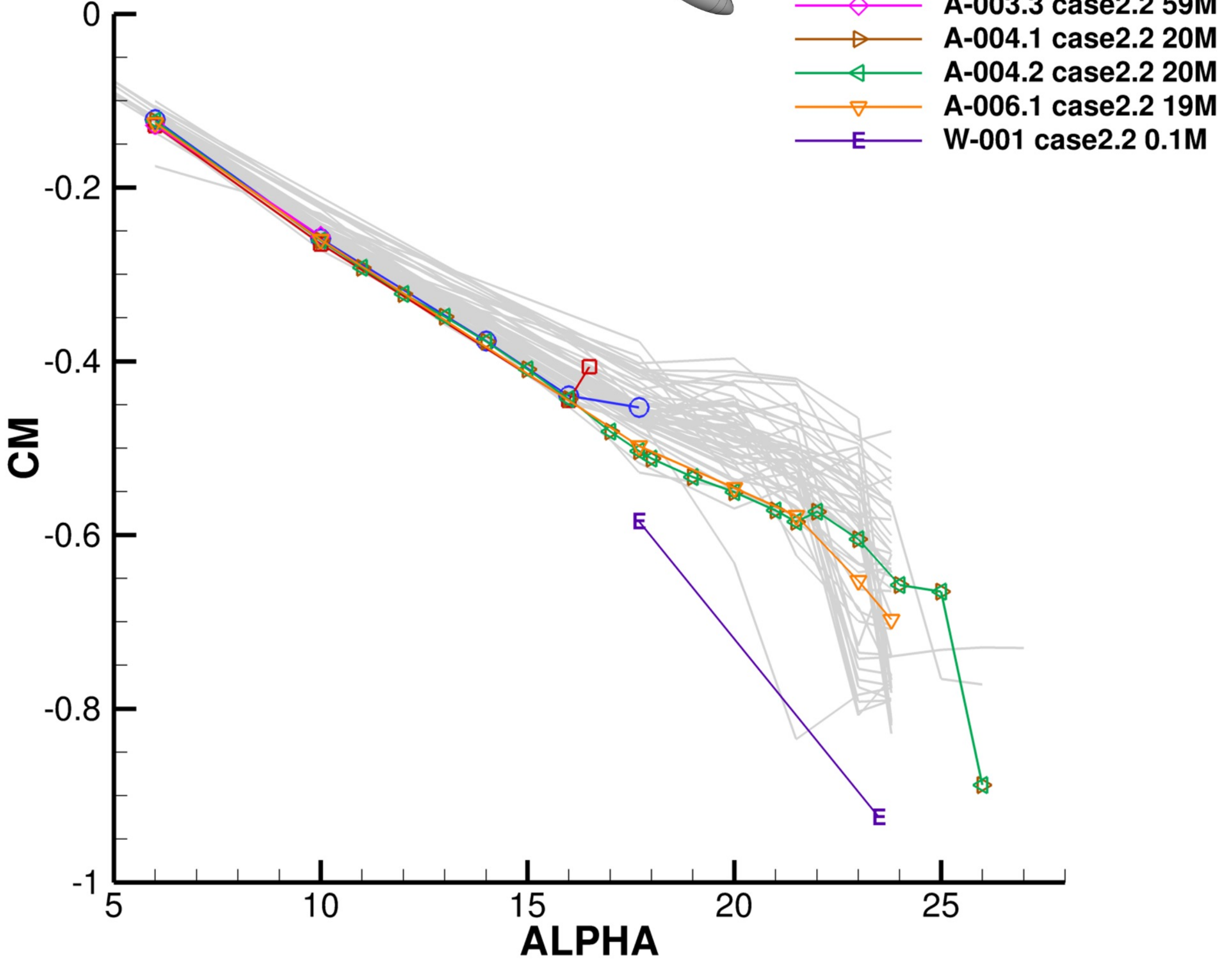
Test Case 2.2



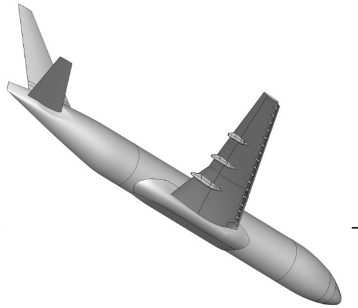
Lift

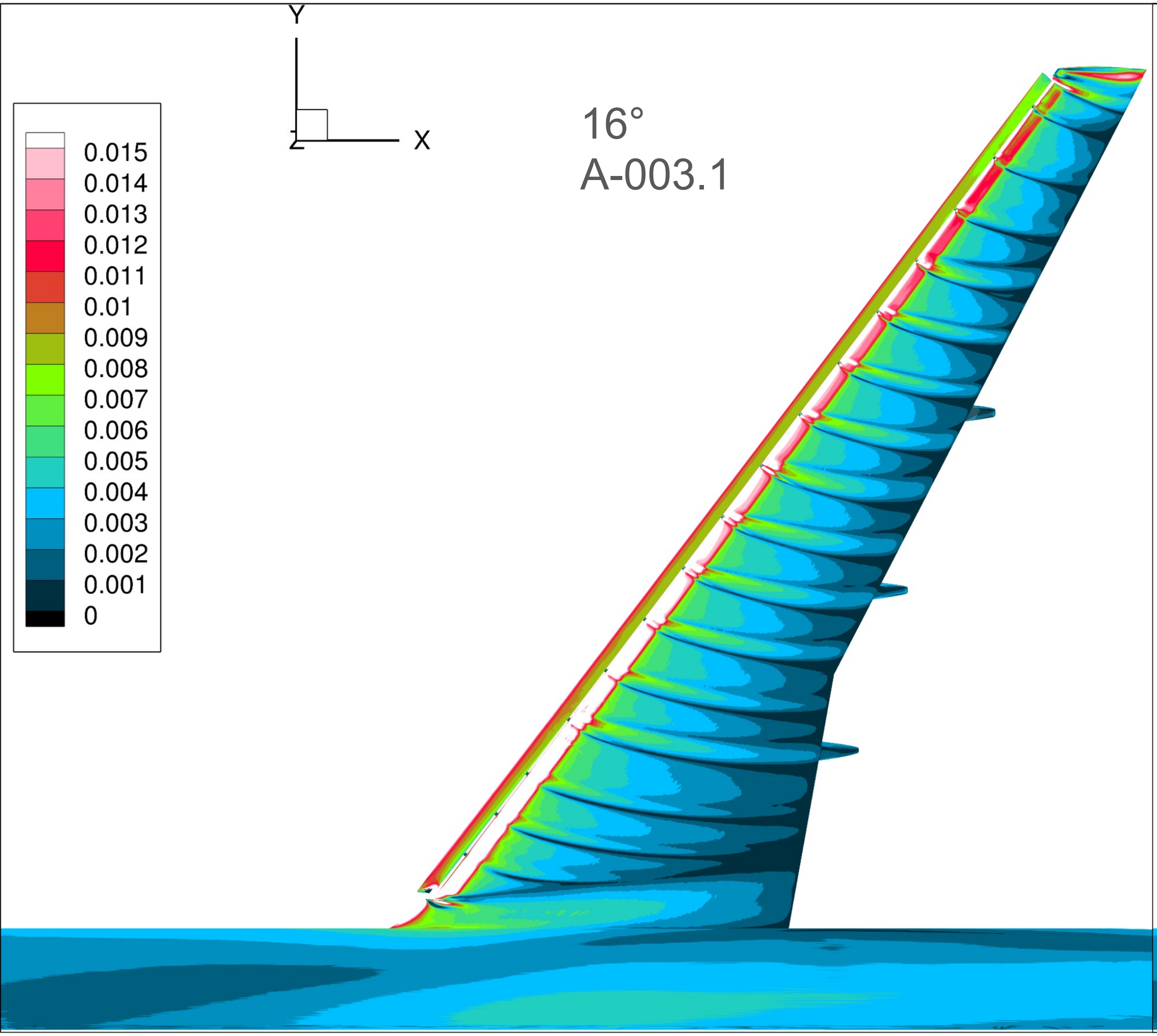


Pitching Moment



Test Case 2.2





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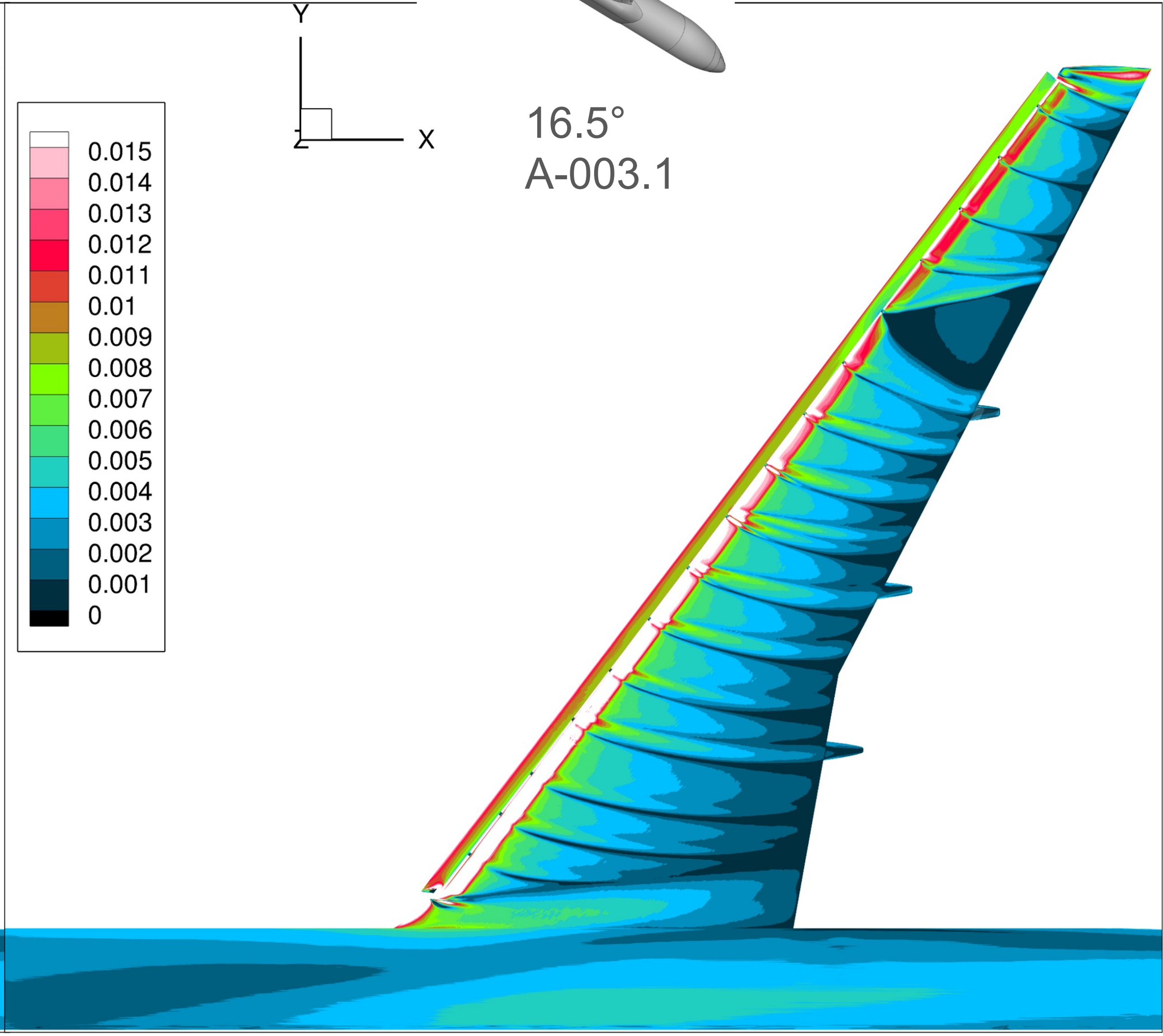
Z
16°
A-003.1



0.015
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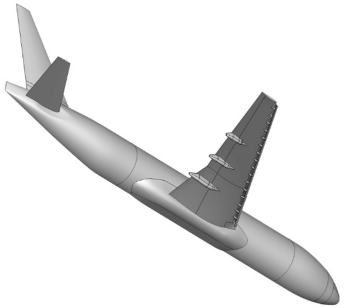
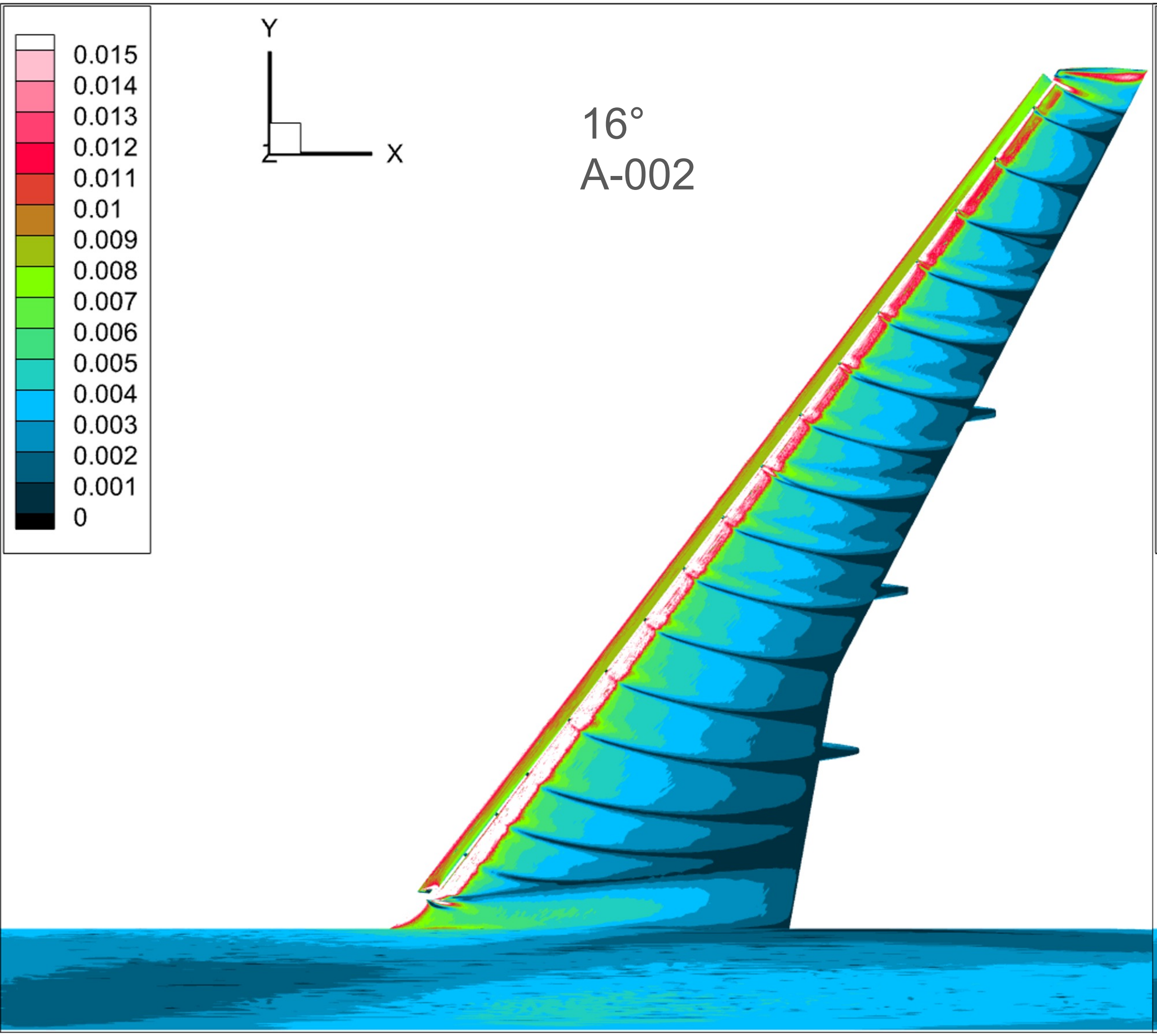
Y
X
Z
16.5°
A-003.1

Test Case 2.2





0.015
0.014
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0.011
0.01
0.009
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0.004
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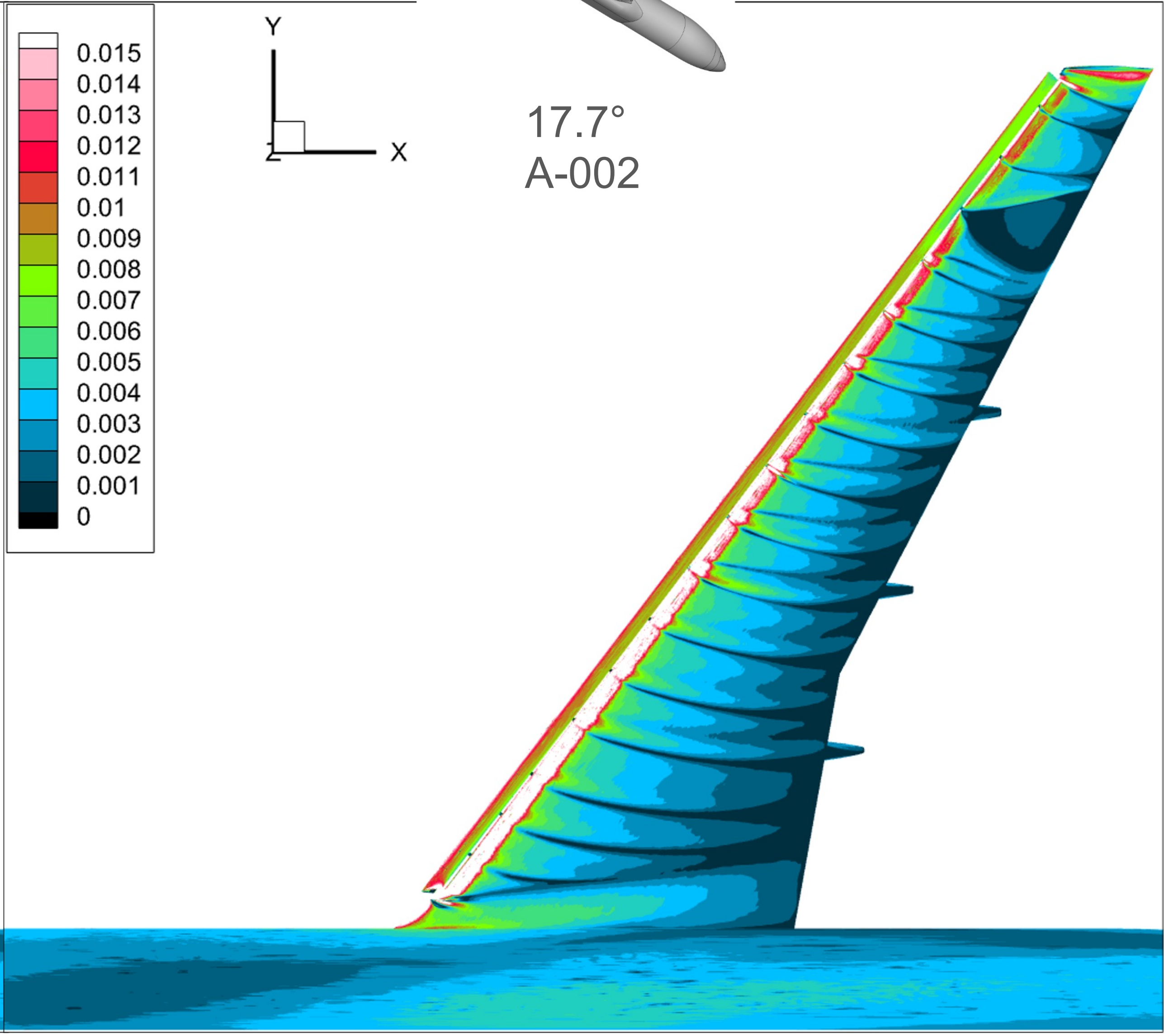
Y
X
16°
A-002



