7th Drag Prediction Workshop

Saab, VZLU, FOI

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Contribution to DPW7

Common contribution to DPW7

- Saab, Swedish aircraft manufacturer
- VZLU - Czech Aerospace Research and Test Establishment
- FOI - Swedish Research and Defence Agency
- Commonality – M-Edge flow solver

Submitted to DPW7

- Case1a (grid convergence) , Case2a (alpha sweep) , Case3 (Re+q effects)
  - Common unstructured grids from JAXA; Models SA and EARSM k-ω
  - Common multi-block grids from Boeing

Not submitted but presented (in part, new ongoing computations)

- Case1a
  - Unstructured grids from DLR; Model SA
- Case5a, hybrid RANS-LES
  - Common unstructured grids from JAXA; Models HYB0, DDES, IDDES

Flow solver M-Edge

M-Edge originates from Edge

- Some functionalities from Edge broken out in Modules
- Saab has taken over rights of M-Edge from FOI
- Continued development under Saab lead

M-Edge core

- Finite volume for unstructured grids, node-based, dual grid formulation
- Explicit/implicit (fully, line-implicit) in time, central/upwind
- Weak boundary conditions everywhere

In DPW7

- **Fully implicit scheme for steady state (GMRES + ILU), or in dual time for time accurate**
- Central discretization in space, artificial dissipation (JST). For mean flow and turbulence
- Turbulence models: SA standard, EARSM k-ω Hellsten (RANS); HYB0, DDES, IDDES (RANS-LES)

Division of work

- RANS SA results by Saab
- RANS EARSM results by VZLU
- Hybrid RANS-LES results by FOI

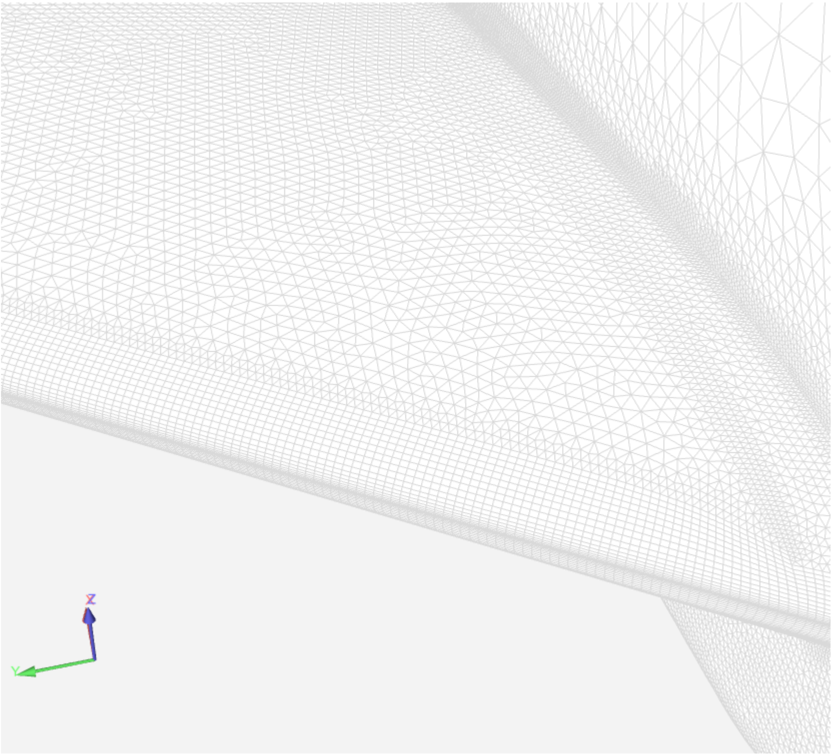
Case 1a

- Grid convergence study
- JAXA grids
  - SA model
  - k-ω Hellsten EARSM
- Boeing grids
  - SA model
- DLR grids
  - SA model

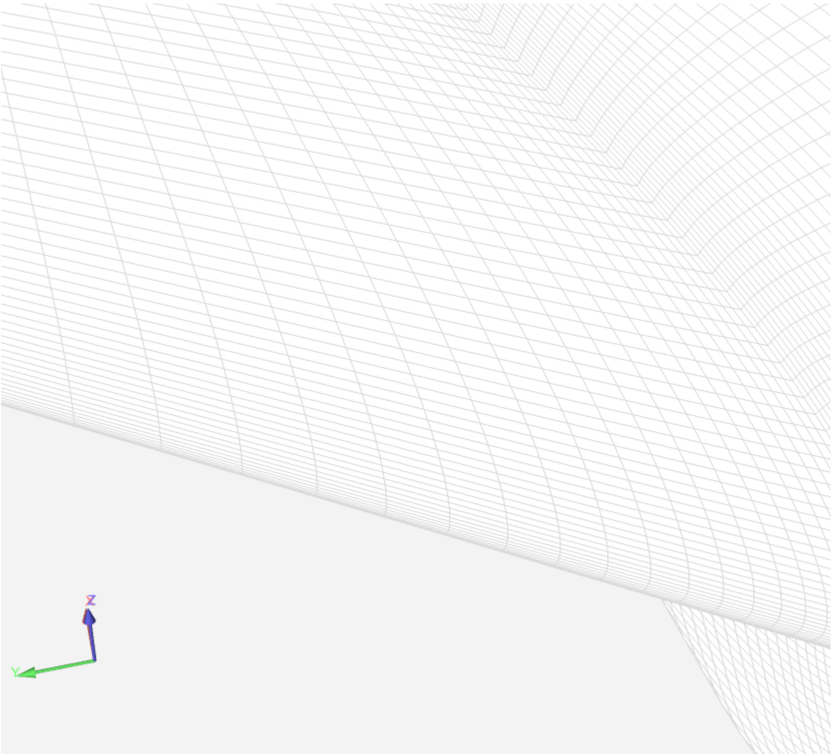
Grid families

- Tiny – ultra fine, # M nodes: 8.7 – 291 (JAXA), 5.2 – 220 (Boeing), 11.7 – 164 (DLR)

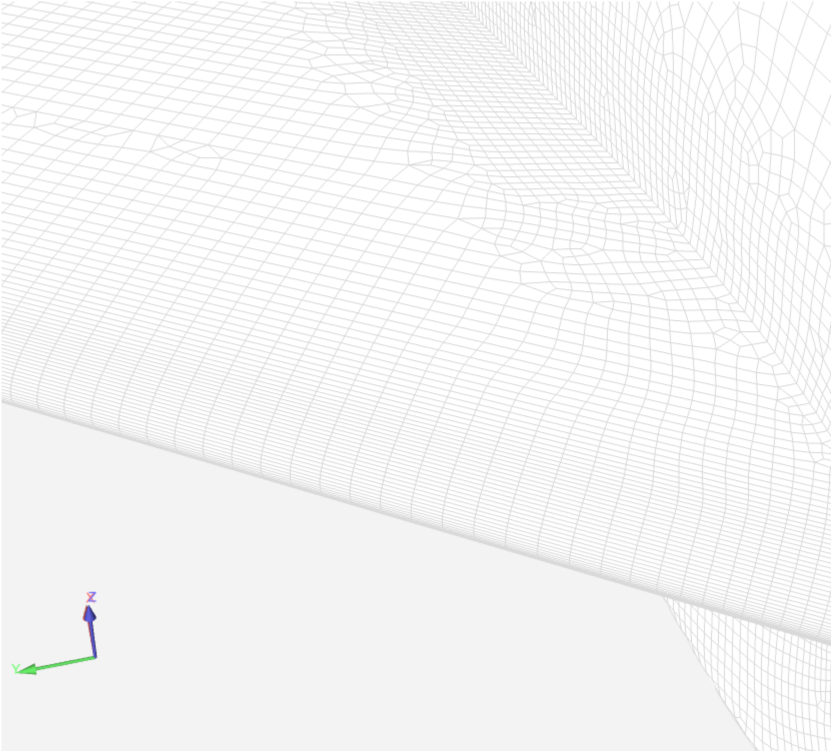
JAXA tiny



Boeing tiny



DLR tiny



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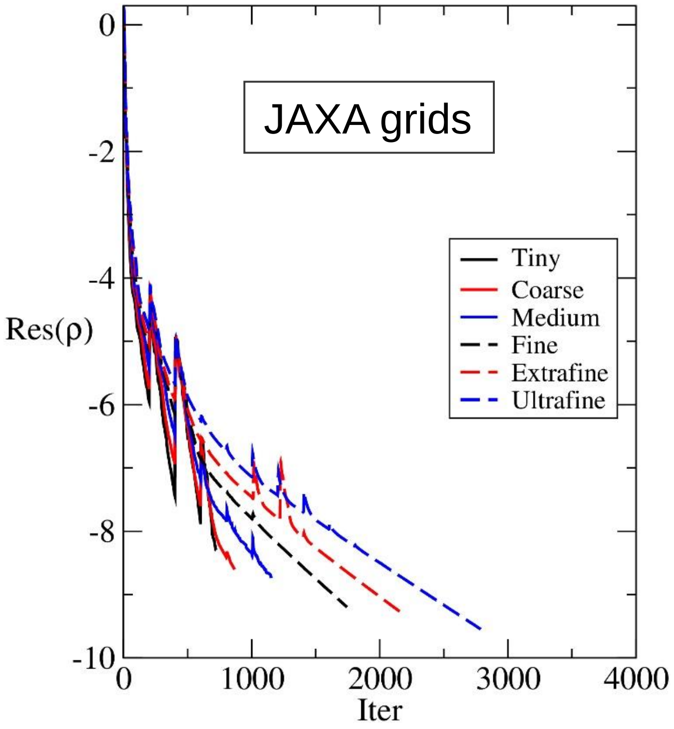
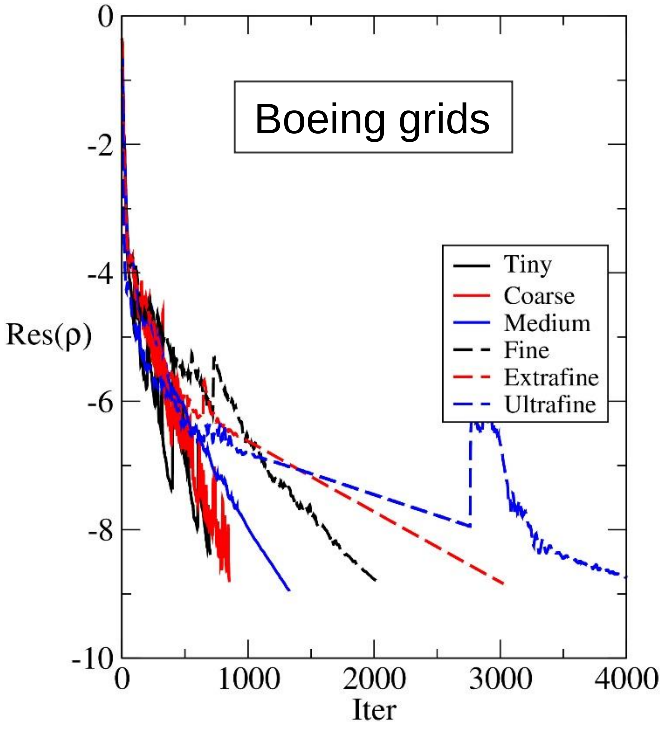
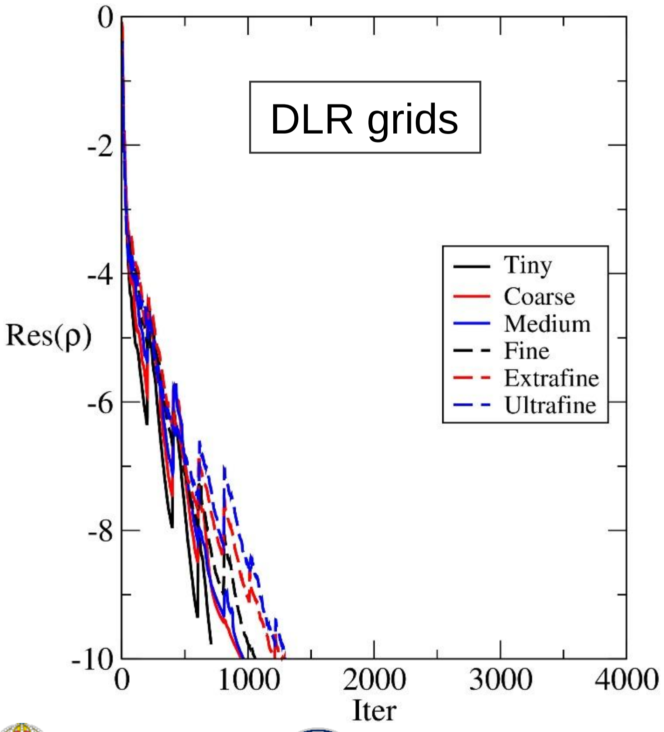
Steady state convergence, Case1a, SA

