Application of CFD to Abrupt Wing Stall Using RANS and DES

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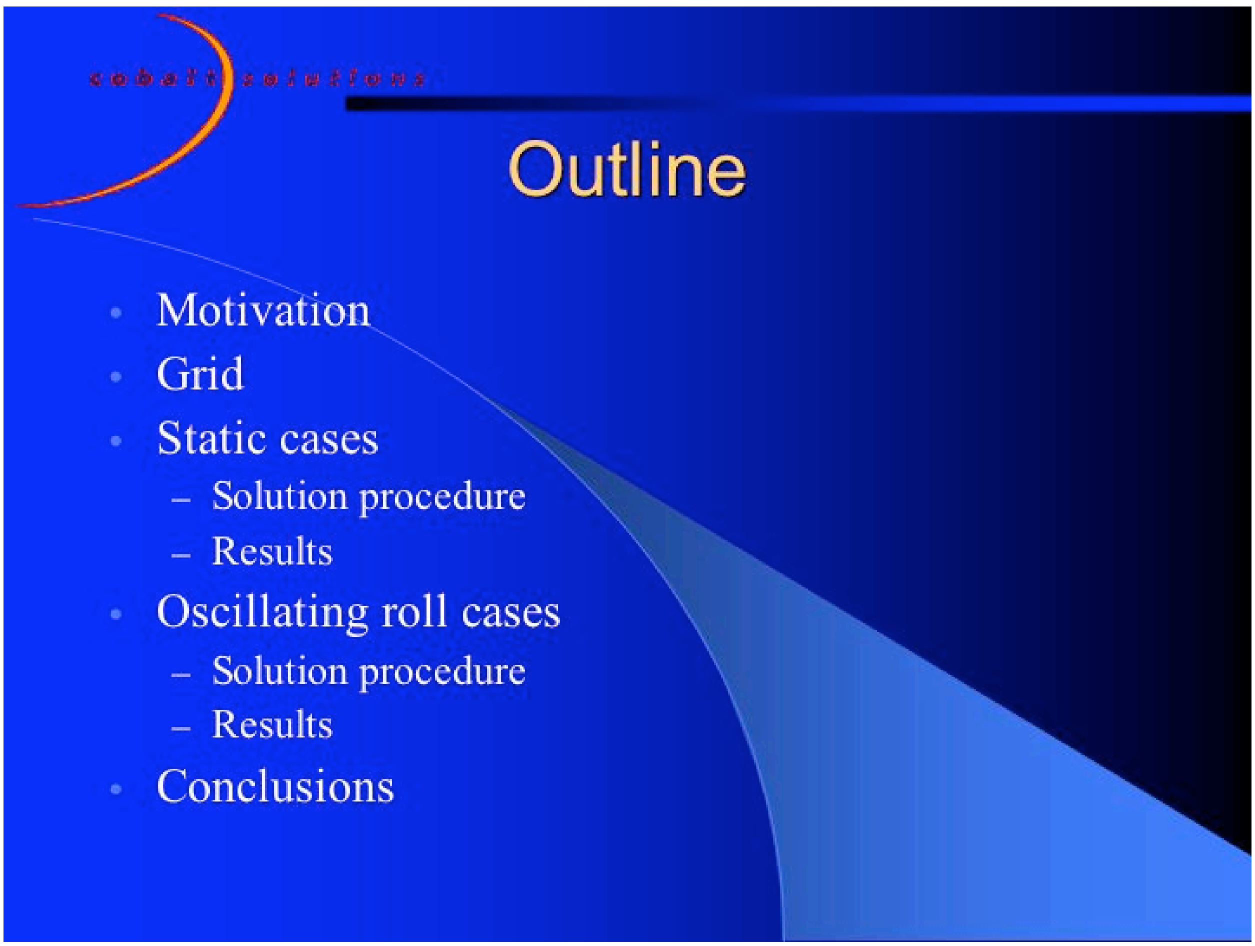