0.015
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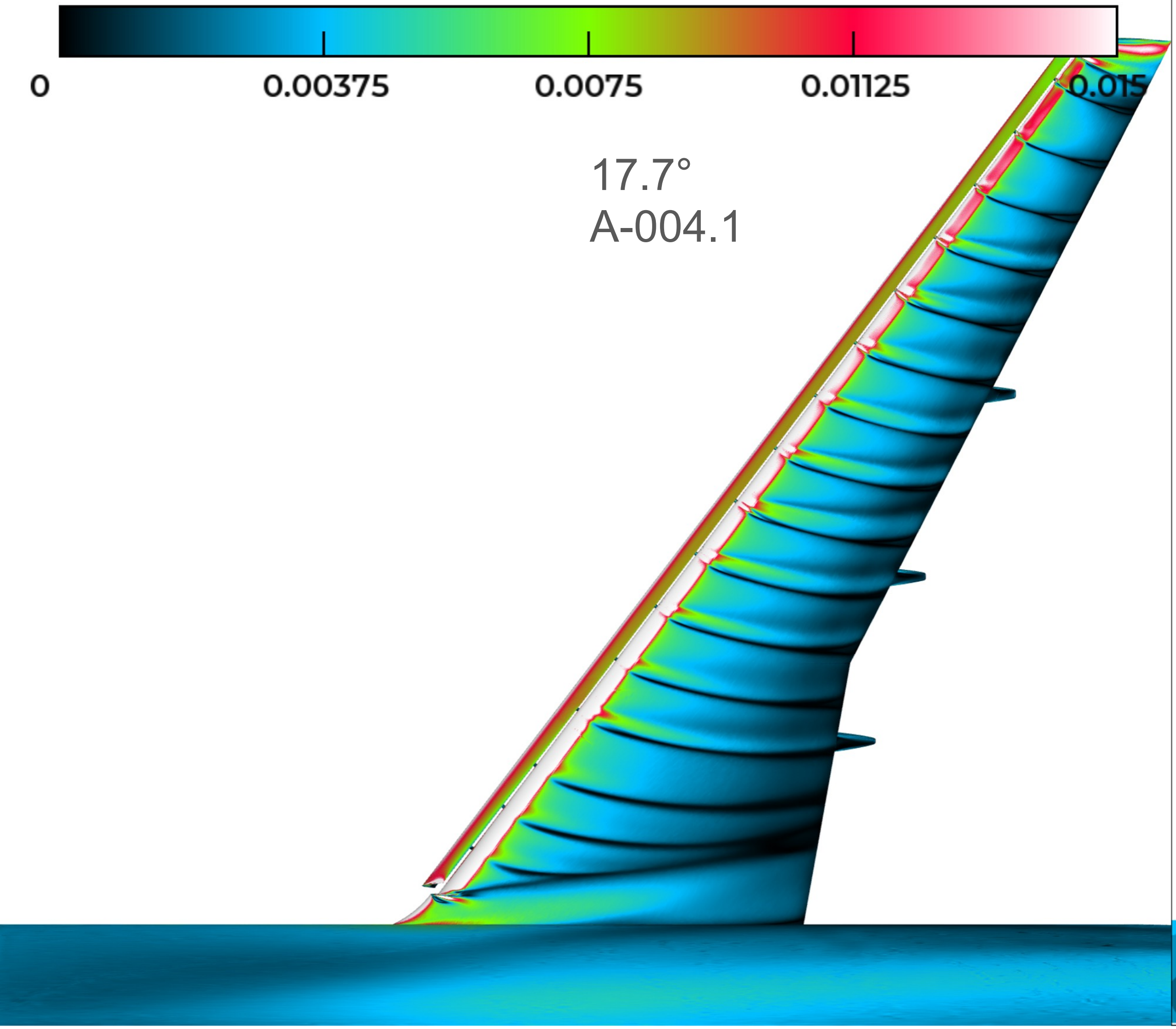
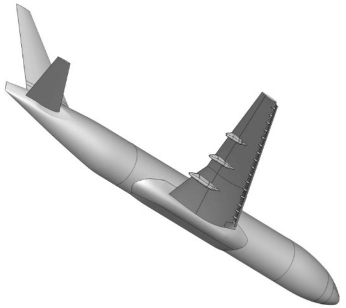
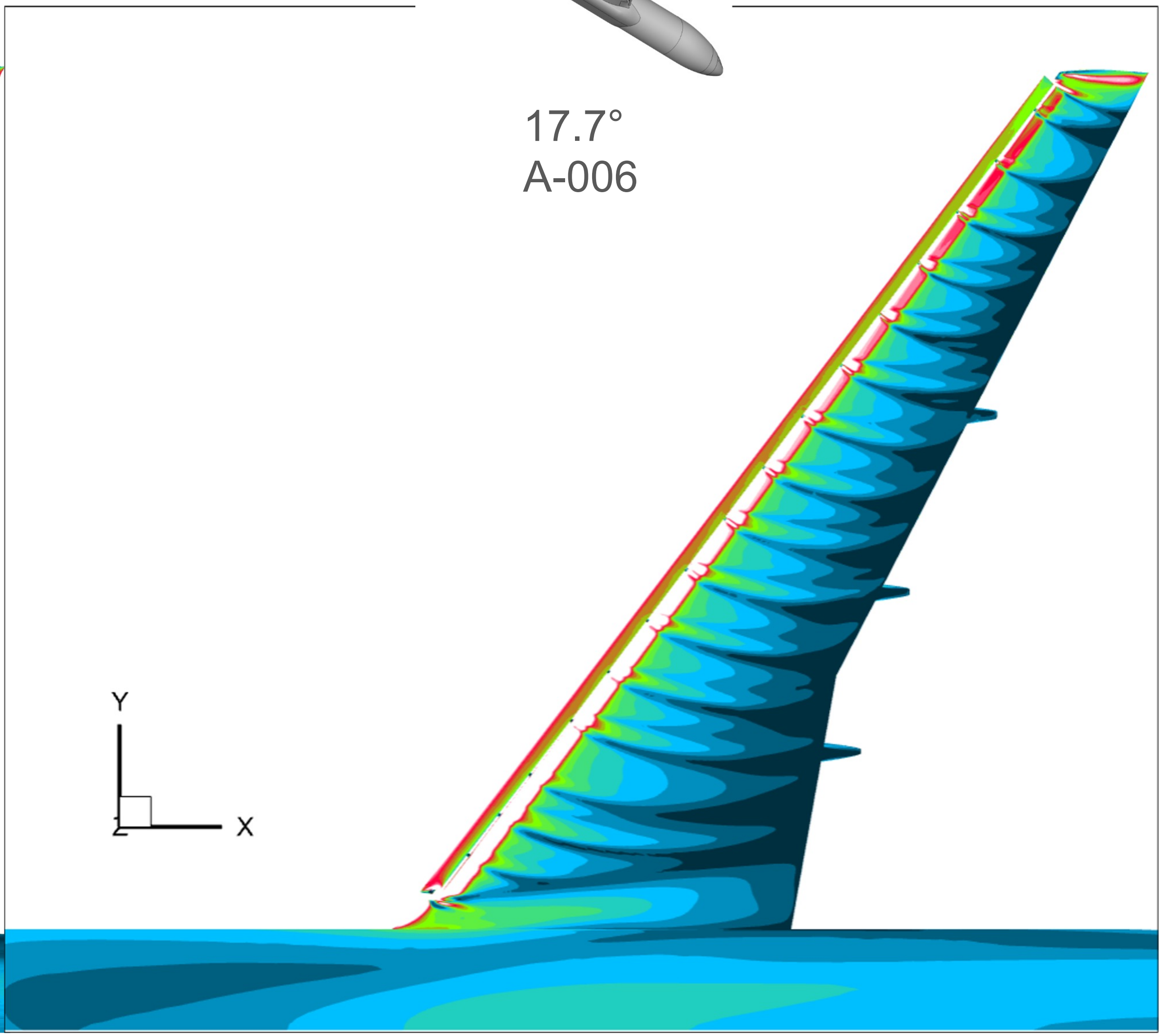
0.006
0.005
0.004
0.003
0.002
0.001
0
Y
X
17.7°
A-002