- Tiny – ultra fine, # M nodes: 8.7 – 291 (JAXA), 5.2 – 220 (Boeing), 11.7 – 164 (DLR)
- All calculations start from free stream
- Up to 2048 cores used
- All solutions within 1 hour wall clock time, lift converged after 6 orders reduction

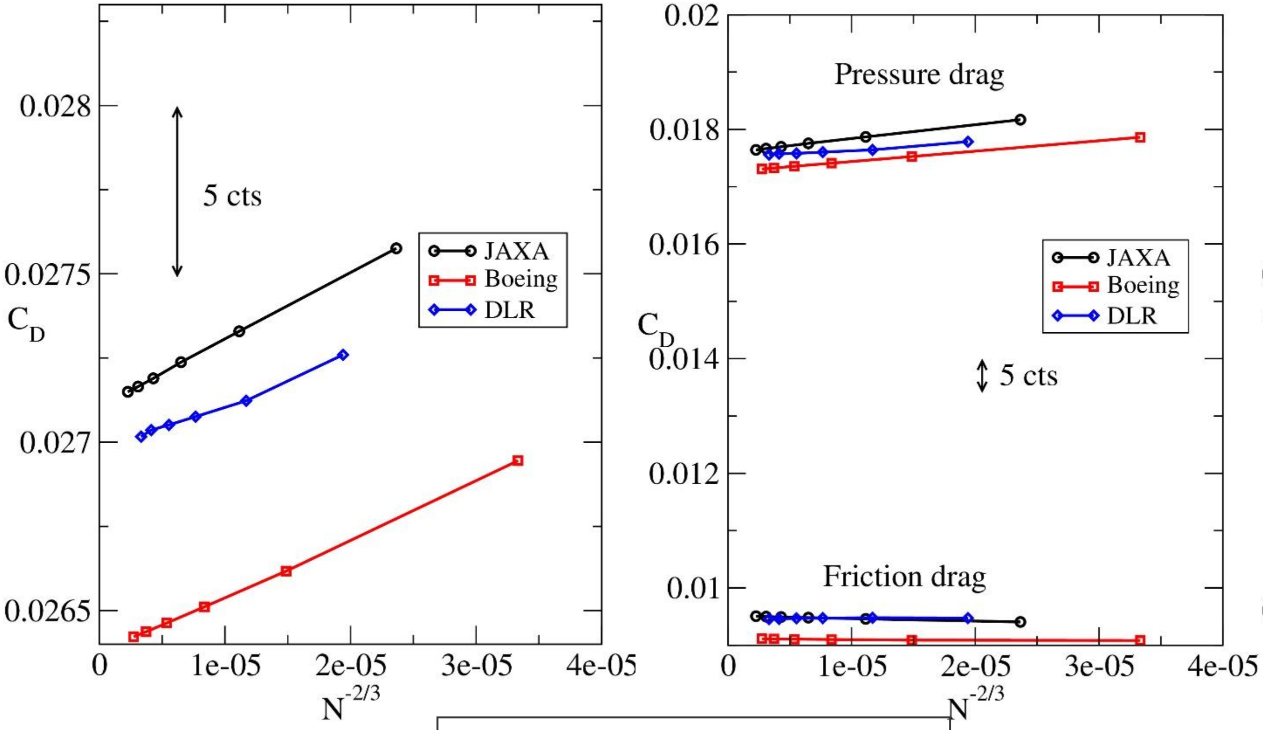




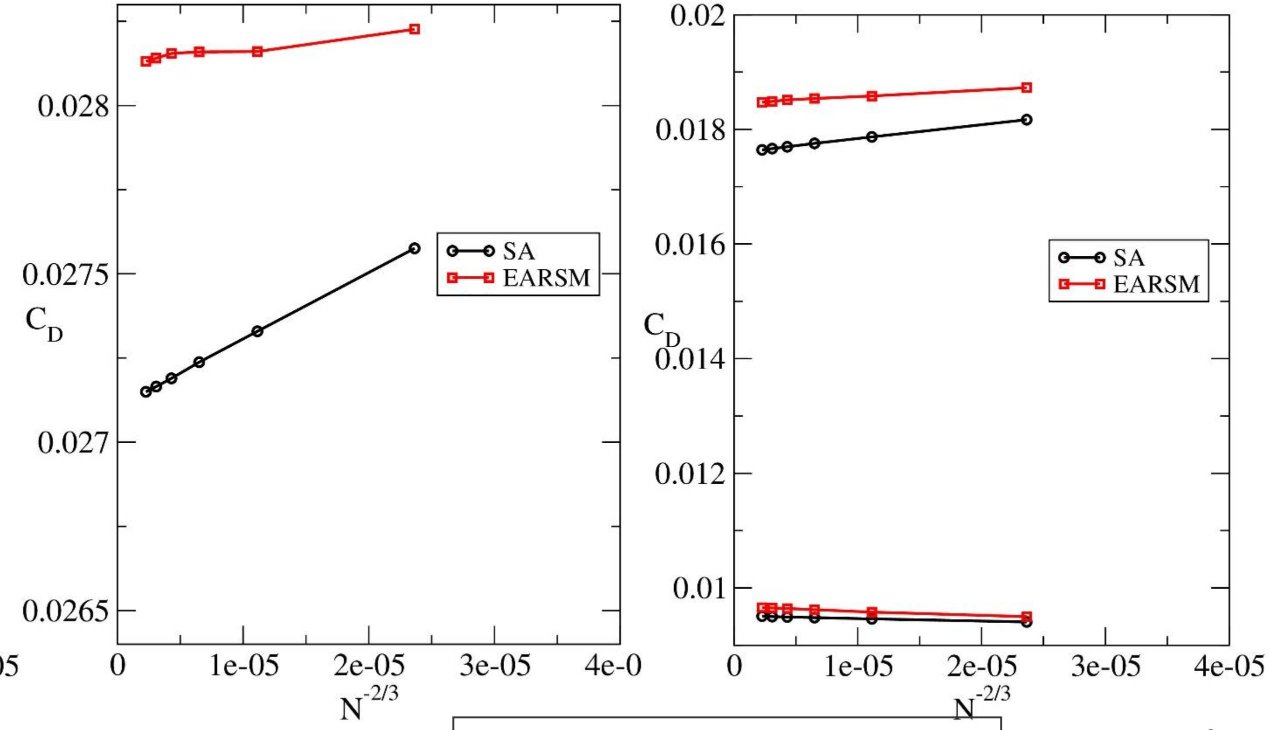


Case1a, grid and model dependence

- About 5 cts difference tiny - ultrafine
- Highest drag with JAXA grids, about 5 cts higher than Boeing
- EARSM gives higher drag than SA, mainly from pressure drag