Test Case 2.2

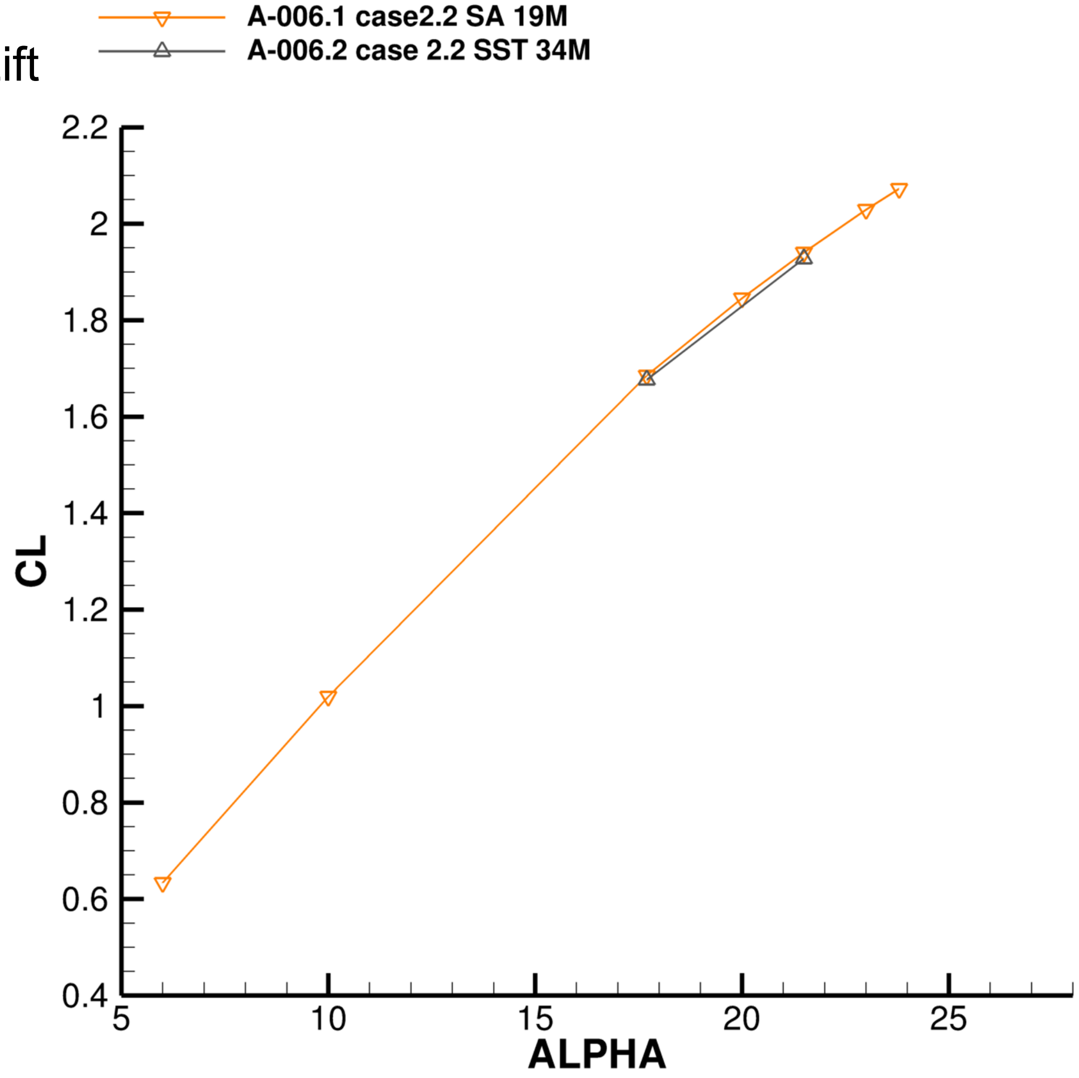




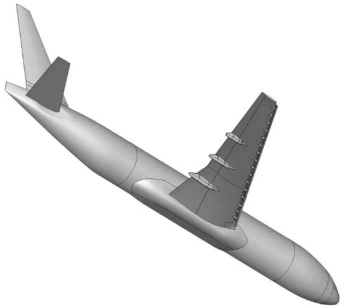


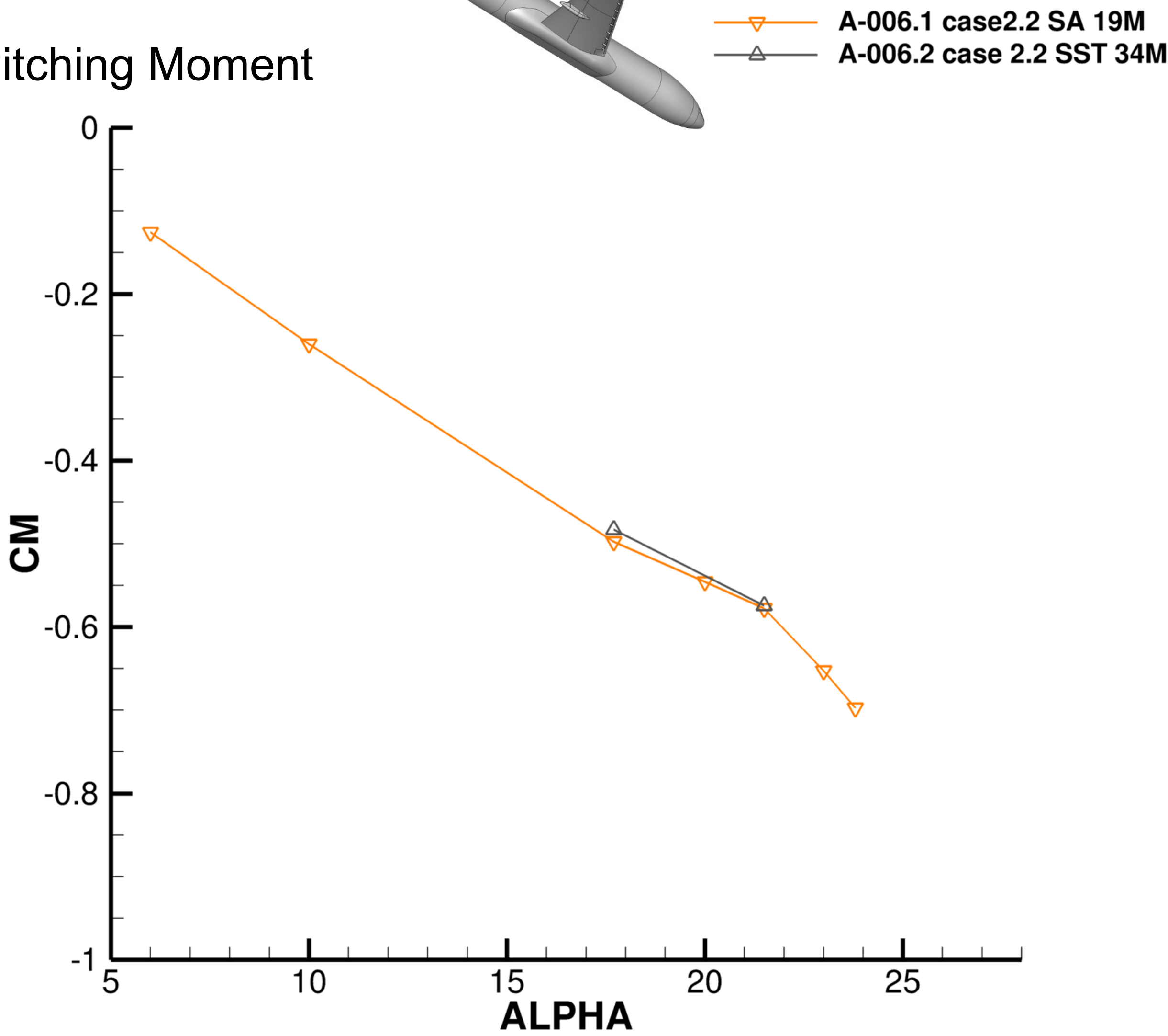
Test Case 2.2 SA and SST

Lift

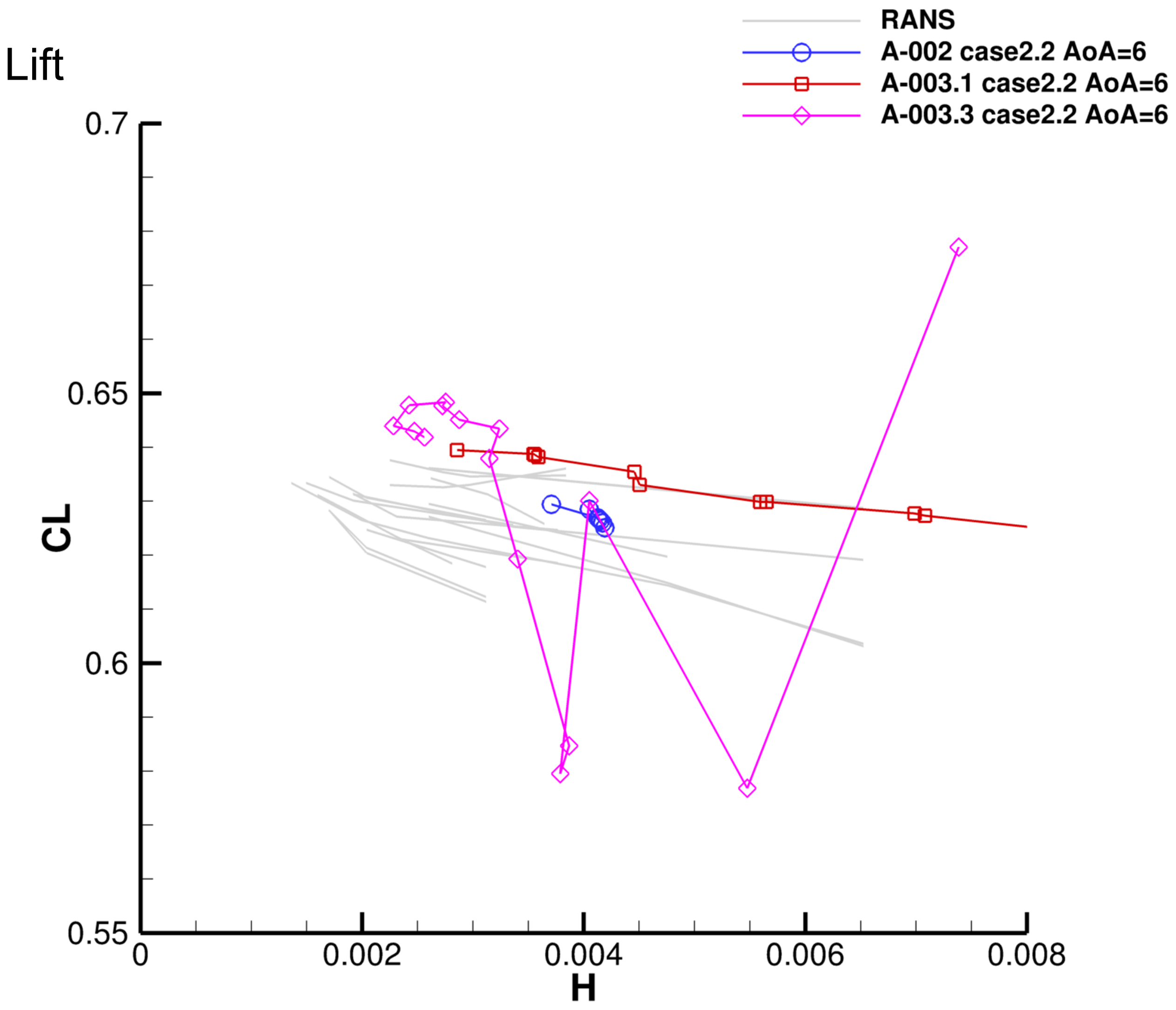


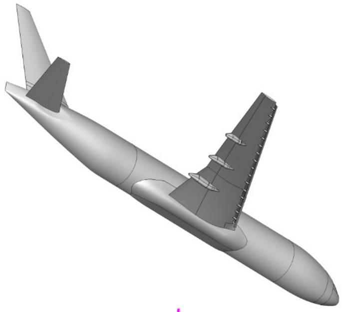
Pitching Moment

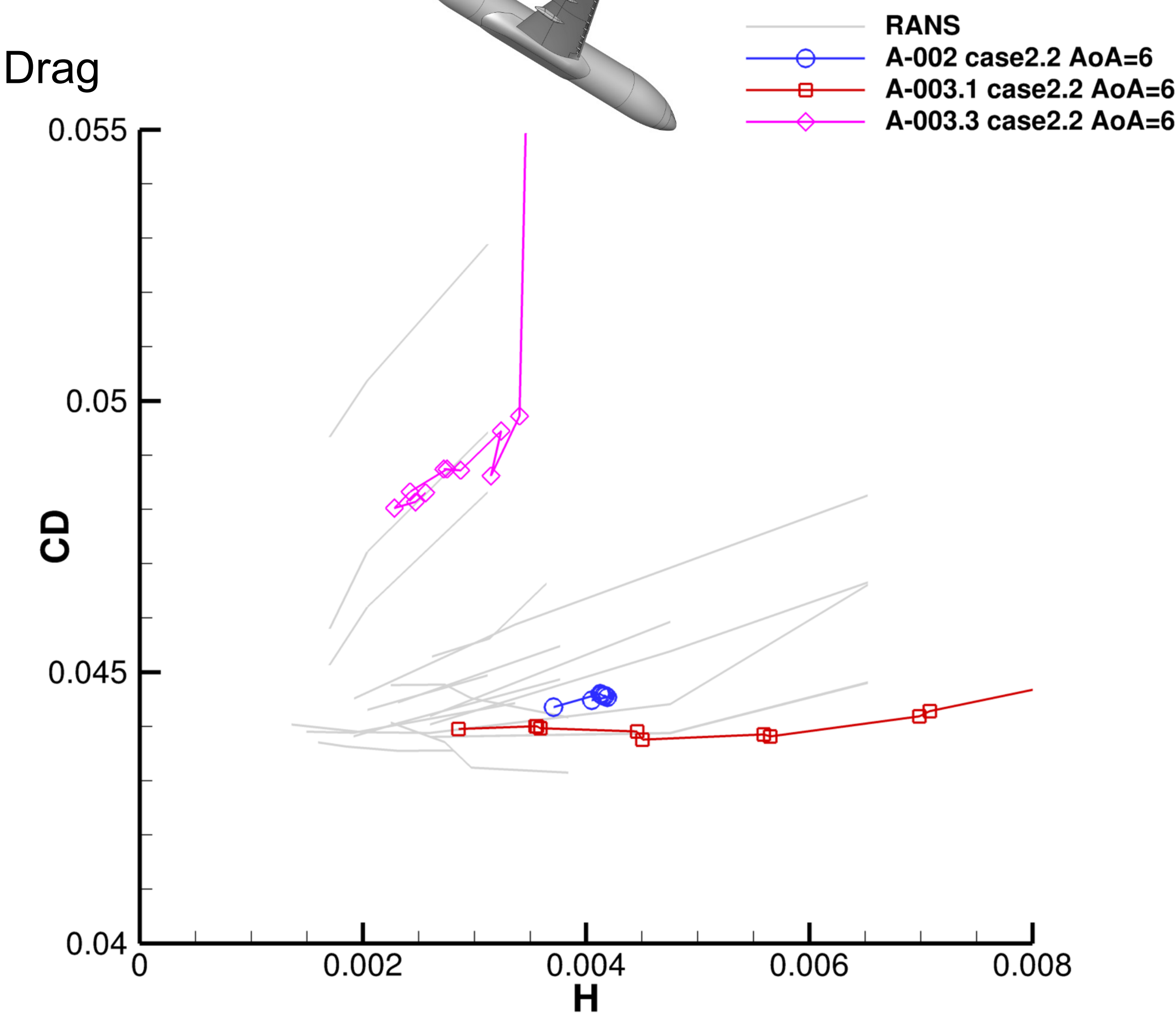




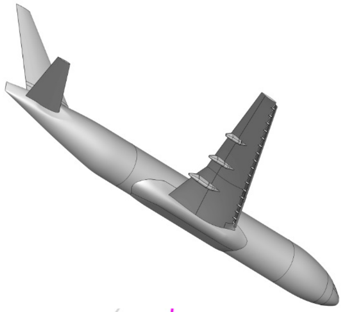
Test Case 2.2, 6° Angle of Attack



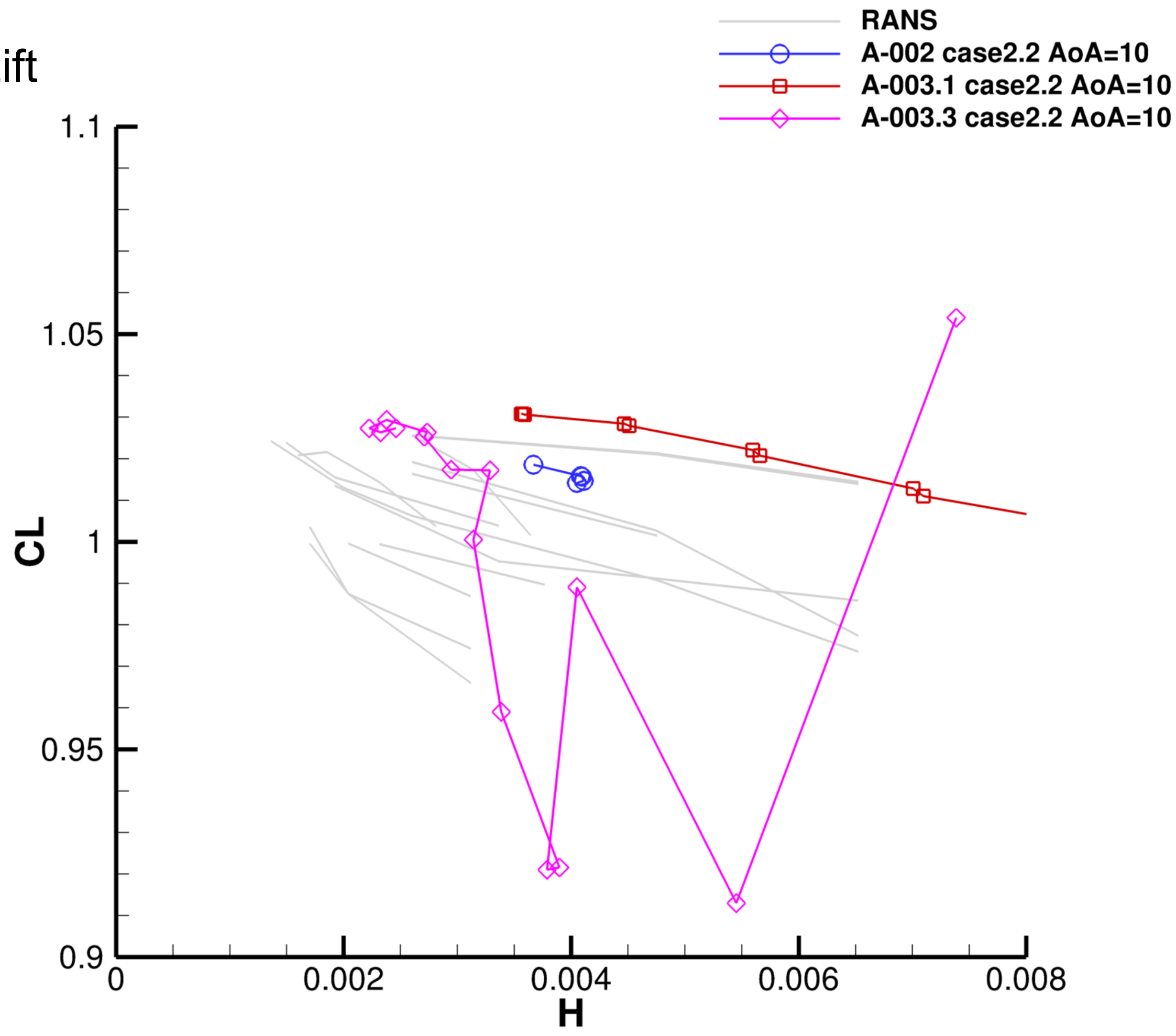




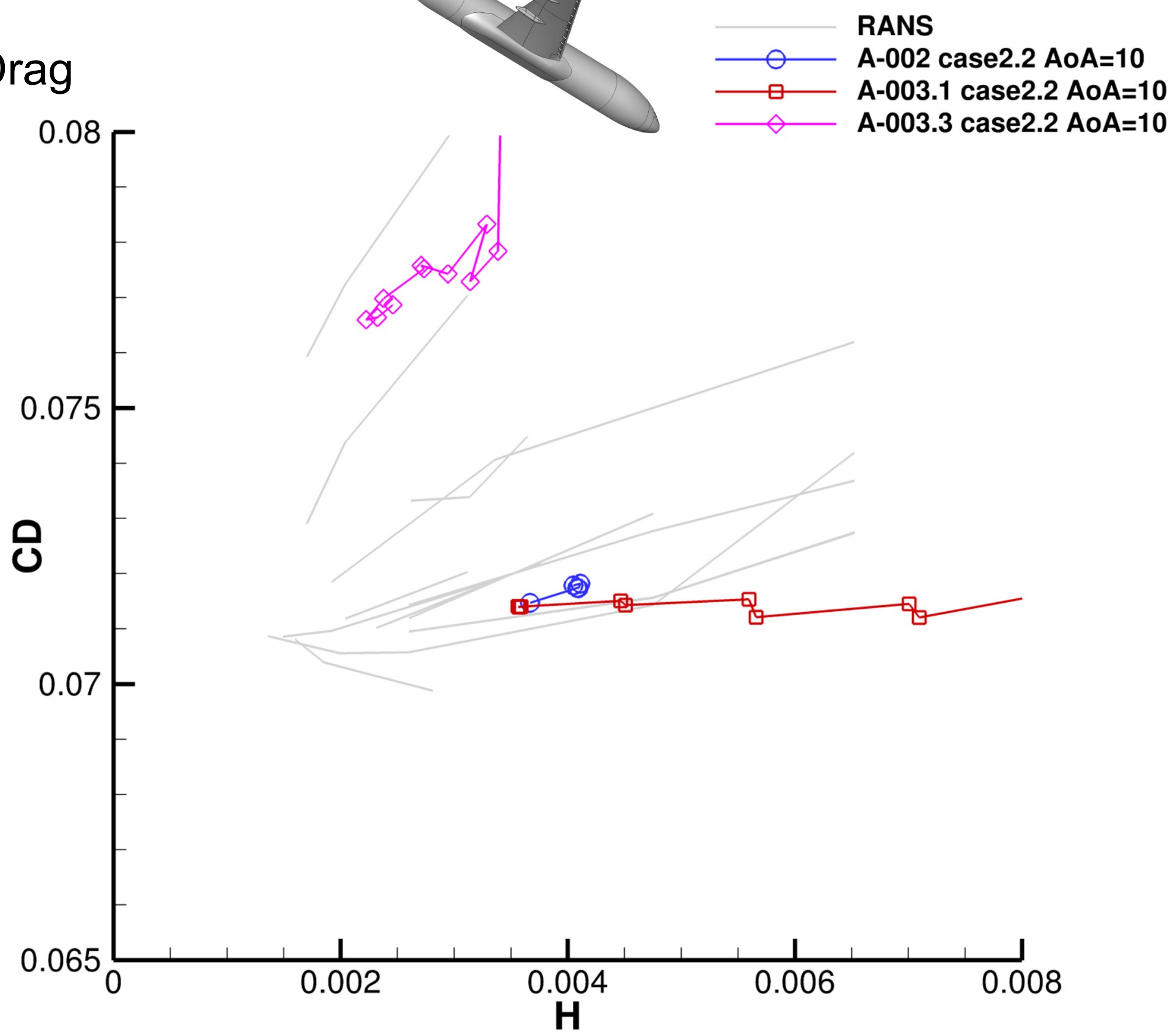
Test Case 2.2, 10° Angle of Attack



Lift

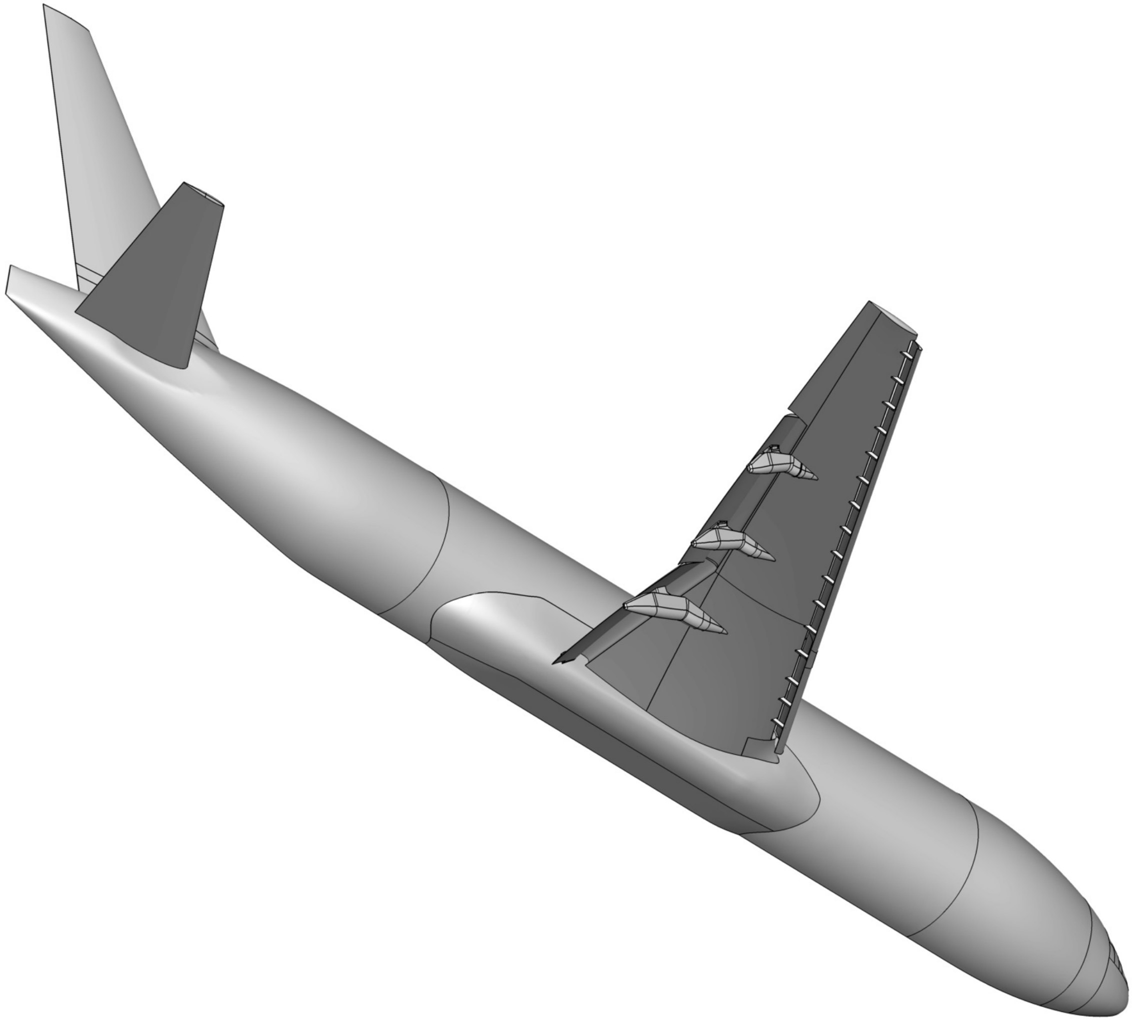


Drag

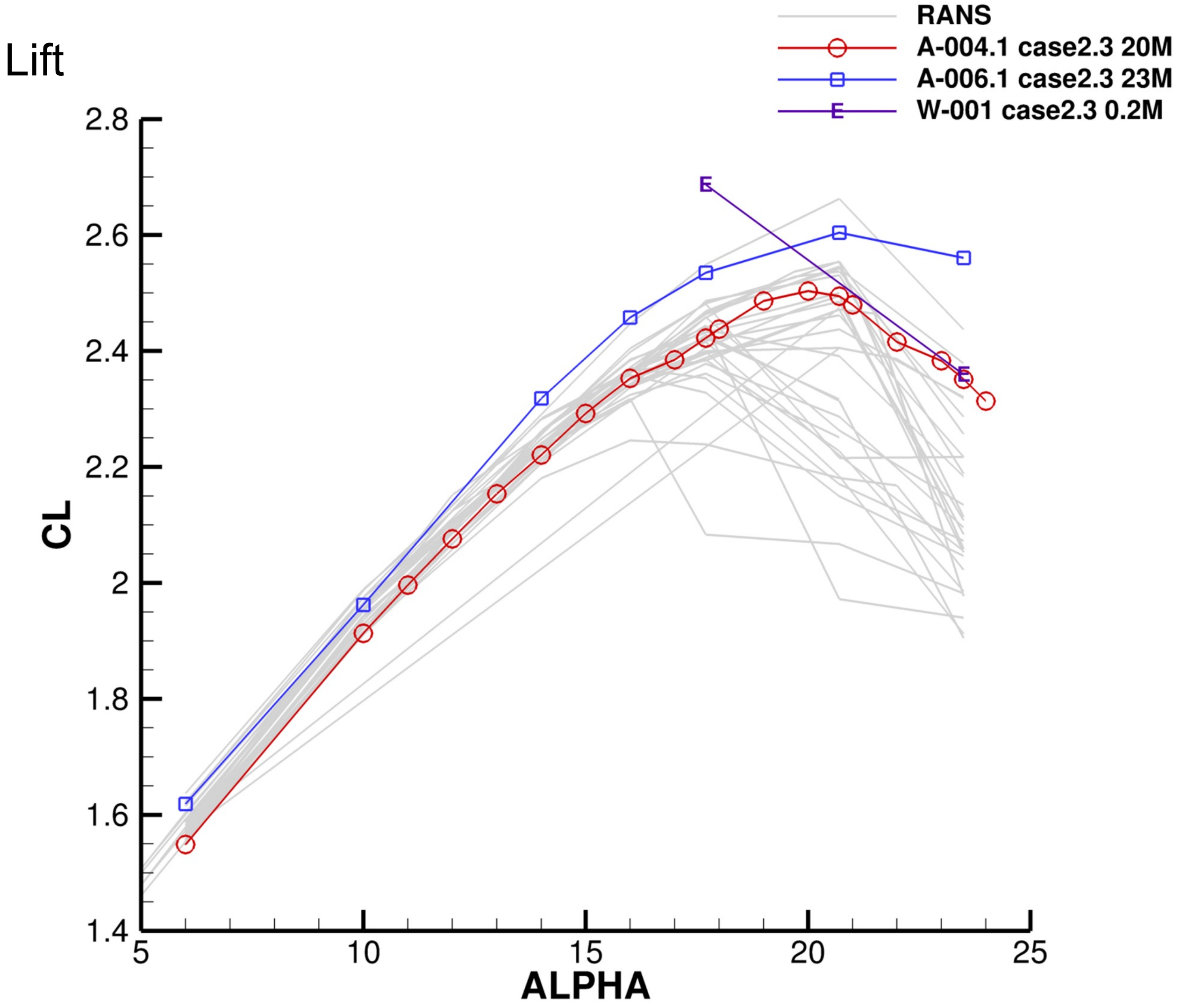


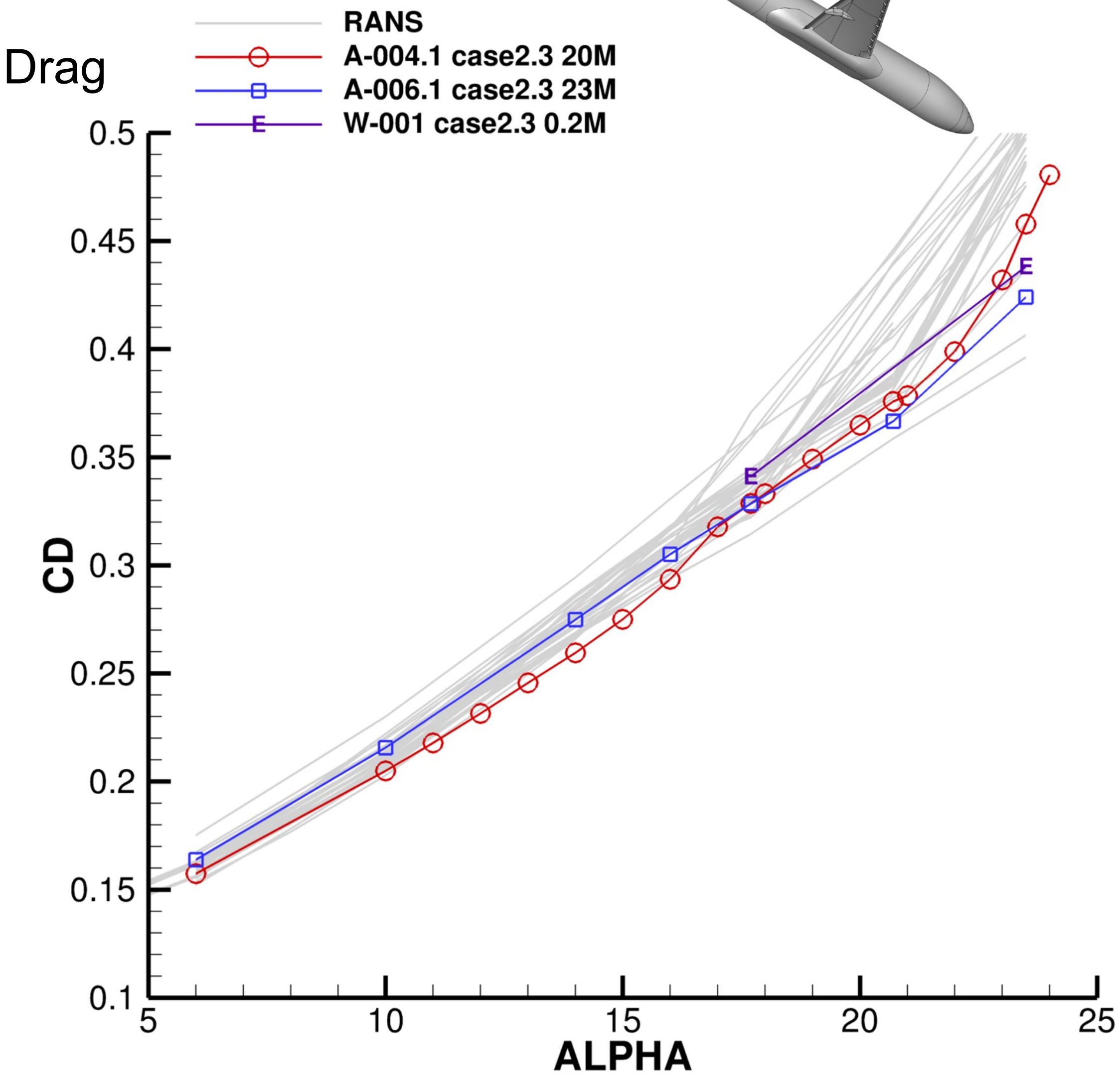
Test Case 2.3

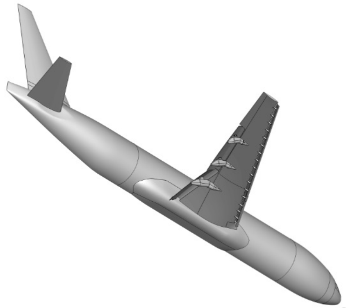
- 2.3: ONERA_LRM-WBSFHV adds deployed flaps



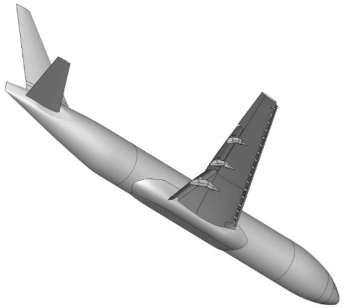
Test Case 2.3


Lift
RANS
A-004.1 case2.3 20M
A-006.1 case2.3 23M
W-001 case2.3 0.2M
CL
ALPHA
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
5
10
15
20
25

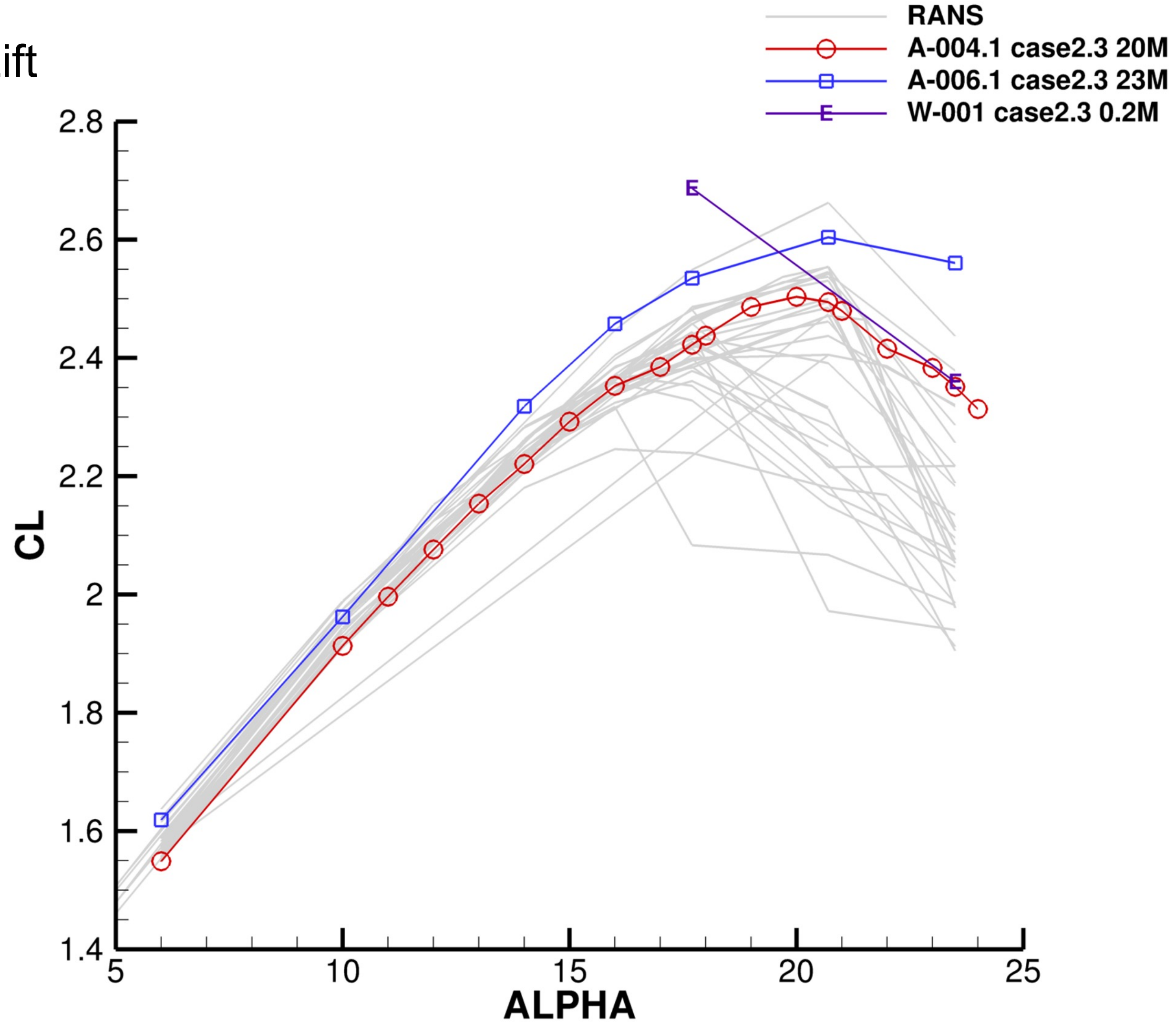

Drag
RANS
A-004.1 case2.3 20M
A-006.1 case2.3 23M
W-001 case2.3 0.2M
CD
ALPHA
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
5
10
15
20
25