3 grid families, SA model

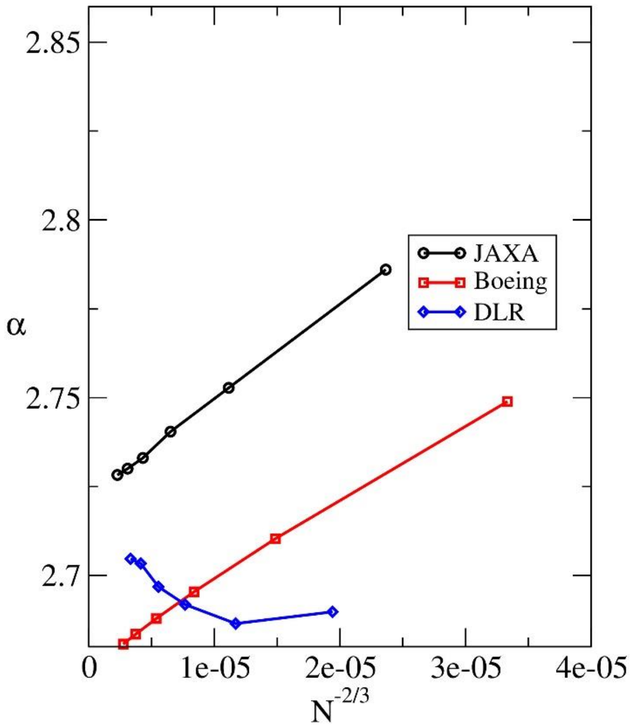


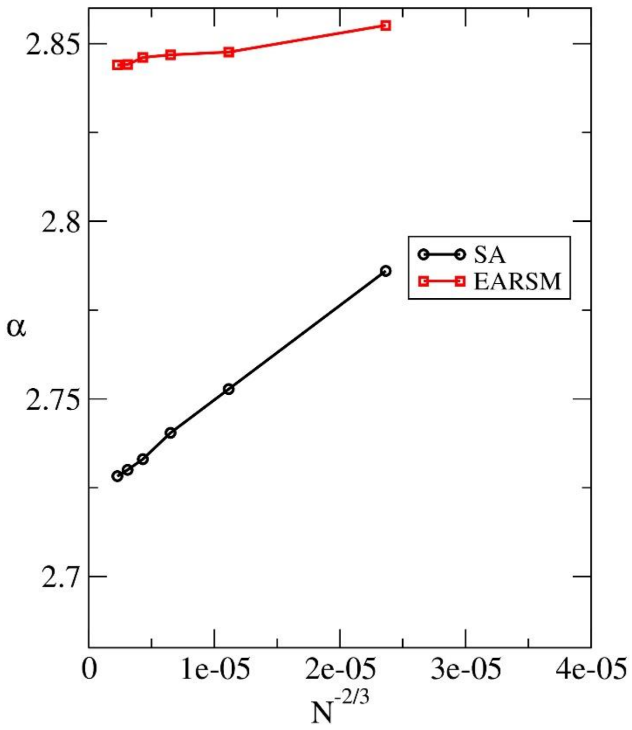
JAXA grid family, 2 models

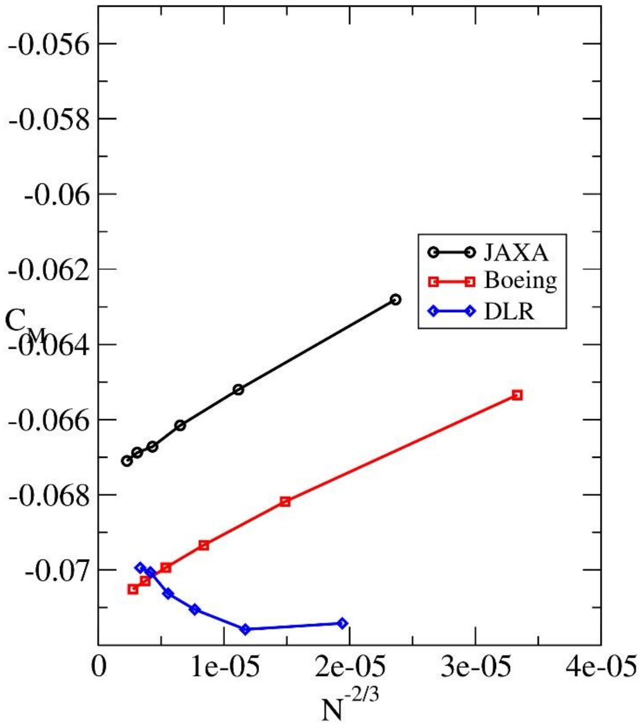
Case1a, α and C_M

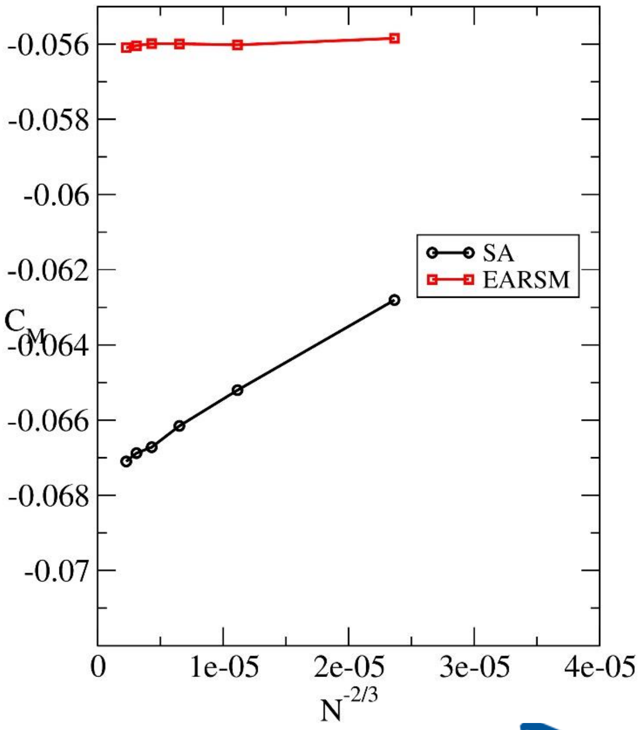
- SA: about 0.05° difference in α, tiny – ultrafine. DLR grids behave differently
- Smaller variation in α for EARSM
- Higher CM (note: BMC used) with EARSM vs SA