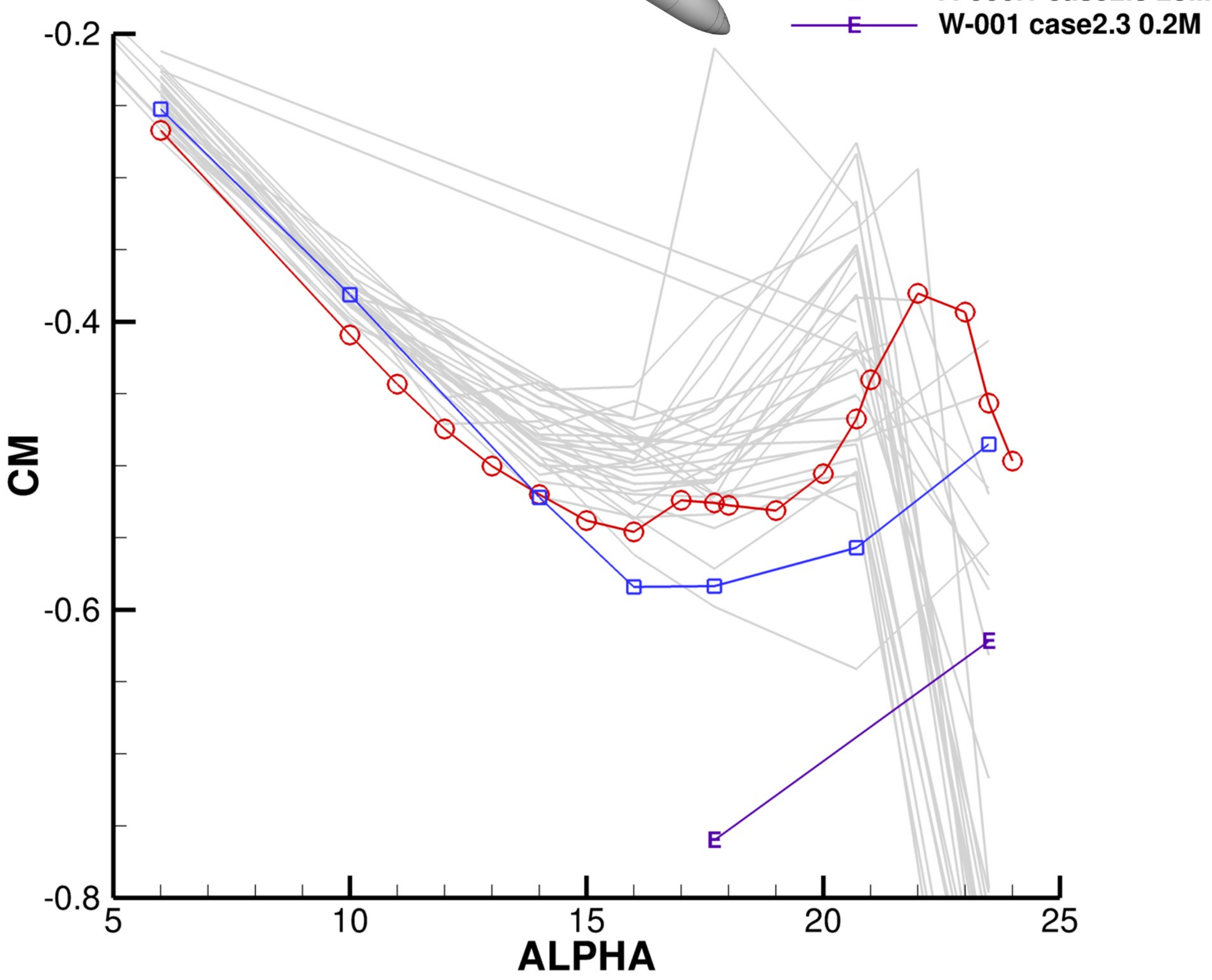
Test Case 2.3



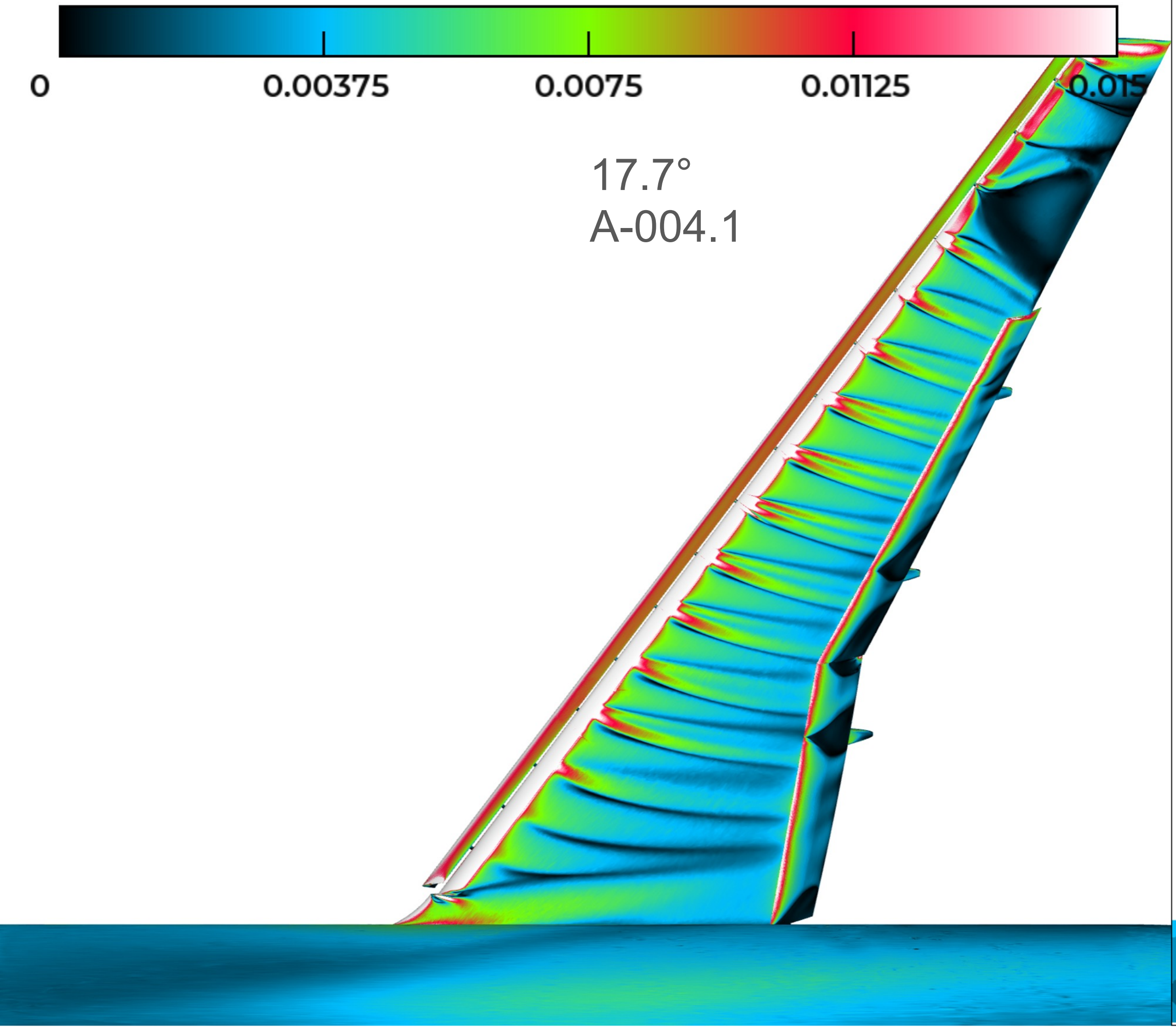
Lift

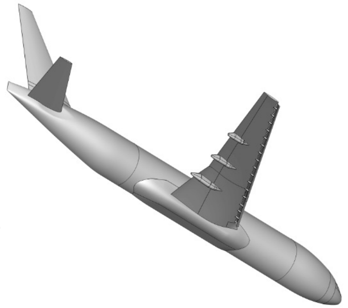


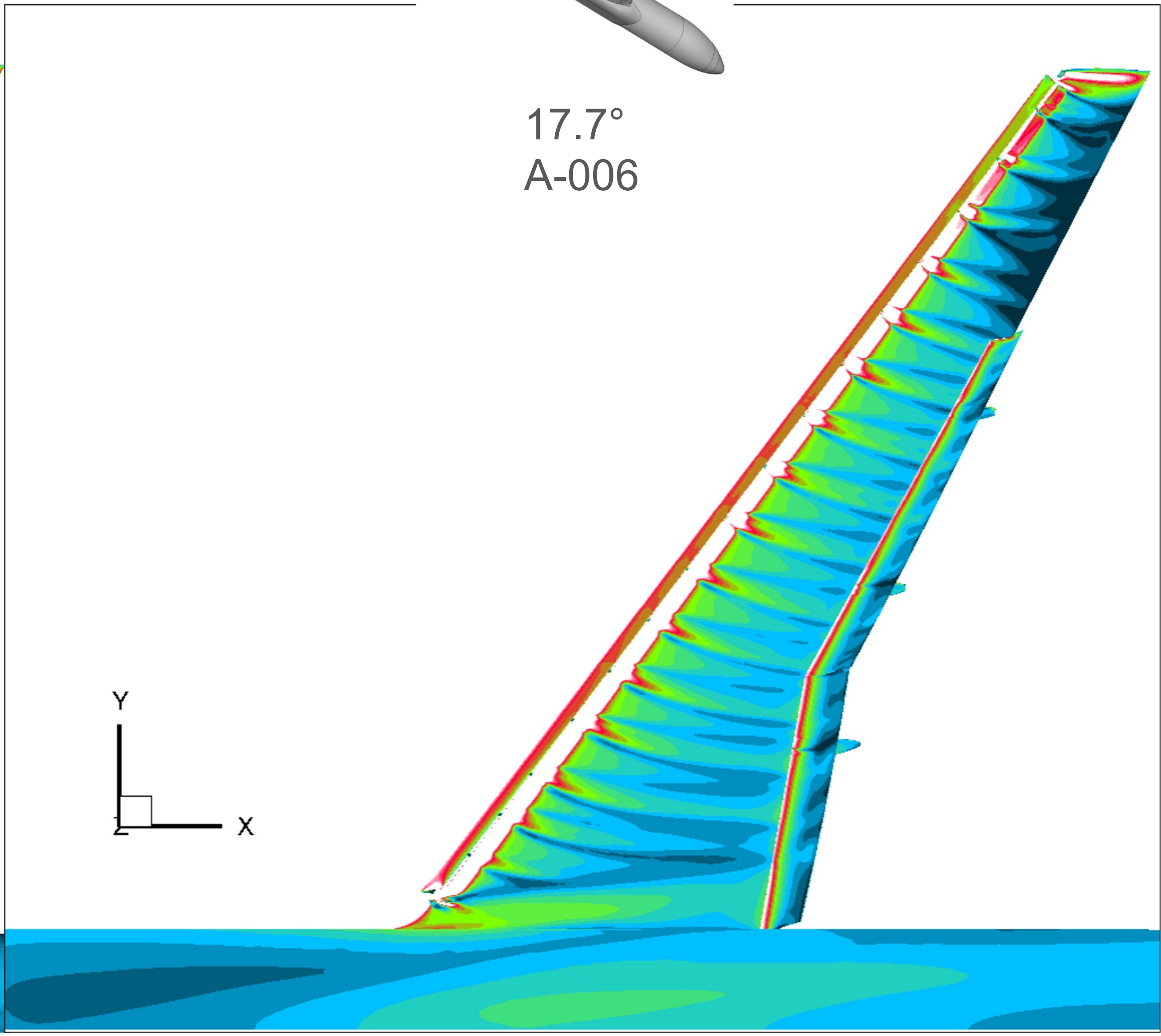
Pitching Moment



Test Case 2.3

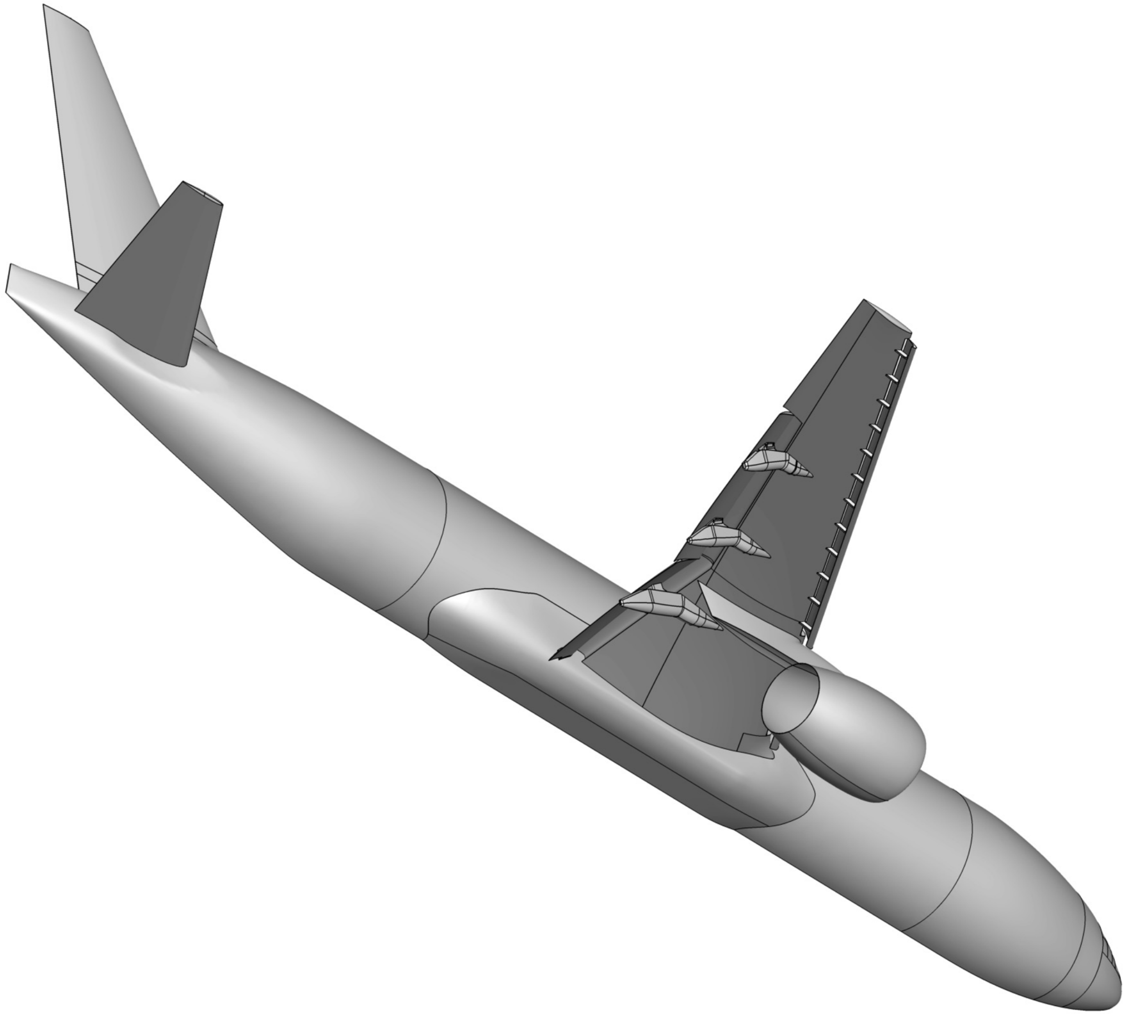






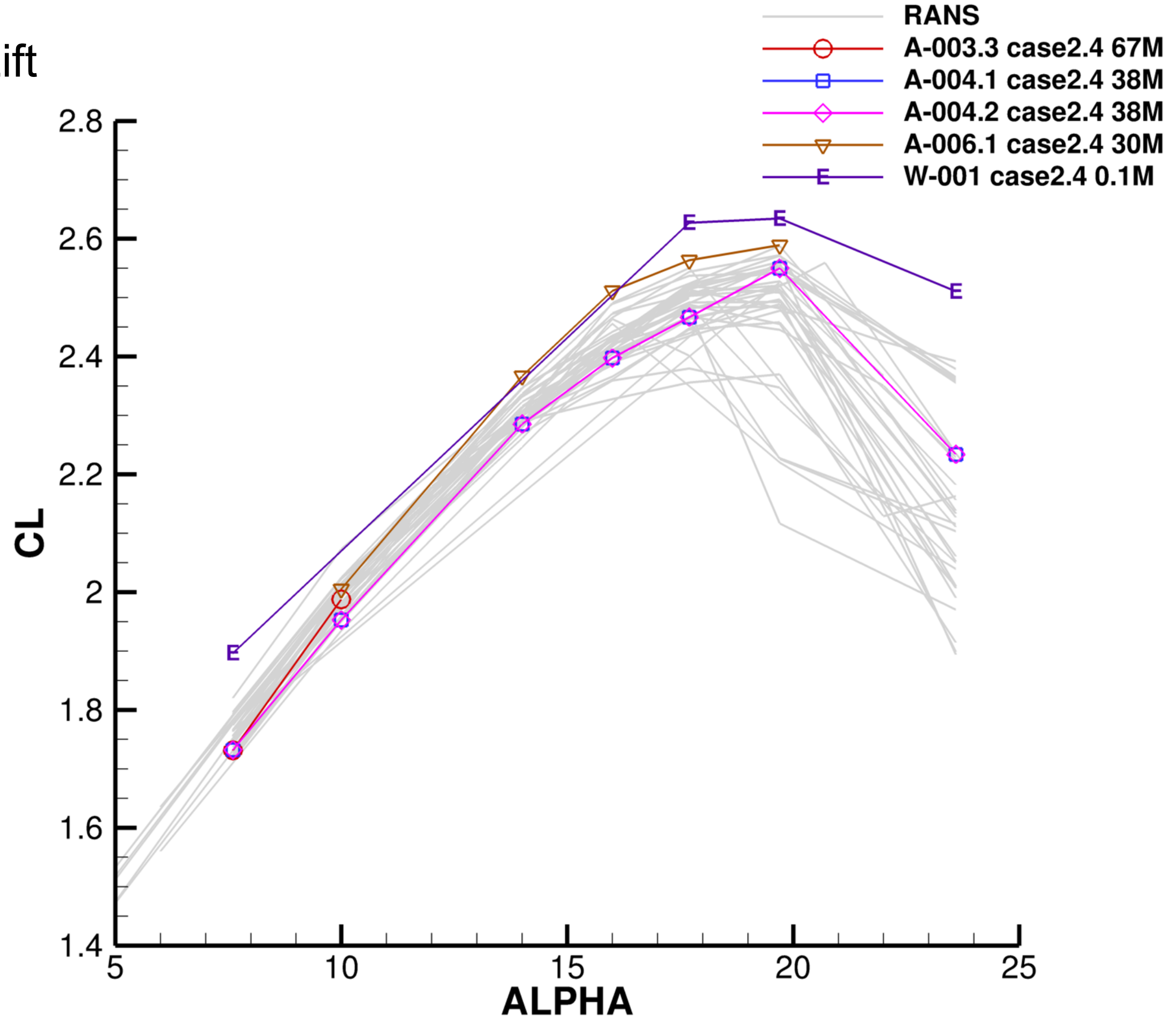
Test Case 2.4

- ONERA_LRM-LDG-HV add nacelle, pylon, and slat break

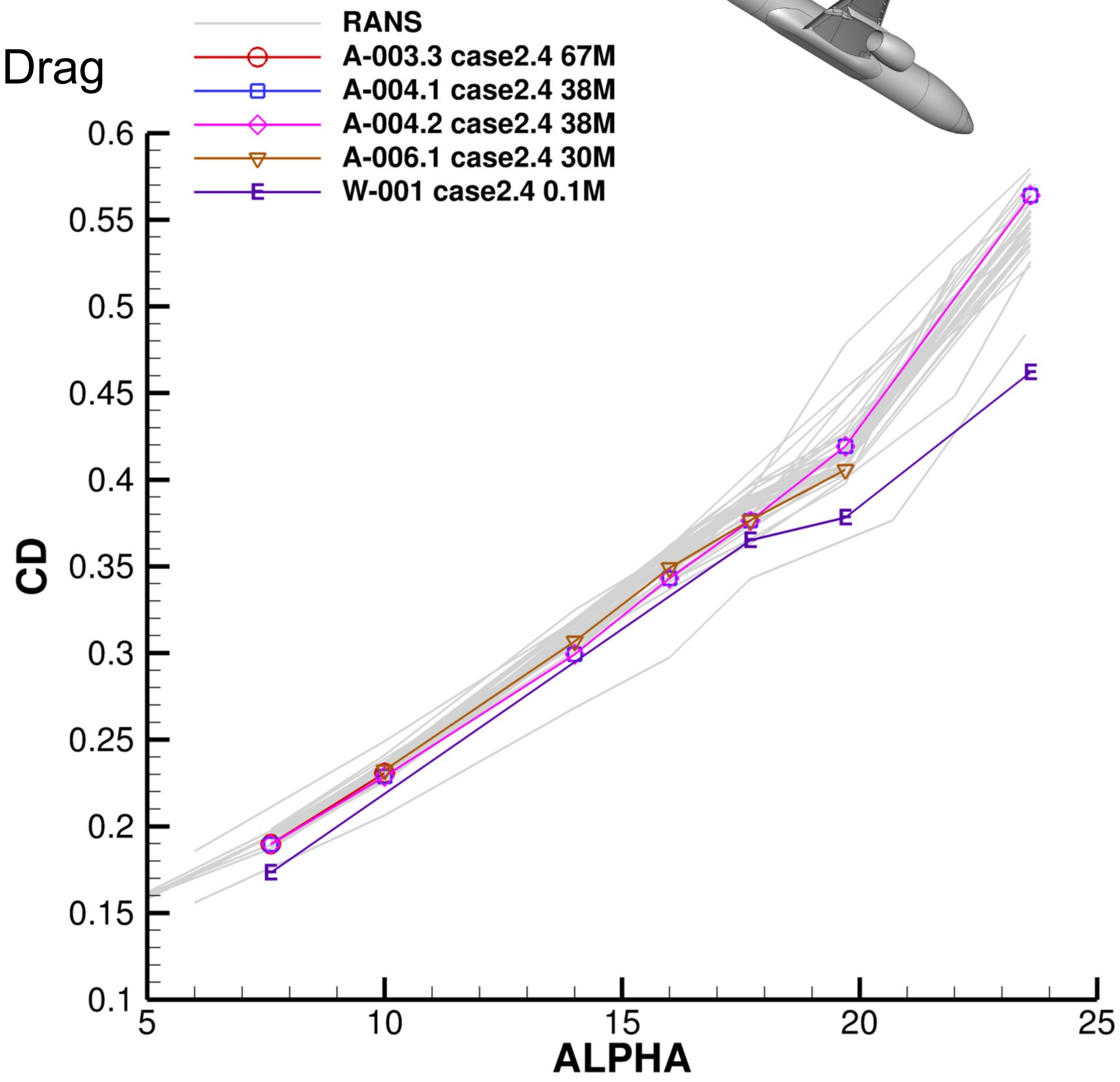


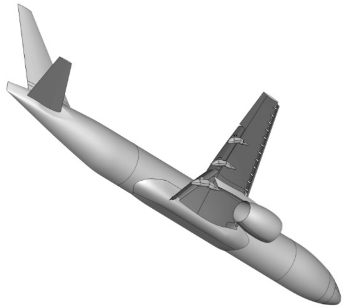
Test Case 2.4

Lift

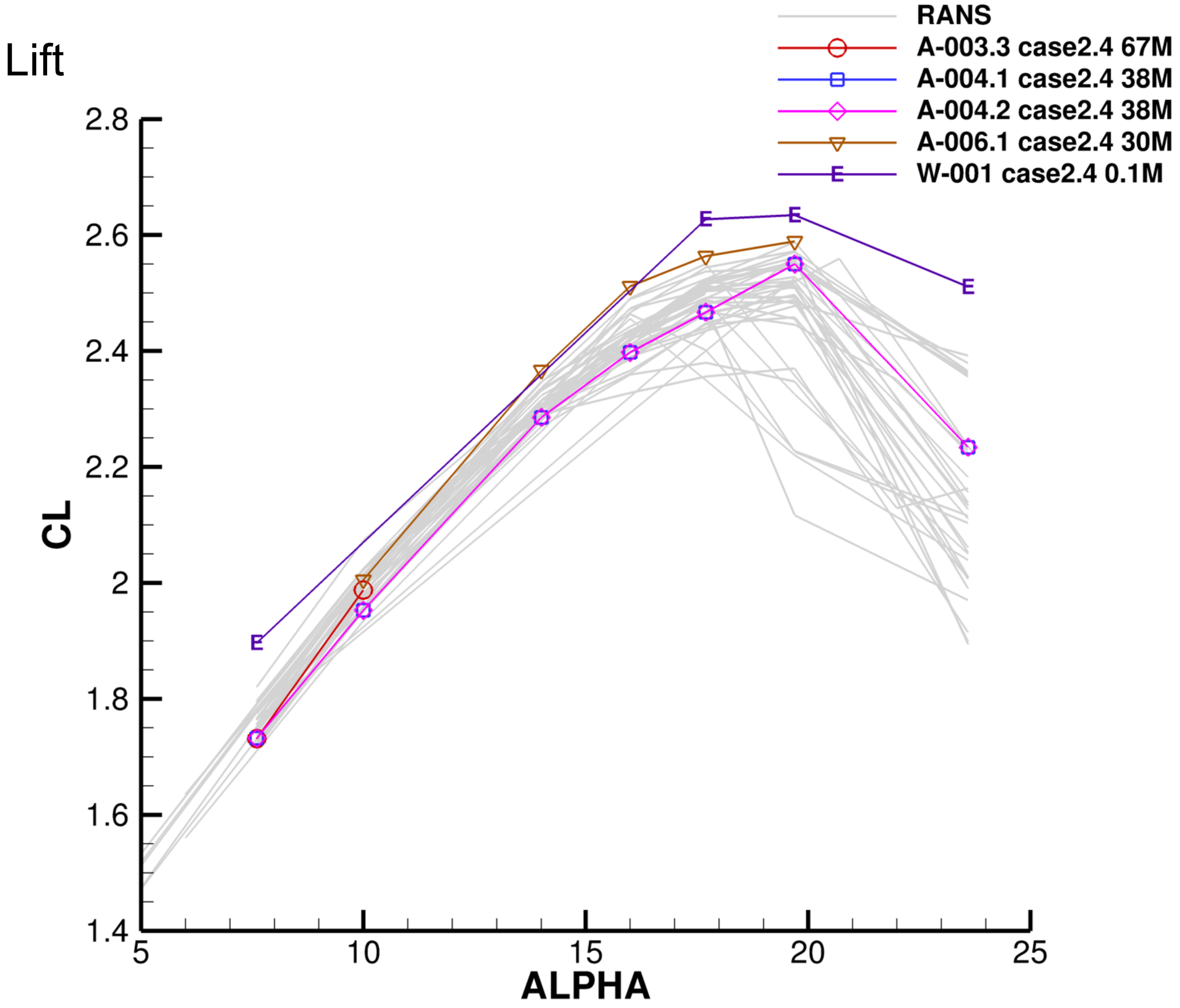


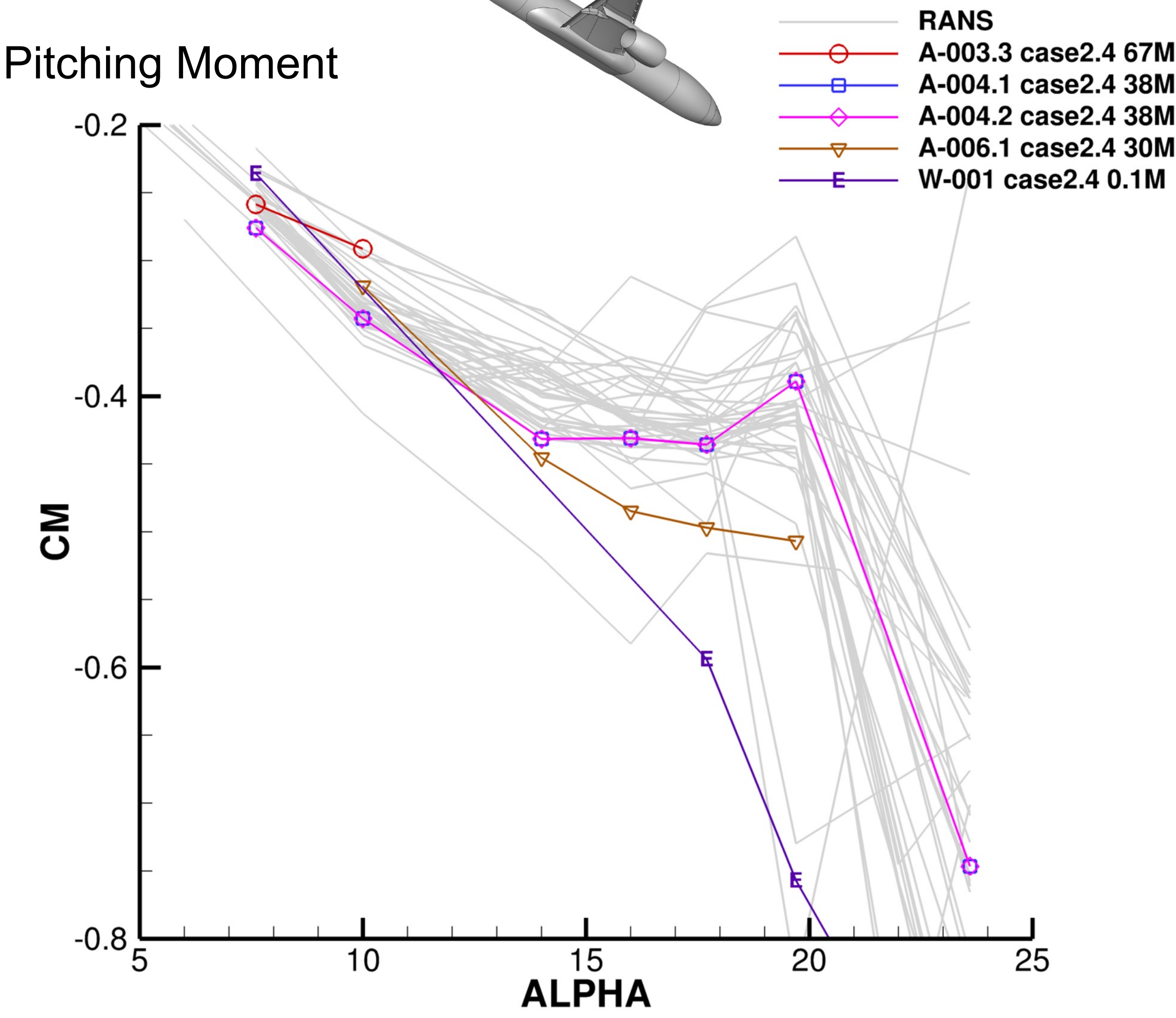
Drag

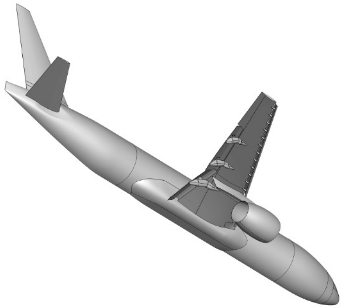




Test Case 2.4


Lift
RANS
A-003.3 case2.4 67M
A-004.1 case2.4 38M
A-004.2 case2.4 38M
A-006.1 case2.4 30M
W-001 case2.4 0.1M
CL
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
5
10
15
20
25
ALPHA


Pitching Moment
RANS
A-003.3 case2.4 67M
A-004.1 case2.4 38M
A-004.2 case2.4 38M
A-006.1 case2.4 30M
W-001 case2.4 0.1M
CM
-0.2
-0.4
-0.6
-0.8
5
10
15
20
25
ALPHA



Case 2 Summary

Can adaptive mesh refinement identify consistent trends due to increasing geometric complexity across the angle of attack range?

- The adapted results are consistent with the bulk of the RANS TFG submissions and the RANS Select submissions
- Case 2.2 had the most submissions and consistency between those submission