Ref. BMC





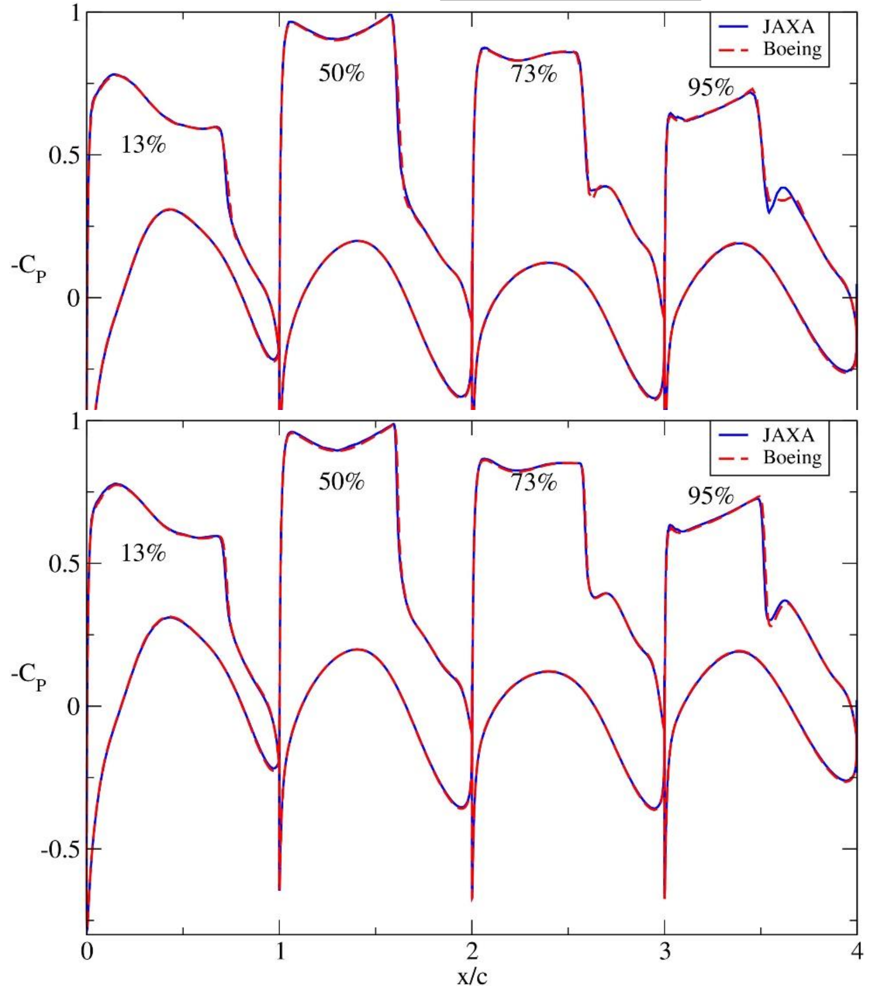




Case1a, Cp

- Larger variation between models than grid families

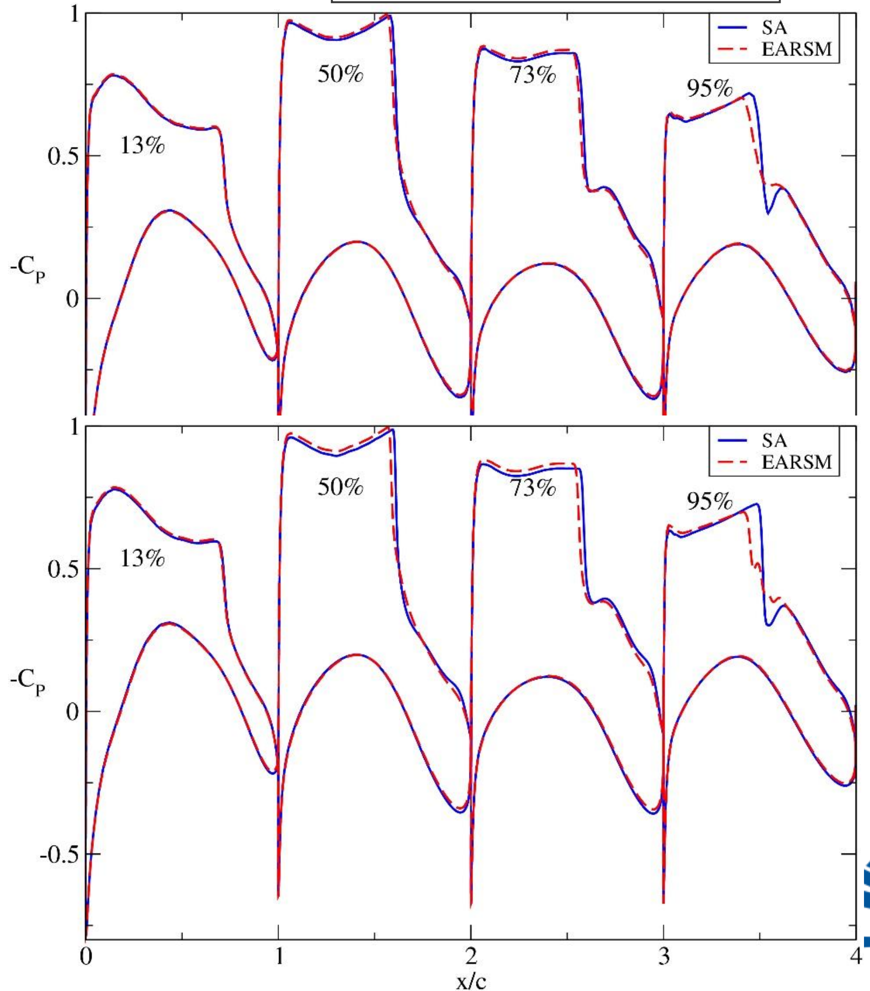
2 Grids, SA



Tiny

Ultrafine

JAXA grids, 2 Models

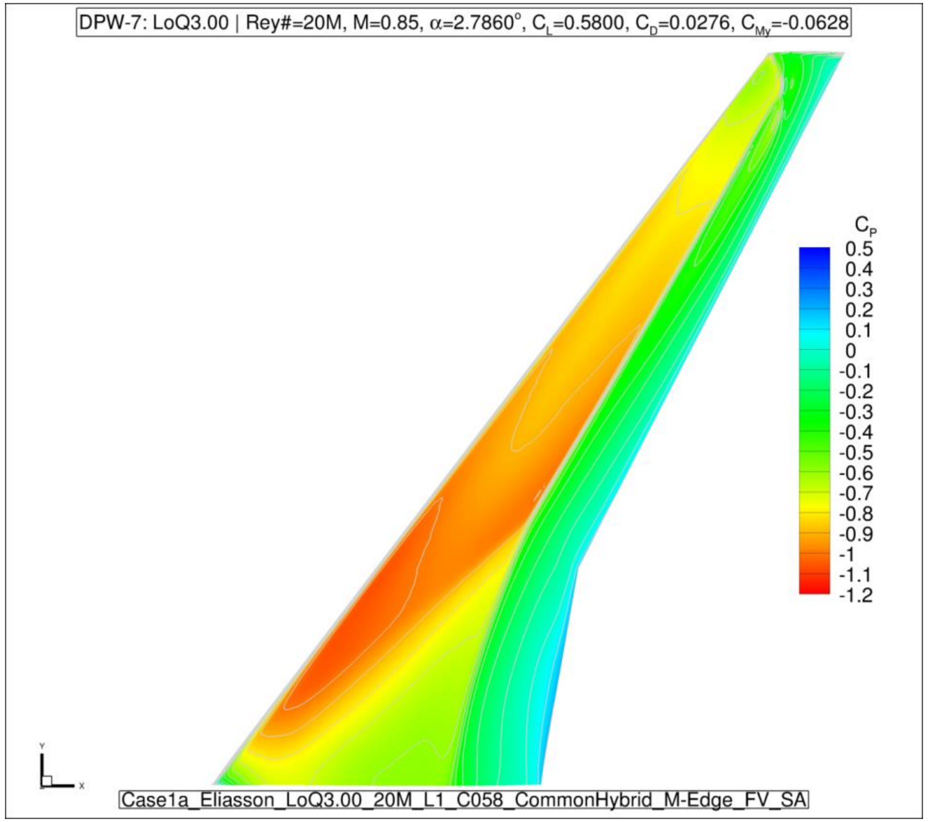


Case1a, Cp images

- Larger variation between models than grid families

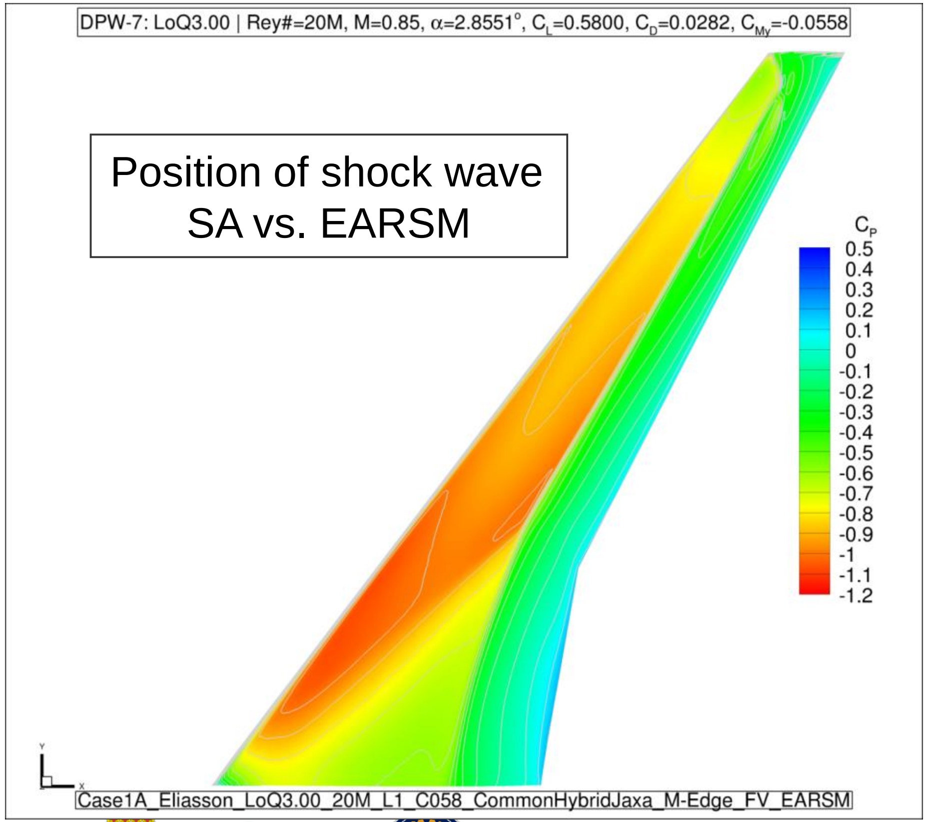
2 Grids, SA

JAXA grids, 2 Models



Tiny

Position of shock wave
SA vs. EARSM



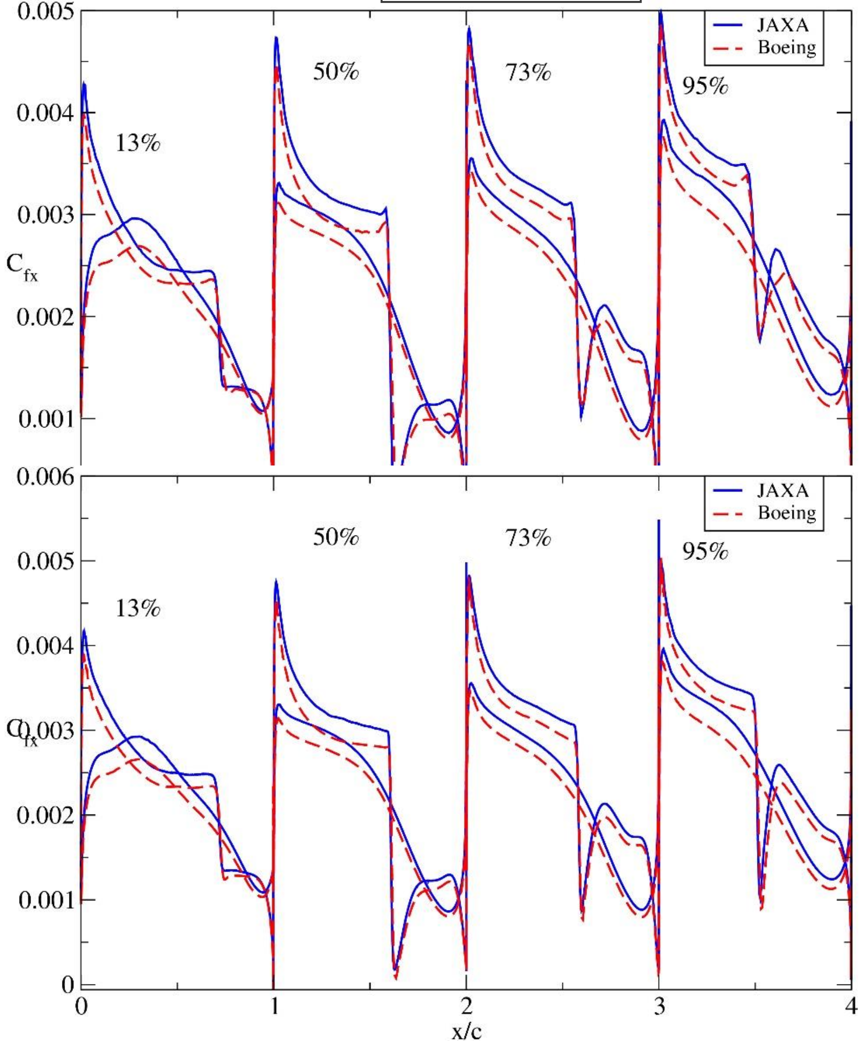