  - Two participants showed a rapid increase in outer wing slat bracket “pizza slice” wake separation above 16° angle of attack for test case 2.2, but others stayed on the high lift branch of solutions
- The difference between adapted SA and SST turbulence models is less than the difference between independent grid series
- The addition of the flaps (increasing lift) created a larger increase in variation than the addition of the slat but the number of submissions decreased making trends difficult to extract

Case 3 Summary

Can adaptive mesh refinement resolve Reynolds number trends in integrated forces, moment, and separation patterns across the angle of attack range?

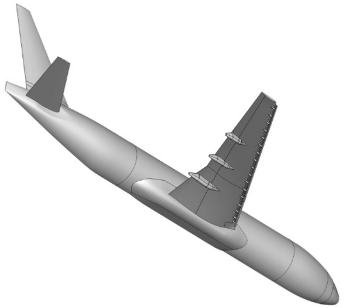
- There are no Adapt TFG submissions for Test Case 3.1-3.4 to study Reynolds number trends

Adapt TFG Summary

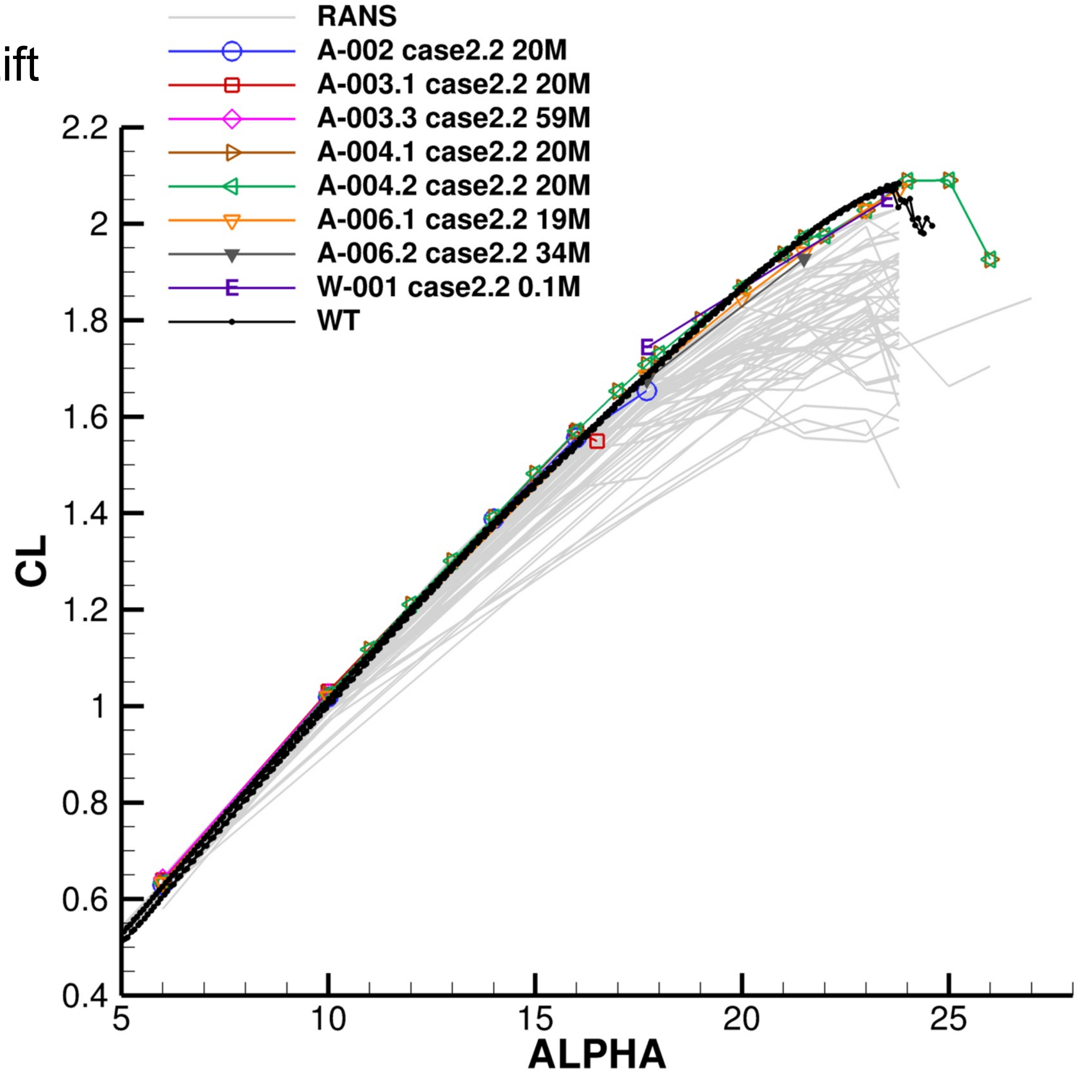
Where can mesh adapted RANS contribute to prediction of high-lift flow physics?

- Improved force and moment consistency at lower angles of attack that show correct trends in turbulence model sensitivity
- Adapted results are consistent with the RANS Select submissions
- Verification is the priority of the Adapt TFG
- Comparison to WT shown for Test Case 2.2-2.4
  - Four wind tunnel (WT) curves shown for mono-strut (upsweep and downsweep) and tri-strut (upsweep and downsweep)