Slightly Sharper shock resolution

Case1a, Cfx

- Larger variation between grids

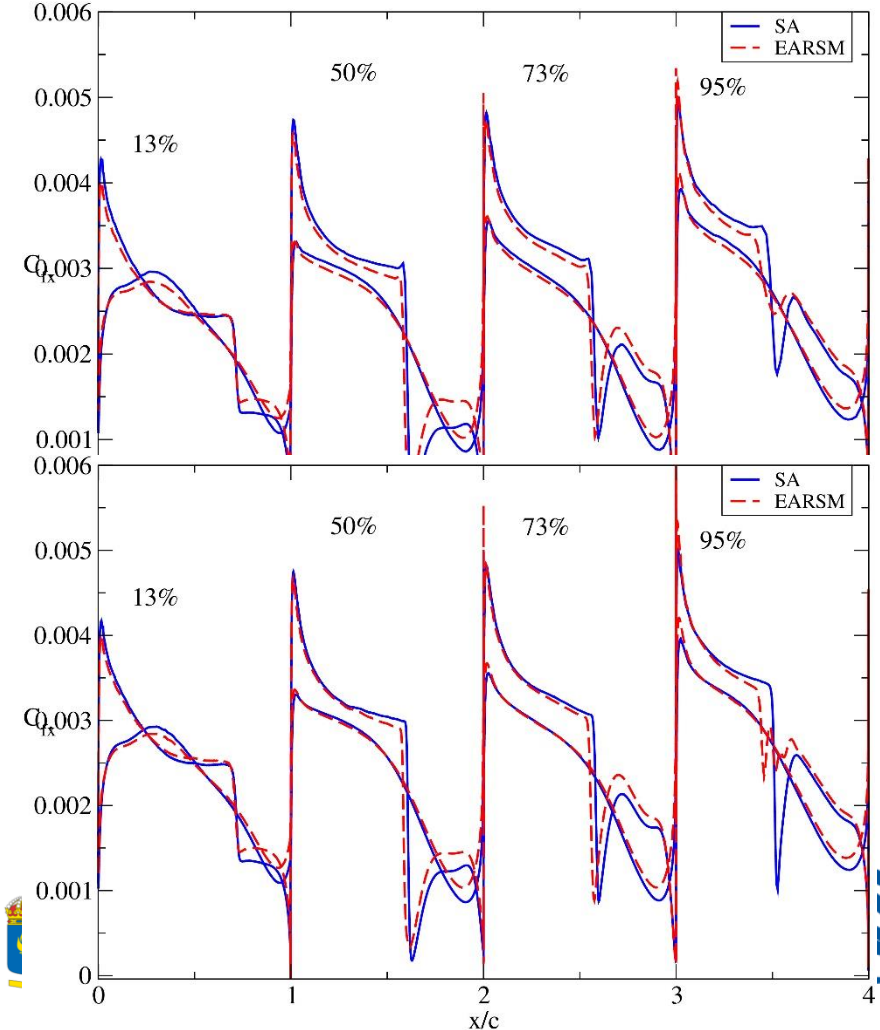
2 Grids, SA

JAXA grids, 2 Models



Tiny

Ultrafine



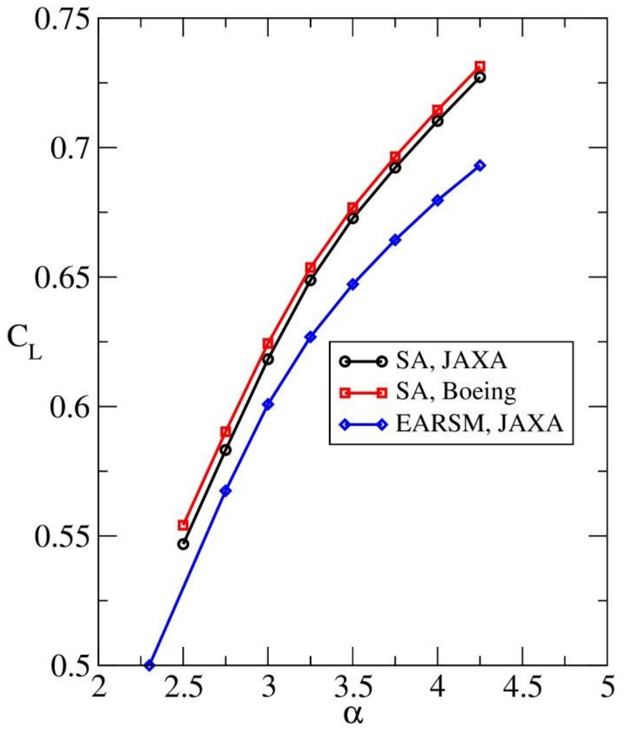
Case 2a

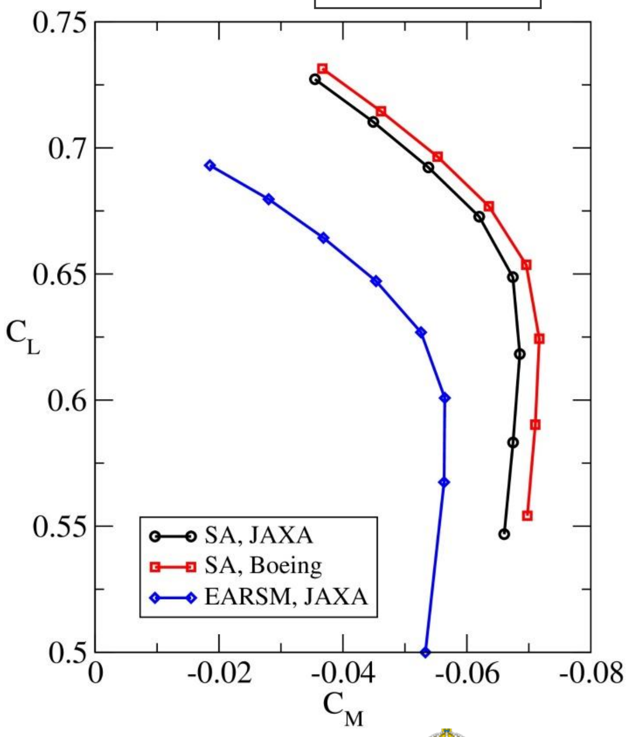
- AoA sweep
- JAXA grids
  - SA model
  - k-ω Hellsten EARSM
- Boeing grids
  - SA model

Case2a, α sweep

- Lower lift with EARSM
- Small variation from grid family, model has larger influence

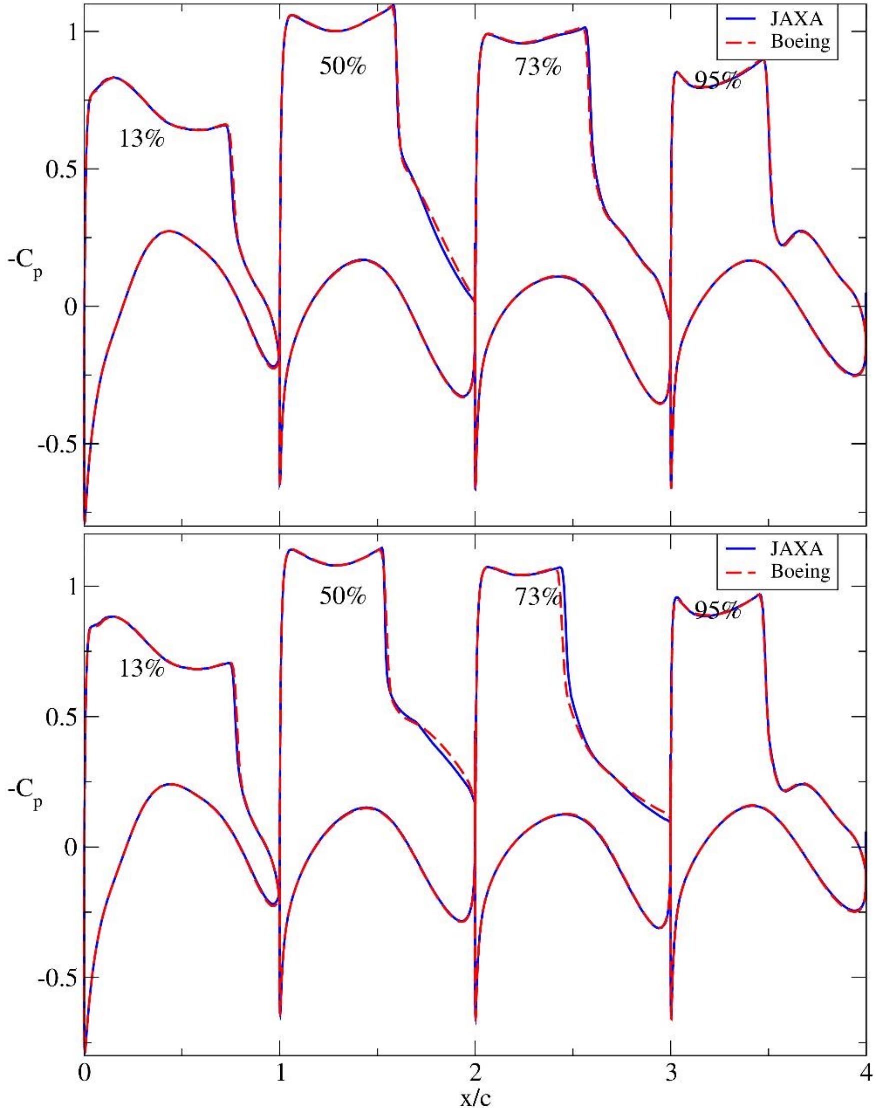
Ref. BMC



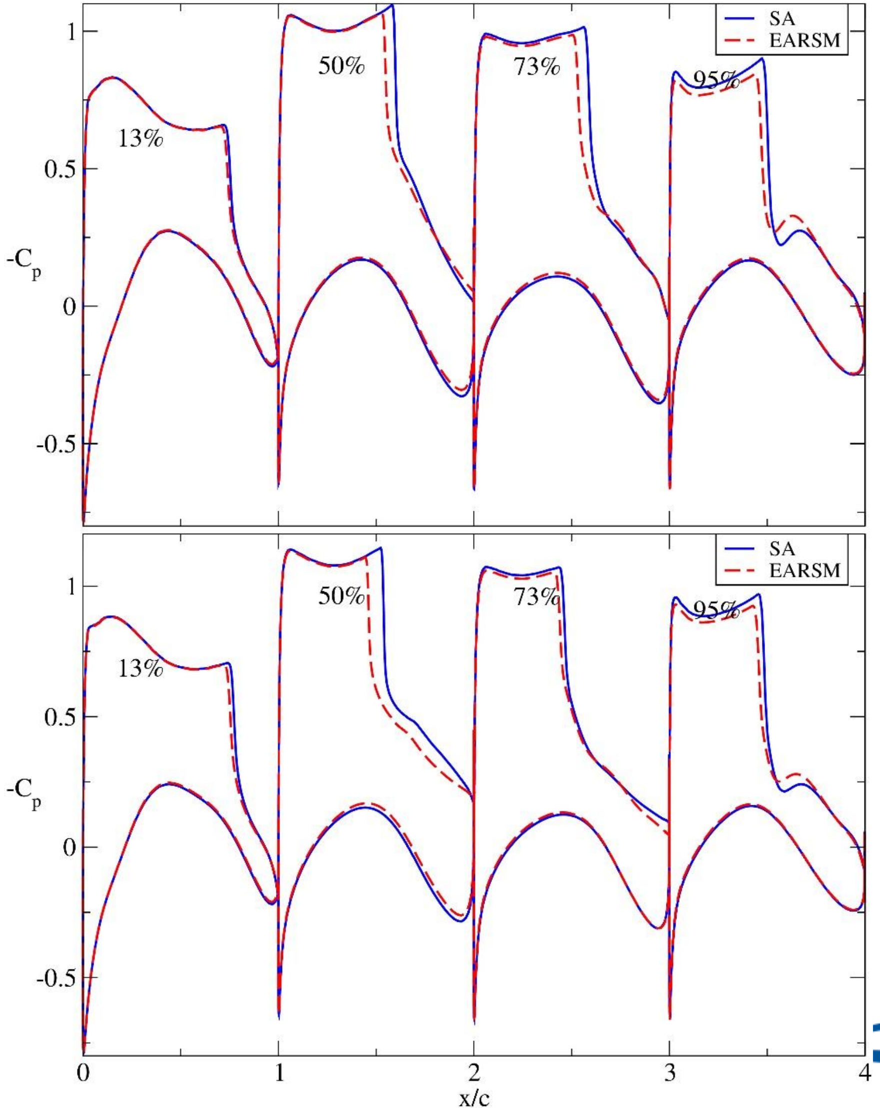


Case2a, Cp

2 Grids, SA



JAXA grids, 2 Models



α=3.5°

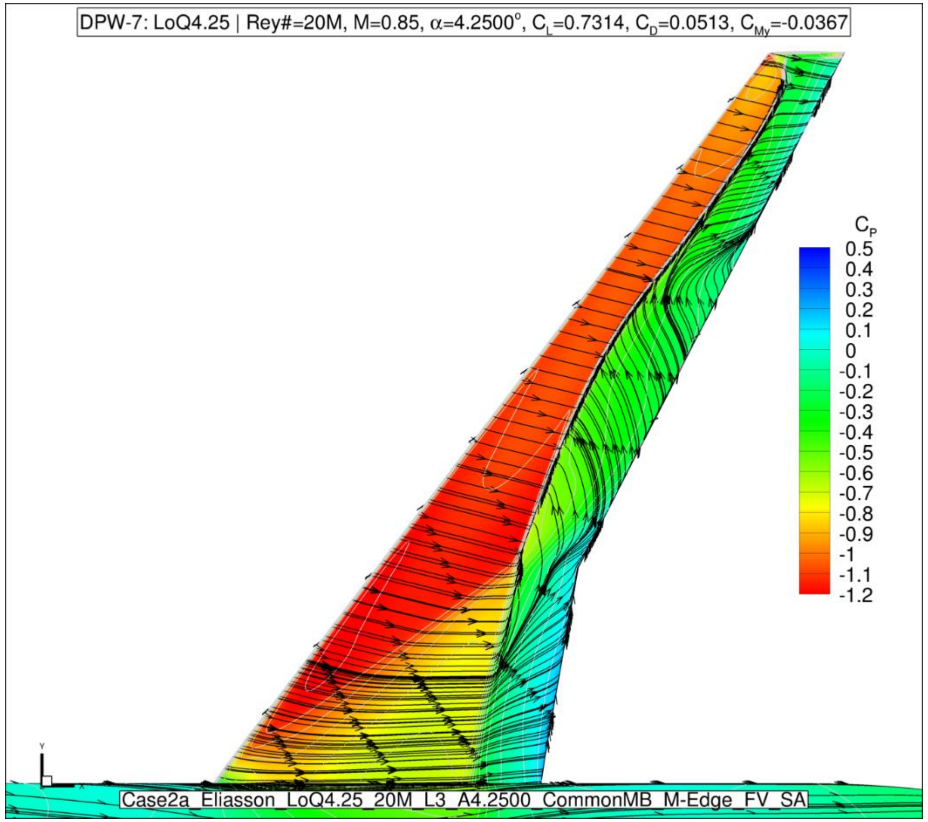
α=4.25°

Case2a, Cp images

- Larger variation between models than grid families

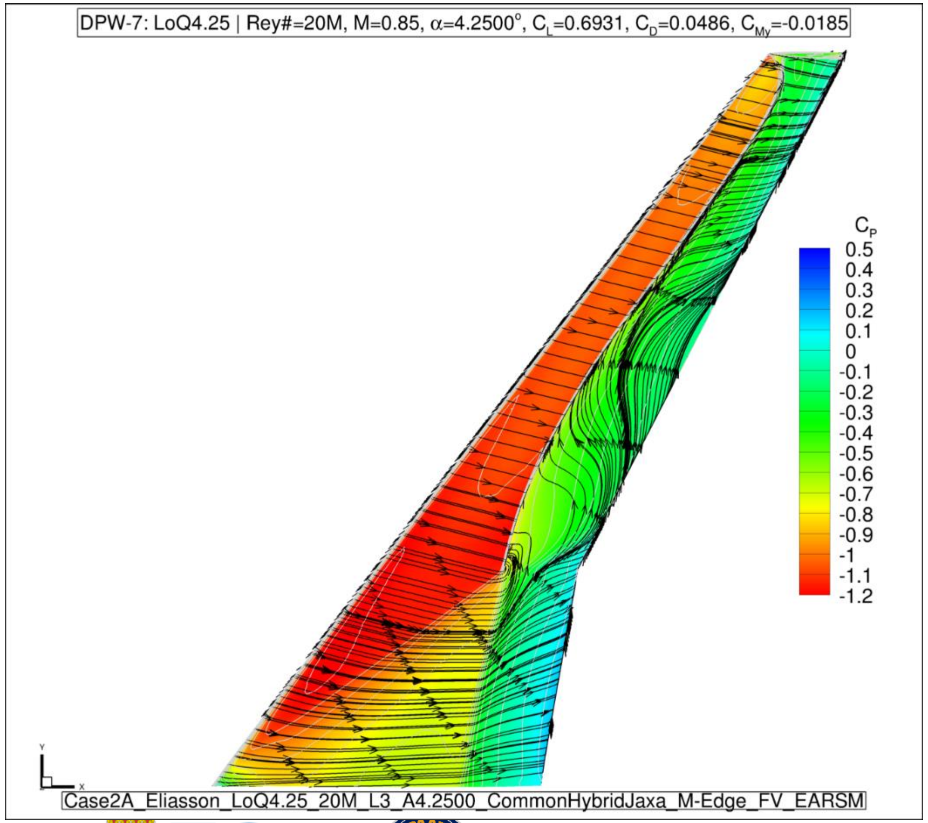
2 Grids, SA

JAXA grids, 2 Models



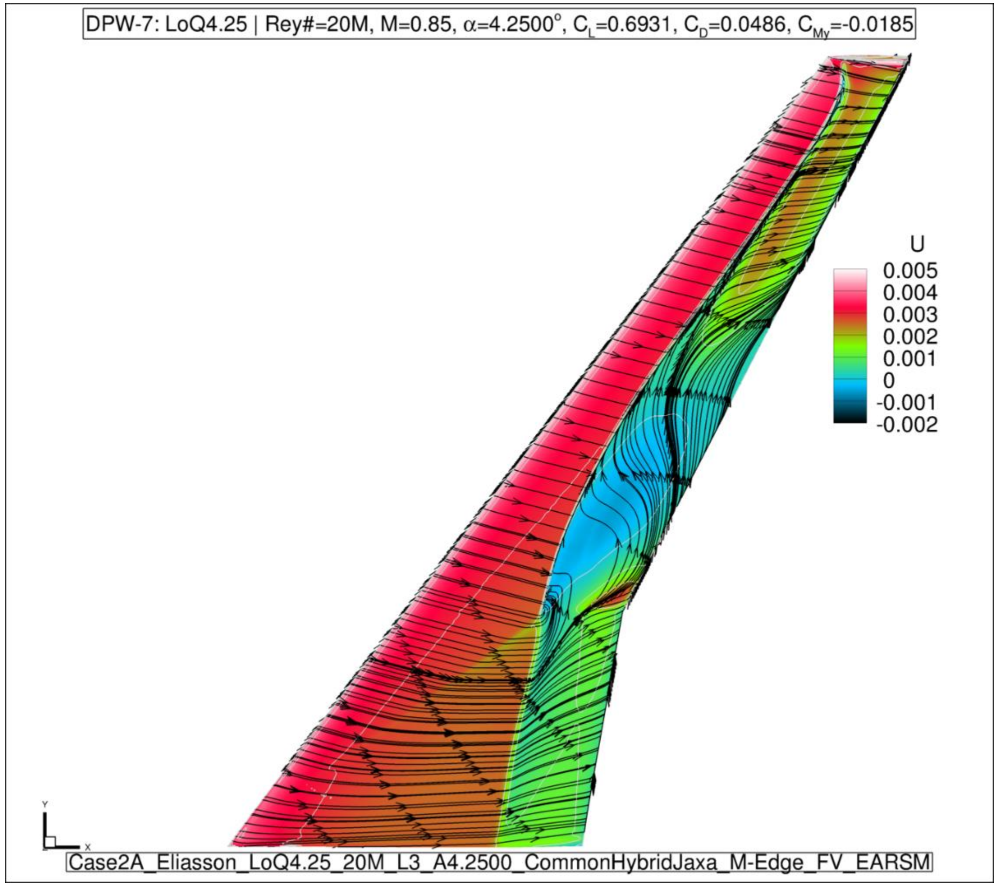
α=4.25°

TE separation



TE separation, Case 2a

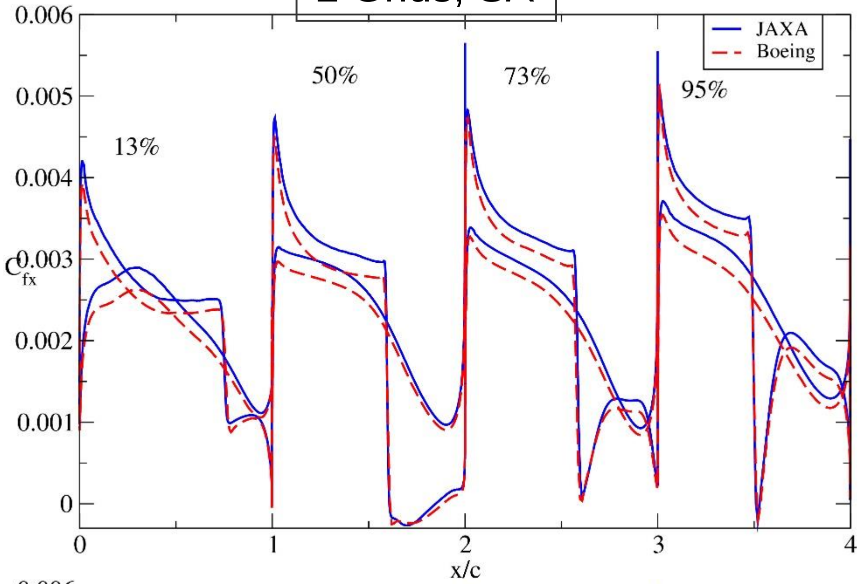
- Present at high AoA (3.5° and more),
  - Negative Cfn (normal to the TE), which extends up to TE
- Shock induced separation occurs at lower AoA, recovers before reaching TE