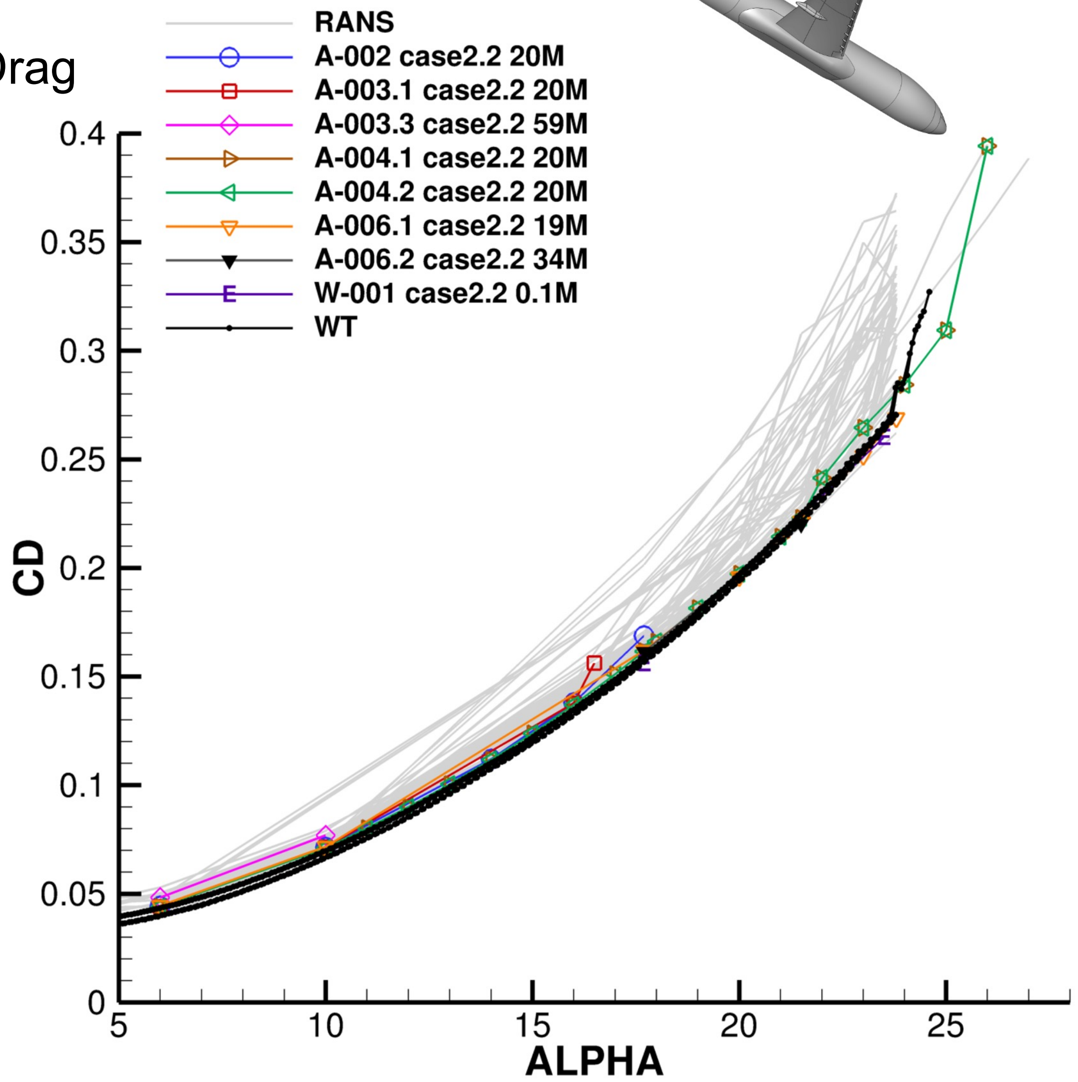
Test Case 2.2 Wind Tunnel Comparison



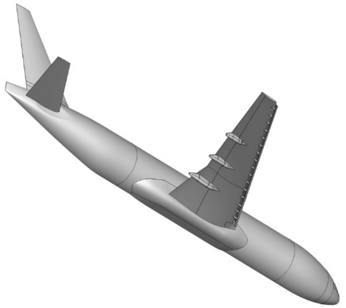
Lift



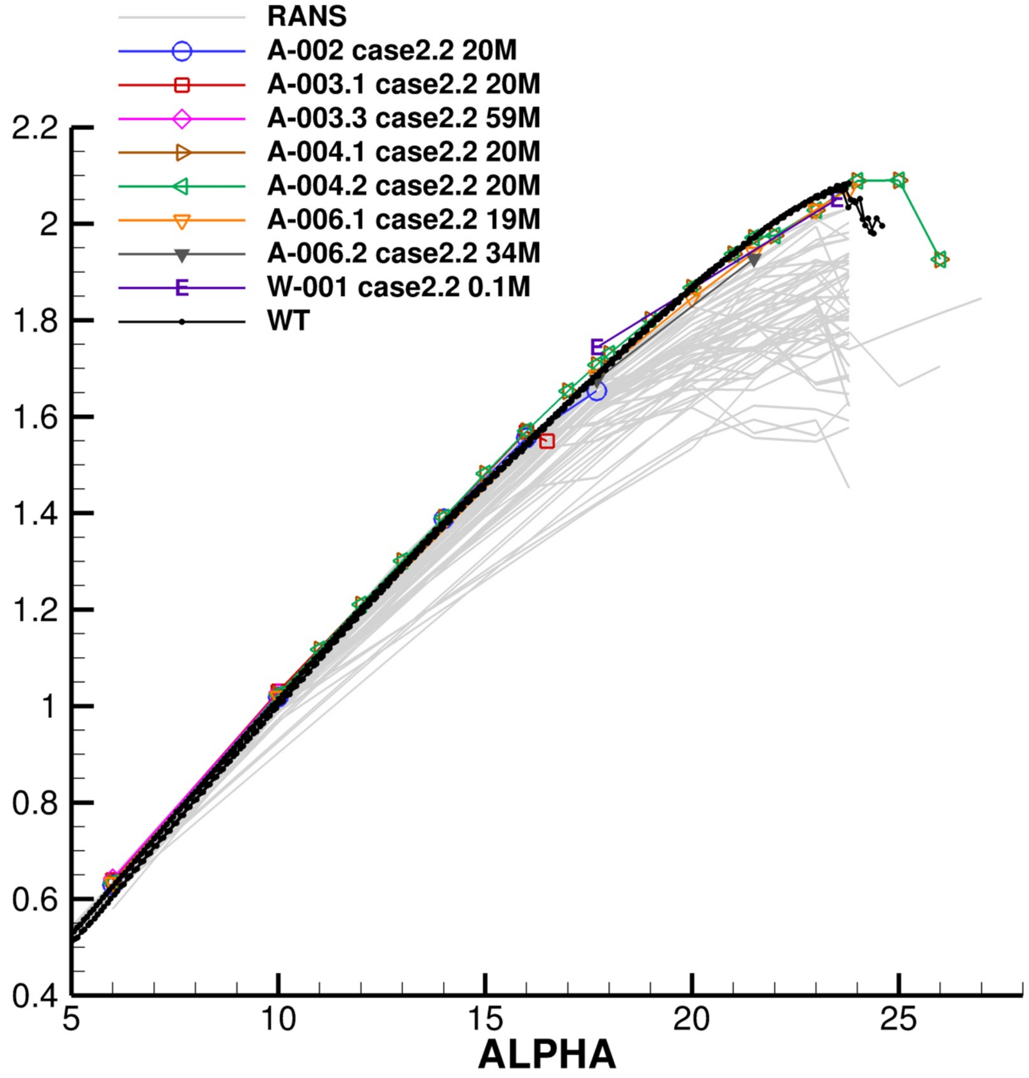
Drag



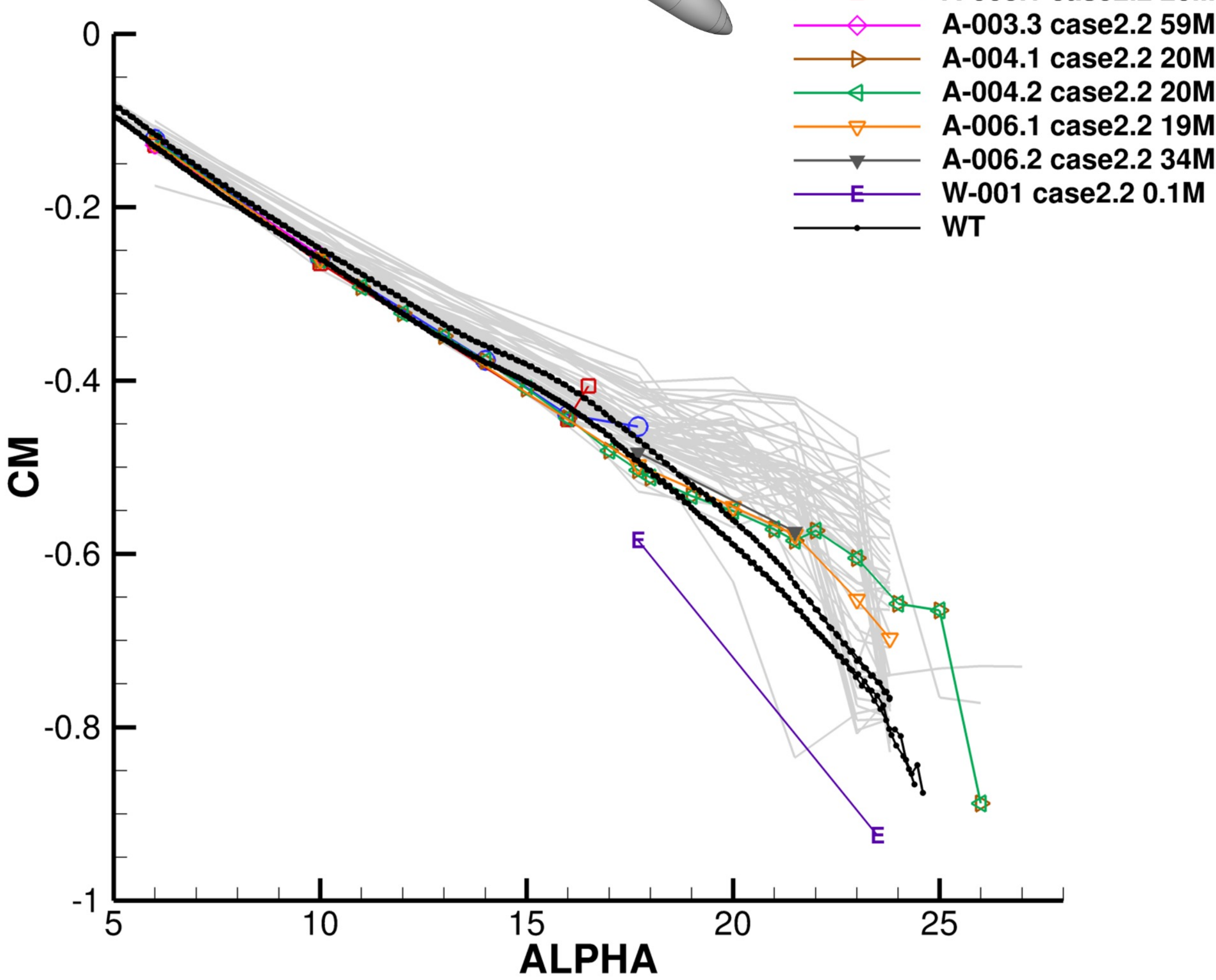
Test Case 2.2 Wind Tunnel Compari



Lift

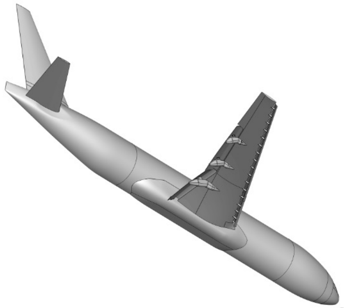


Pitching Moment

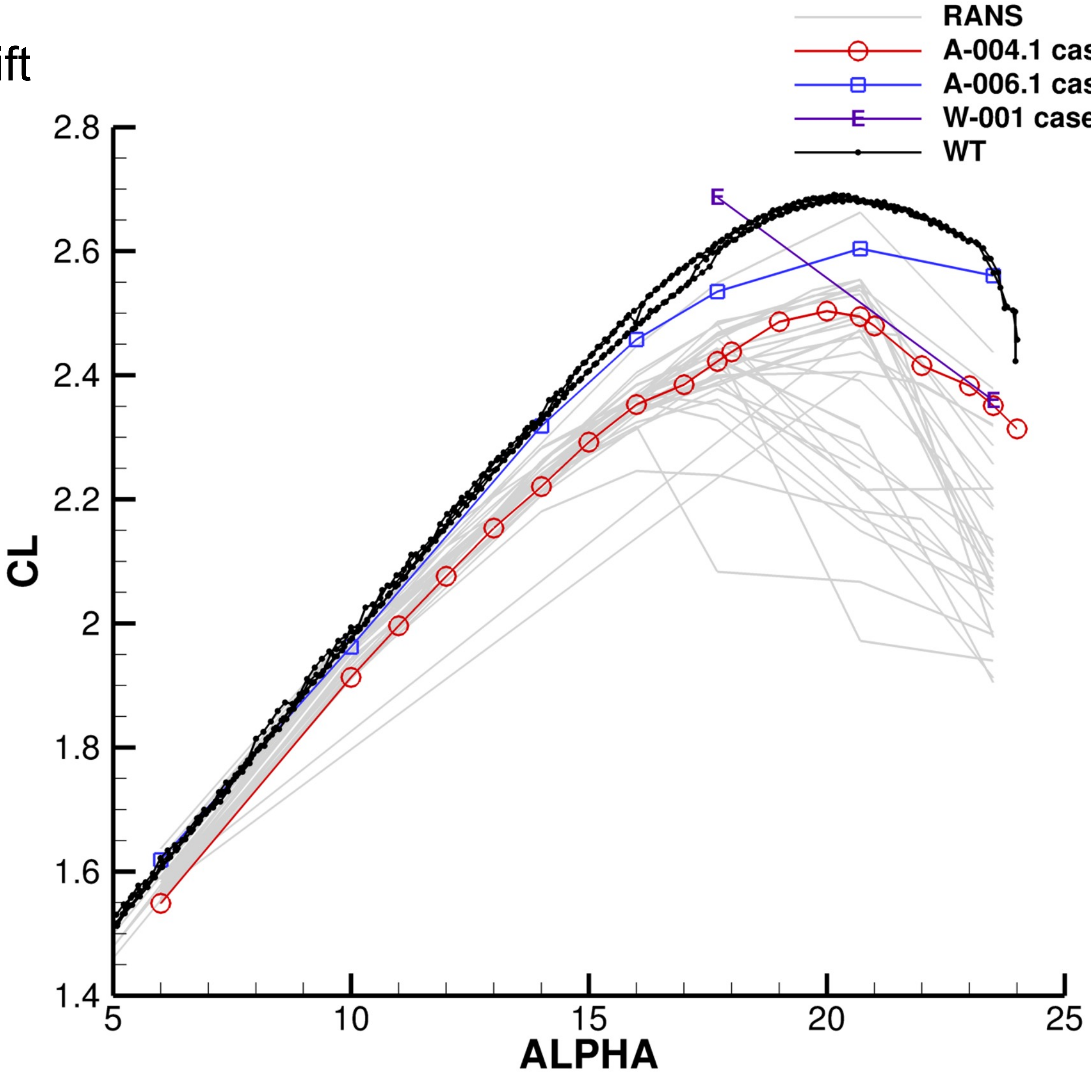


WT data ONERA CC BY-NC-ND 4.0

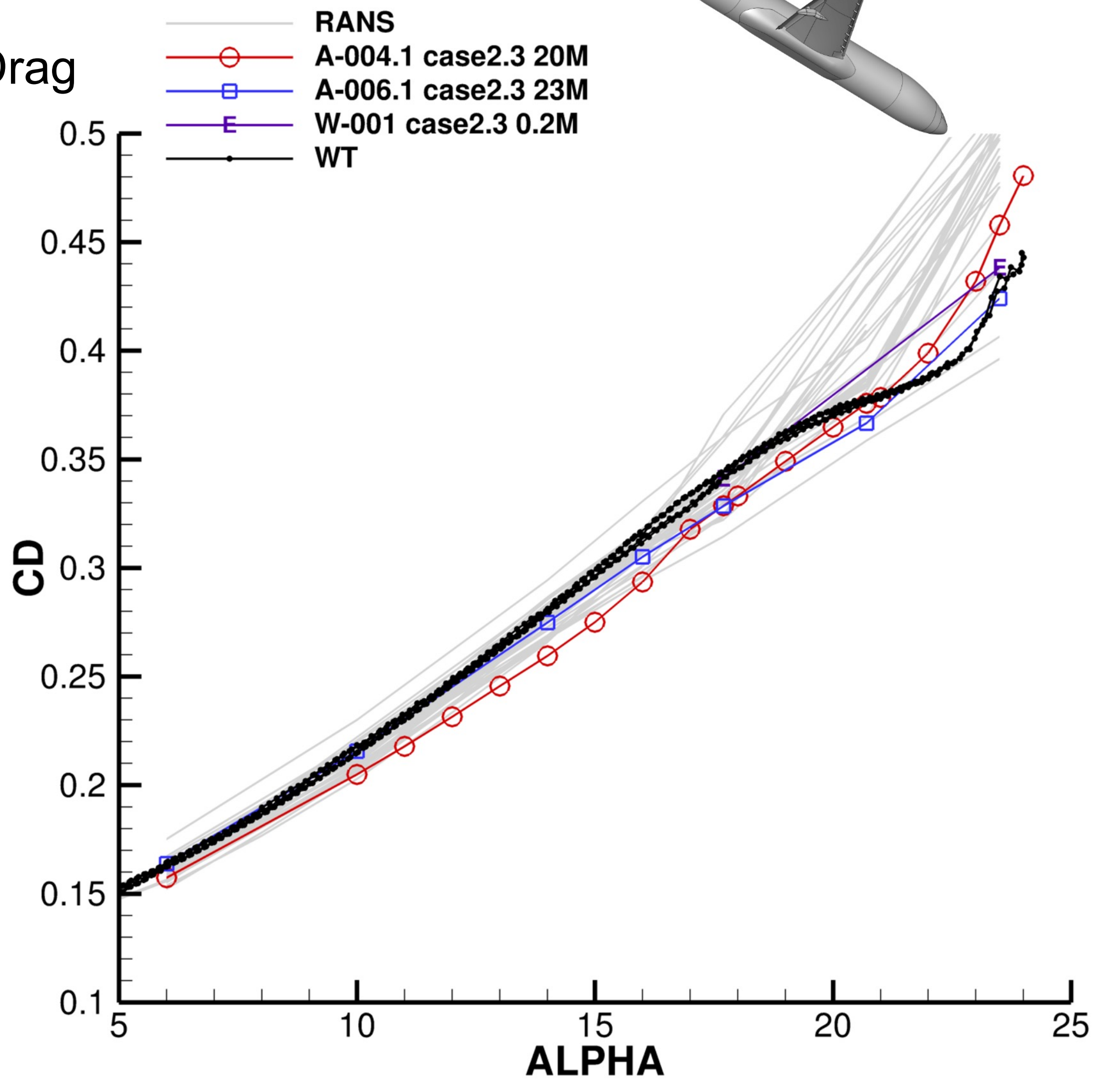
Test Case 2.3 Wind Tunnel Comparison



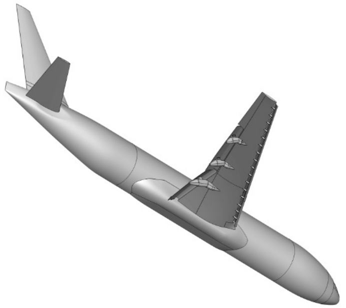
Lift



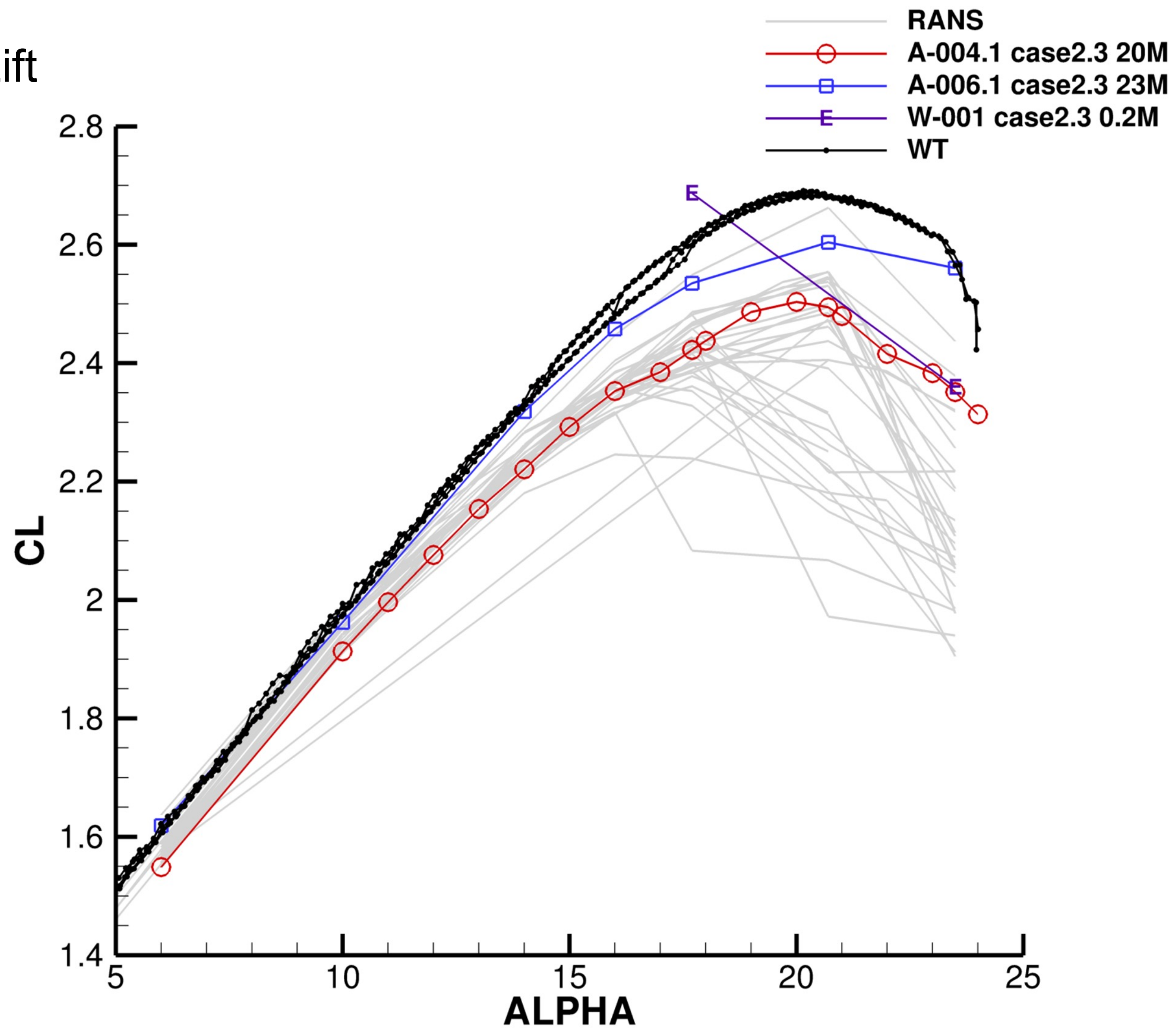
Drag



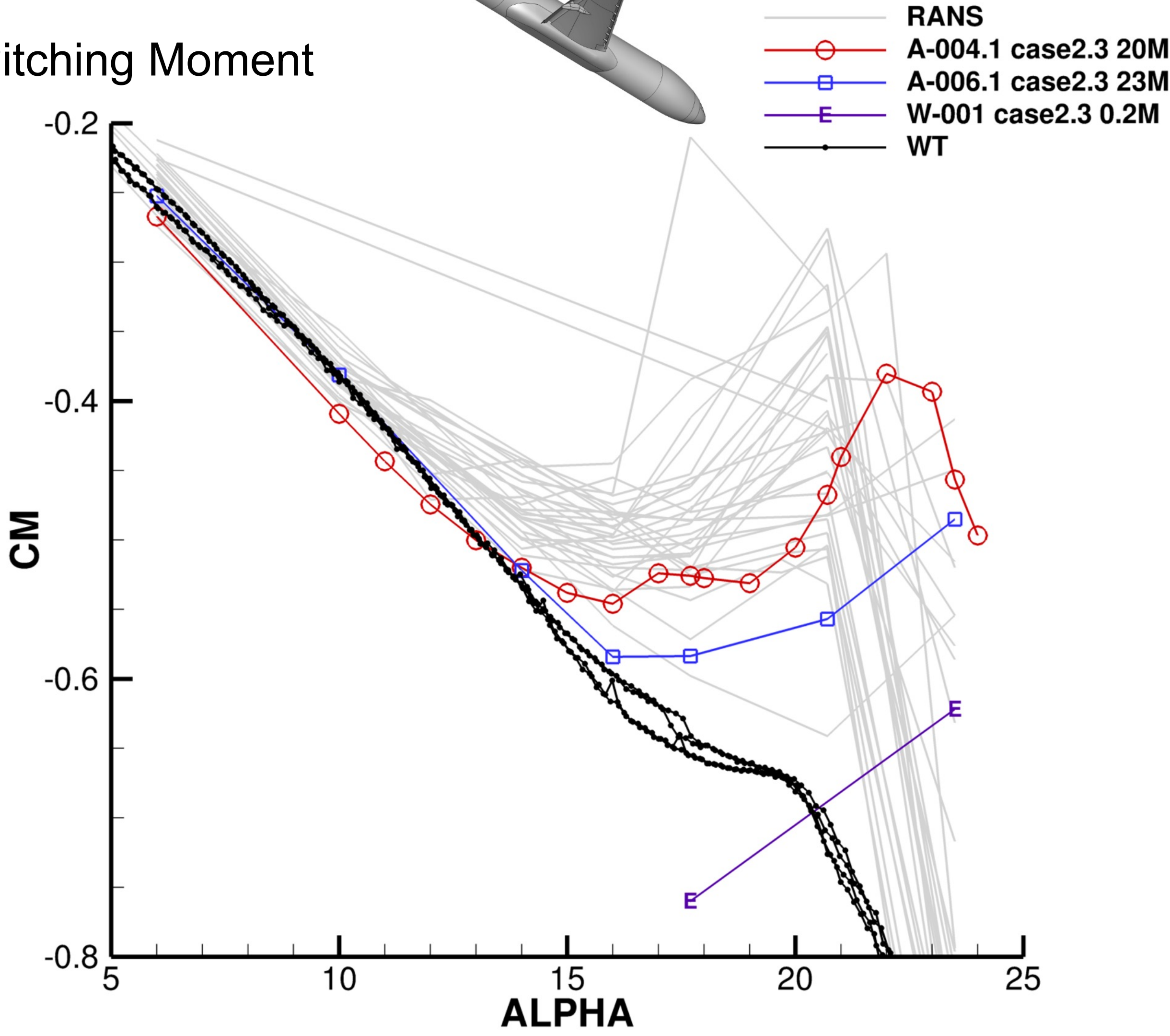
Test Case 2.3 Wind Tunnel Comp.



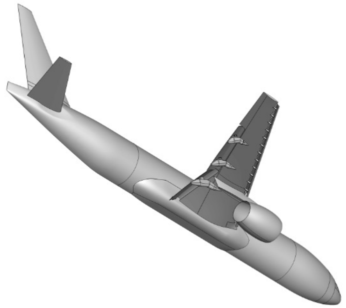
Lift

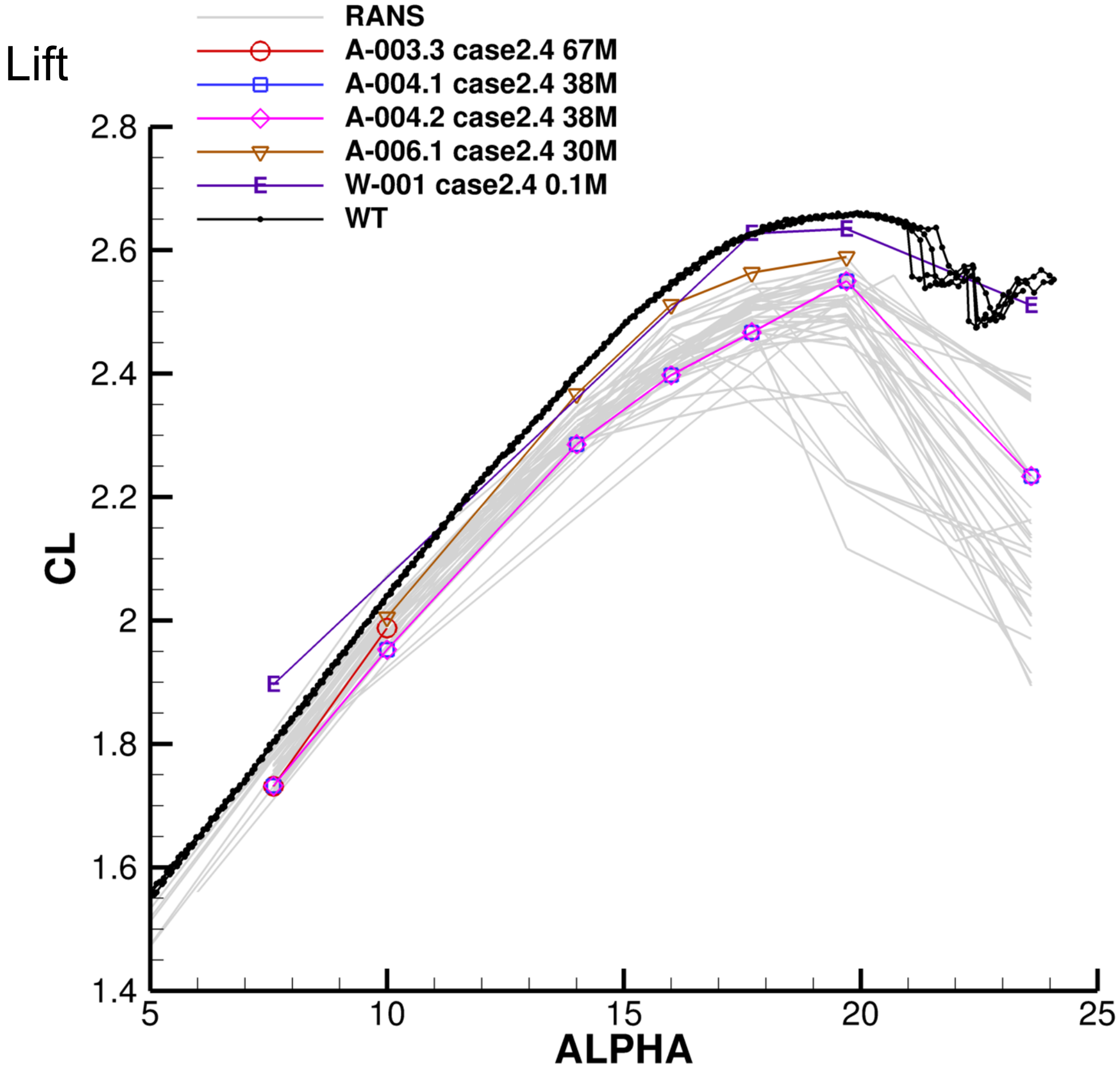


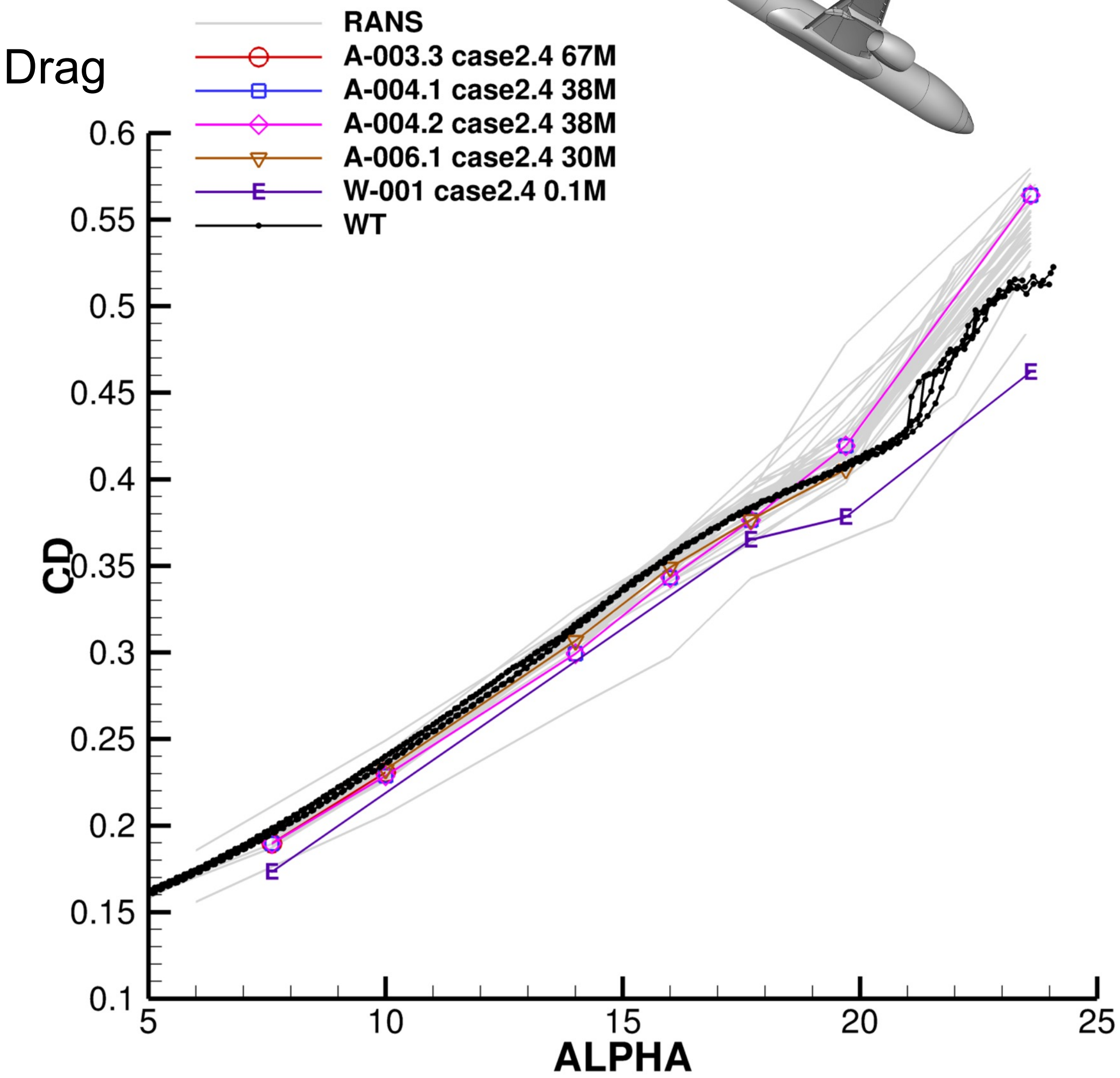
Pitching Moment



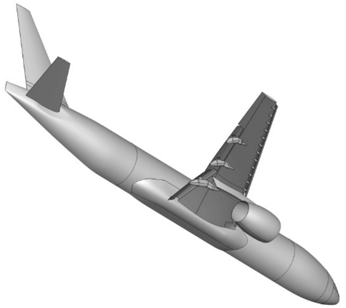
Test Case 2.4 Wind Tunnel Comparison



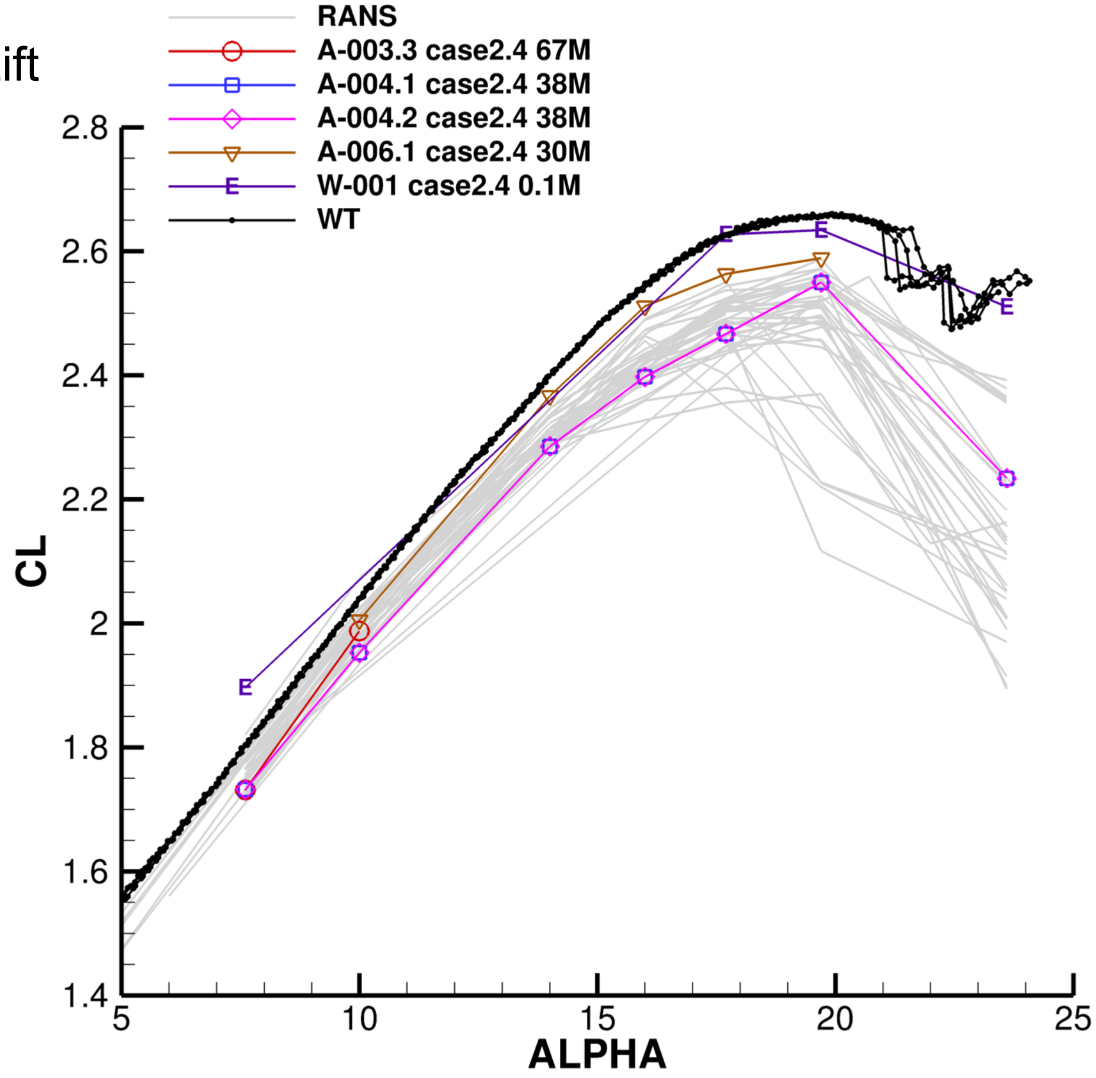




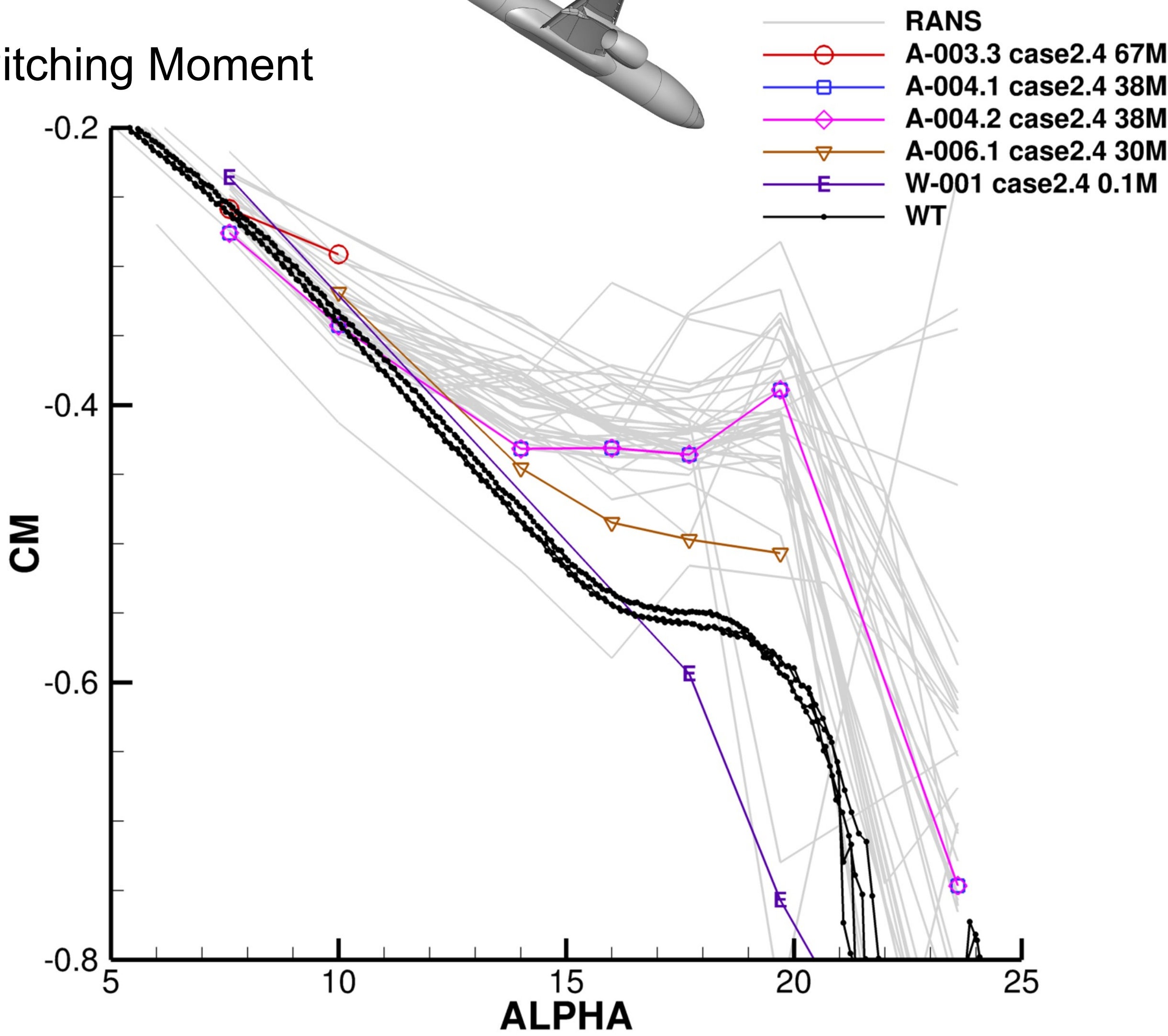
Test Case 2.4 Wind Tunnel Comp.



Lift



Pitching Moment



Test Case 2.2-2.4 Wind Tunnel Comparison

- Test Case 2.2 had the most submissions
  - Variation due to slat wakes remains an open topic
  - Submissions with smaller slat wakes had lower variation and least difference between simulation and measurement
- Test Case 2.3 adds a flap deflection
  - Differences increase above 16°
  - A-006.1 is different from other RANS submissions and closer to WT
  - A-004.1 is different from WT and closer to other RANS submissions
- Test Case 2.4 adds nacelle, pylon, and slat break
  - Largest difference between WT and RANS submissions
  - Change in lift and moment angle of attack slope at 10° not seen in wind tunnel measurement
- The addition of the flaps created a larger difference between simulation and measurement than the addition of the slat

Acknowledgements

Feedback from the HLPW5 organizers, observers, participants, and contributed to this presentation.

Participants and their organizations contributed many hours of their effort and resources over two years.

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