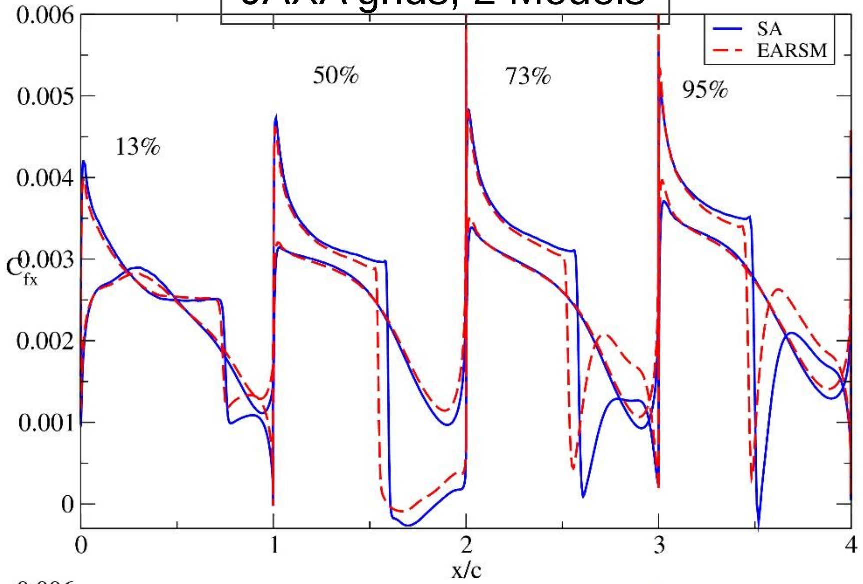


Case2a, Cfx

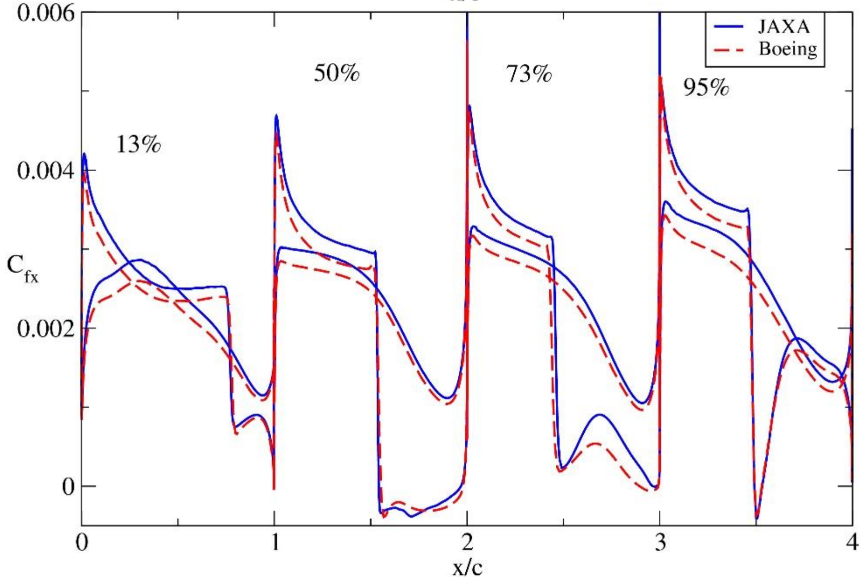
2 Grids, SA

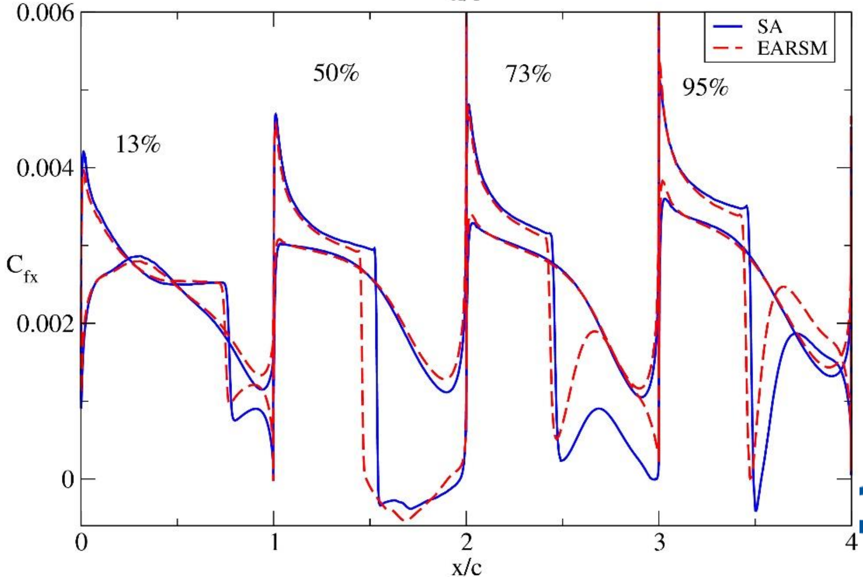
JAXA grids, 2 Models





α=3.5°

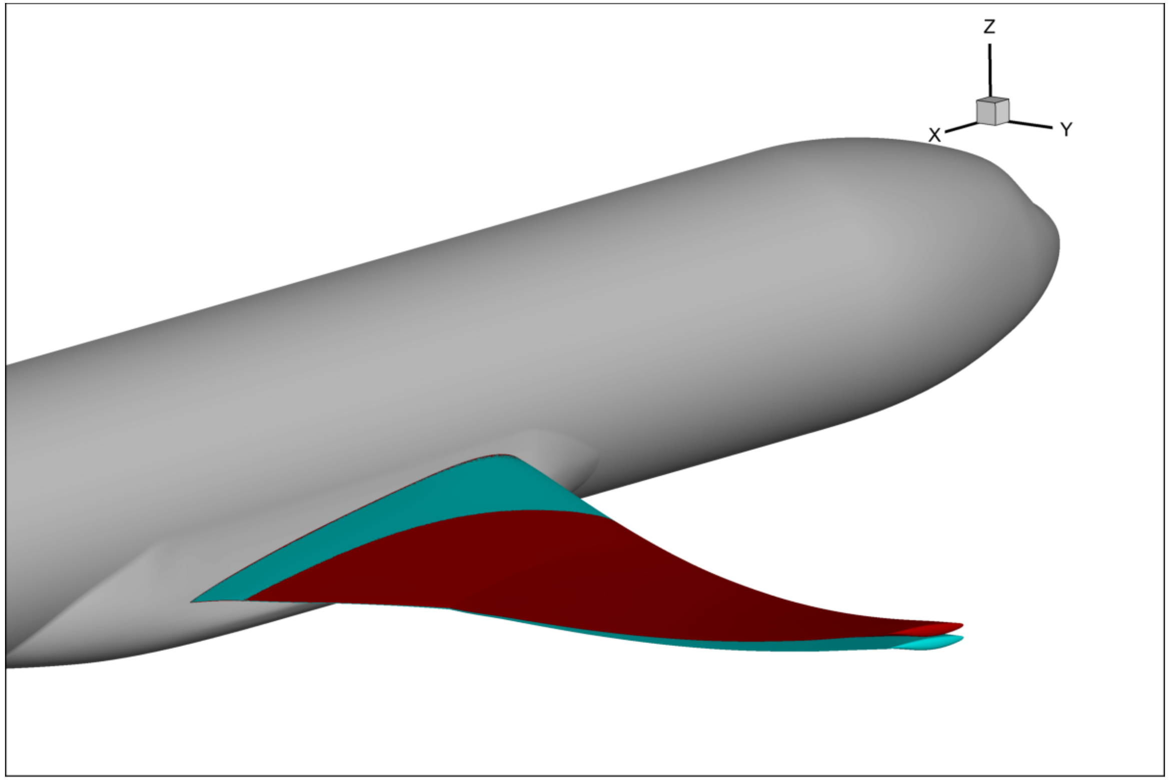




α=4.25°

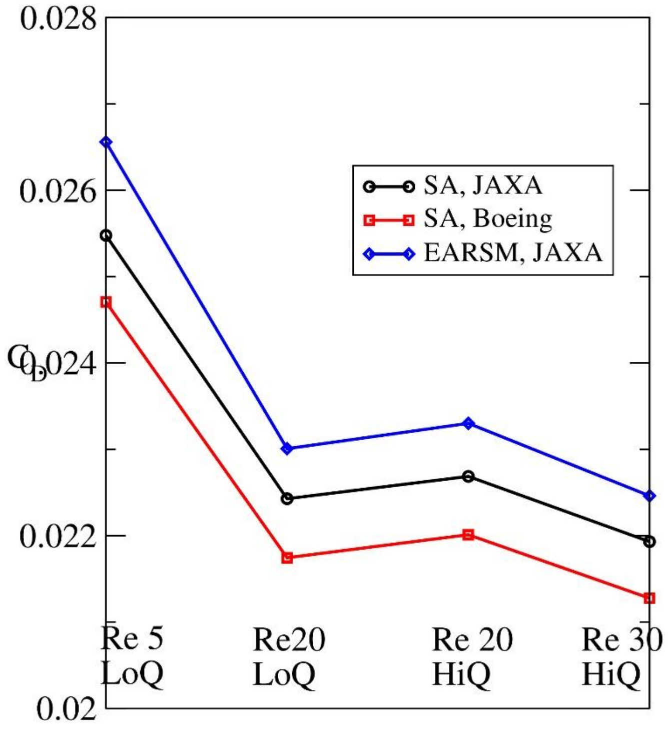
Case 3

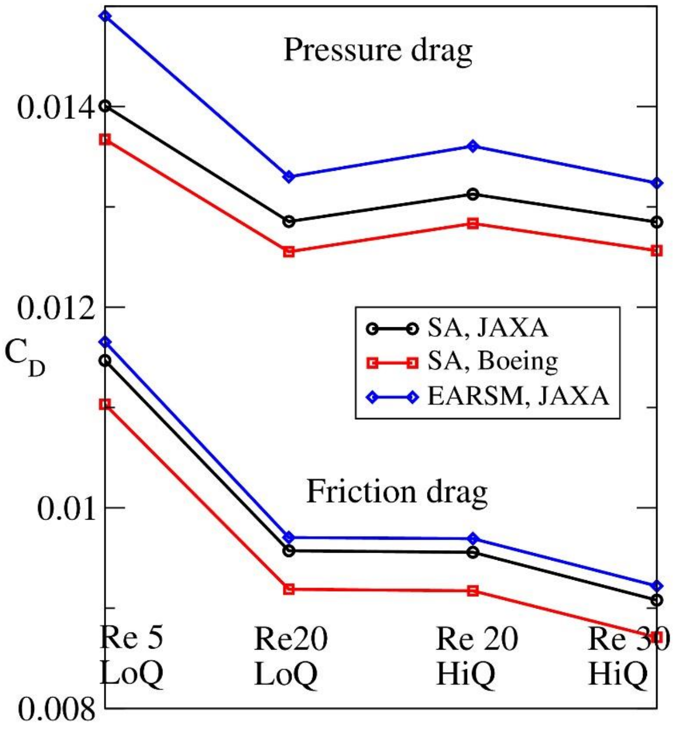
- Two different geometries (LoQ, HiQ)
  - LoQ: Reynolds 5M, 20M
  - HiQ: Reynolds 20M, 30M
- JAXA grids
  - SA model
  - k-ω Hellsten EARSM
- Boeing grids
  - SA model

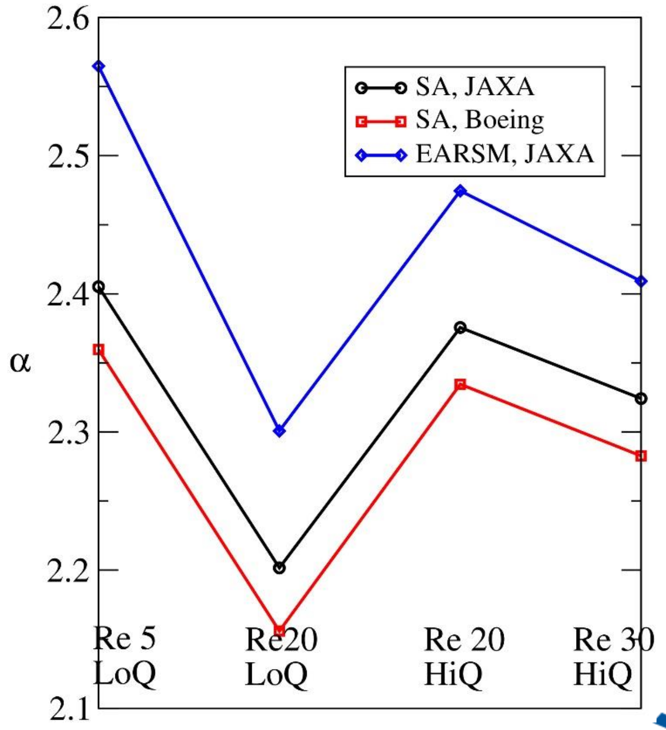


Case3, Cd and α

- No special grid for each Reynolds number, grids suitable for higher Re (y+ resolution)
- Two grids: LoQ (5M & 20M), HiQ (20M & 30M)







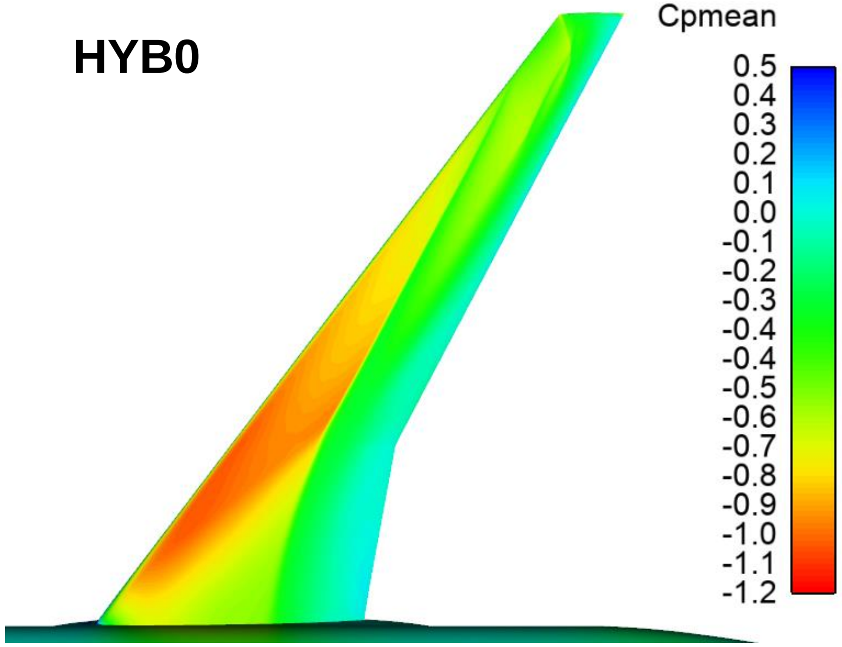
Case 5a

- Exploration of hybrid RANS-LES modelling in drag predictions – single solution at fixed AoA with CL = 0.58.
- RANS (SA model) computations in Case 1a suggest **AoA = 2.75** deg for CL = 0.58
- JAXA grid (medium mesh on *3.00deg LoQ AE CRM* geometry) with about 60M nodes
- Hybrid RANS-LES methods
  - ✓ HYB0 model
  - ✓ SA-DDES model
  - ✓ SA-IDDES model
- Time step: 2×10^{-5} second
- After an initial period with the flow fully developed, statistic analysis conducted usually over a period of about 5000-6000 time steps for HYB0 and SA-IDDES, but SA-DDES returns to RANS-type solution!
- Boeing mesh to be tested with necessary local refinement – ongoing hybrid RANS-LES computations….

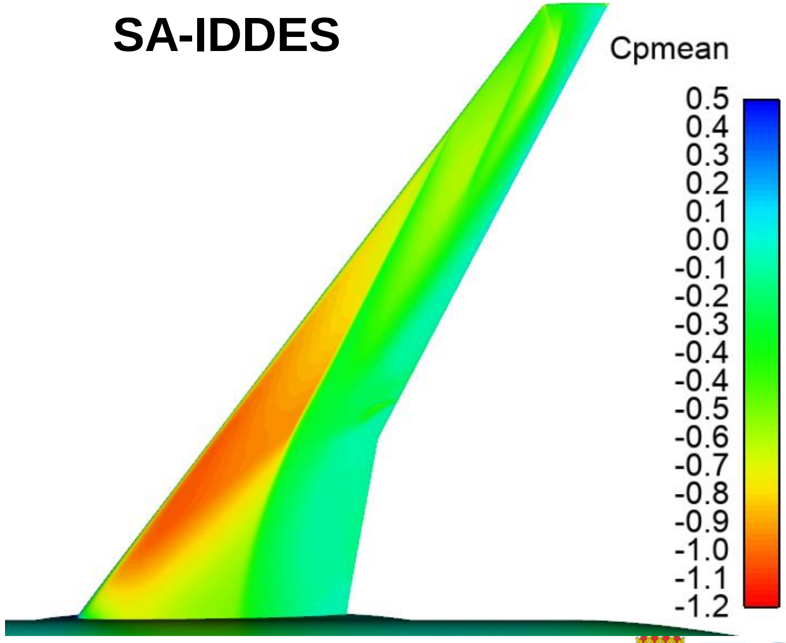
Case 5a: Time-averaged predictions

- In relation to grid resolution (designated for RANS), HYB0 and IDDES computations render inappropriately resolved shock – particularly in the outboard, while the SA-DDES computation returns to its RANS form
- Predictions
  - ✓ **HYB0:** CL = 0.45849, CD = 2.3022E-02, CM = -1.1445E-02
  - ✓ **SA-IDDES:** CL = 0.42499, CD = 2.2624E-02, CM = -6.5173E-03
  - ✓ **SA-DDES:** CL = 0.57584, CD = 2.7018E-02, CM= -6.3010E-03

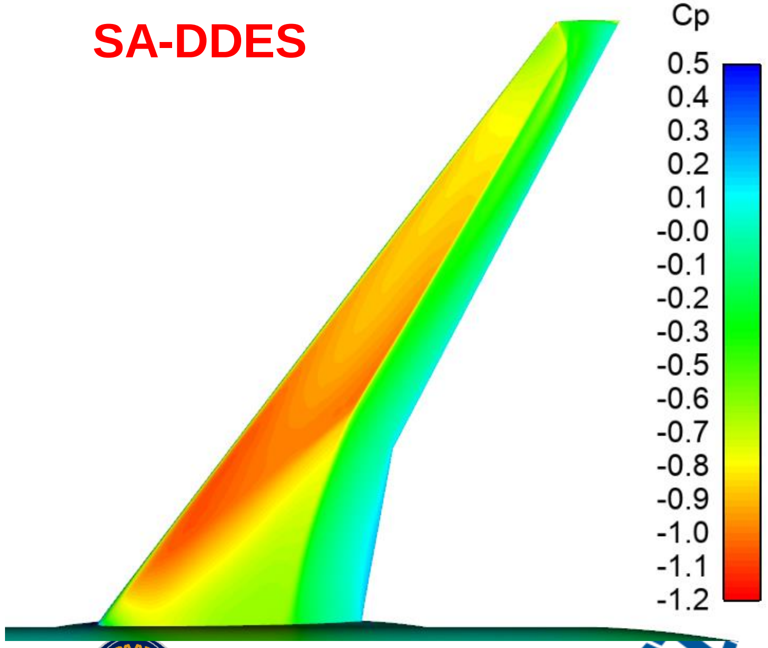
HYB0



SA-IDDES

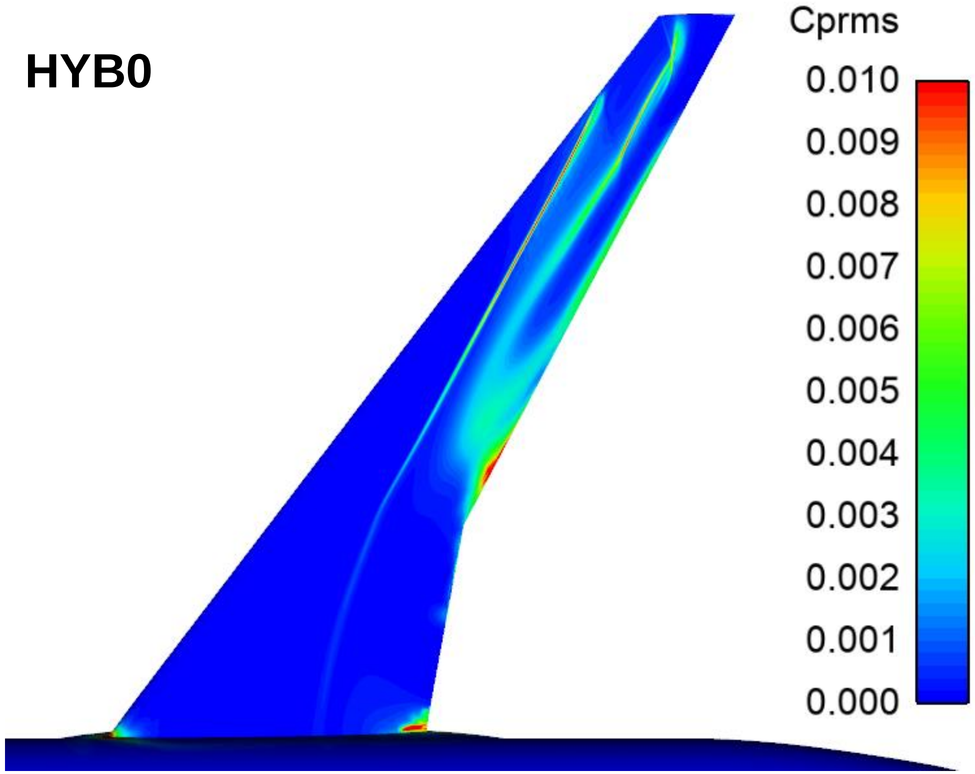


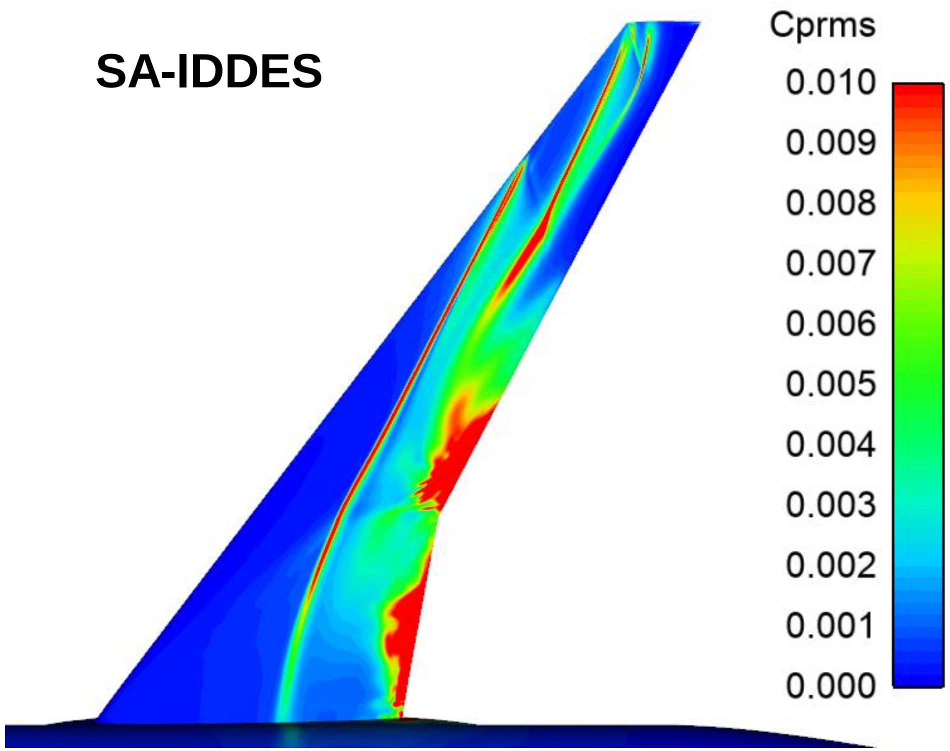
SA-DDES



Case 5a: Resolved surface pressure fluctuastions

- Much intensive pressure fluctuations on wing surface were resolved with the IDDES model
- Grid resolution should be adapted to scale-resolving simulations, not only in the boundary layer and also in the area of trailing wakes.





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Summary

Flow solver

- Considerable speed-up with implicit scheme

Grid convergence

- 5 cts difference tiny-ultrafine SA, 1 ct difference tiny-ultrafine EARSM
- Lower drag, 6-7 cts, with Boeing structured MB grid
- Higher drag, ~10 cts, with EARSM vs SA
- Turbulence-resolving capabilities in RANS-LES computation is closely associated to the grid resolution on shock, boundary layer and their interaction

Alpha sweep

- Smaller variations between grids
- Larger variation between models SA - EARSM

Further work

- Continuous work on hybrid RANS-LES computations with appropriate grid adaptation
- Summary in a paper. Next AIAA?