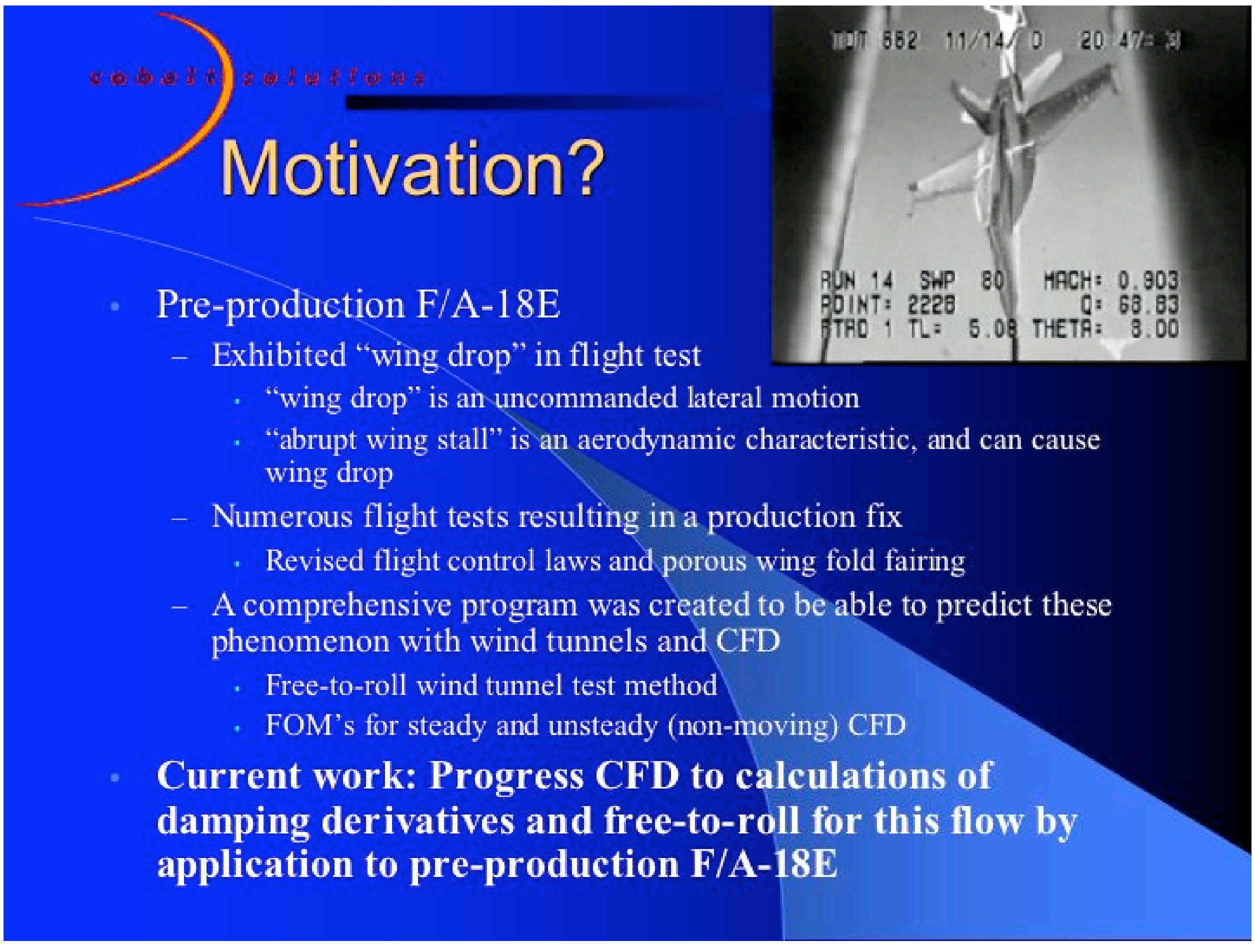
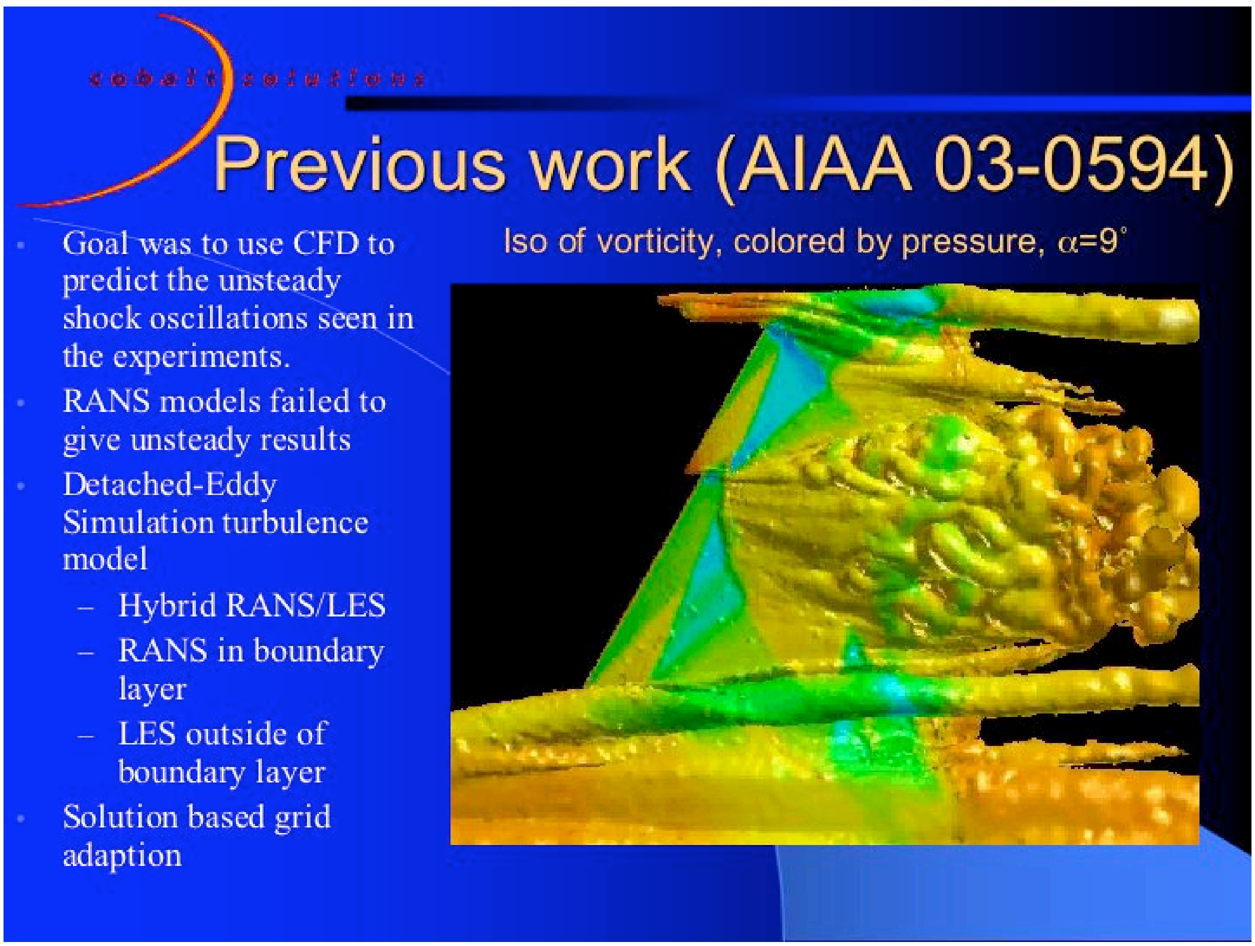
Acknowledgements: Joe Chambers, Paresh Parikh, Scott Morton (USAFA), ASC MSRC


cobalt solutions
Outline
Motivation
Grid
Static cases
Solution procedure
Results
Oscillating roll cases
Solution procedure
Results
Conclusions

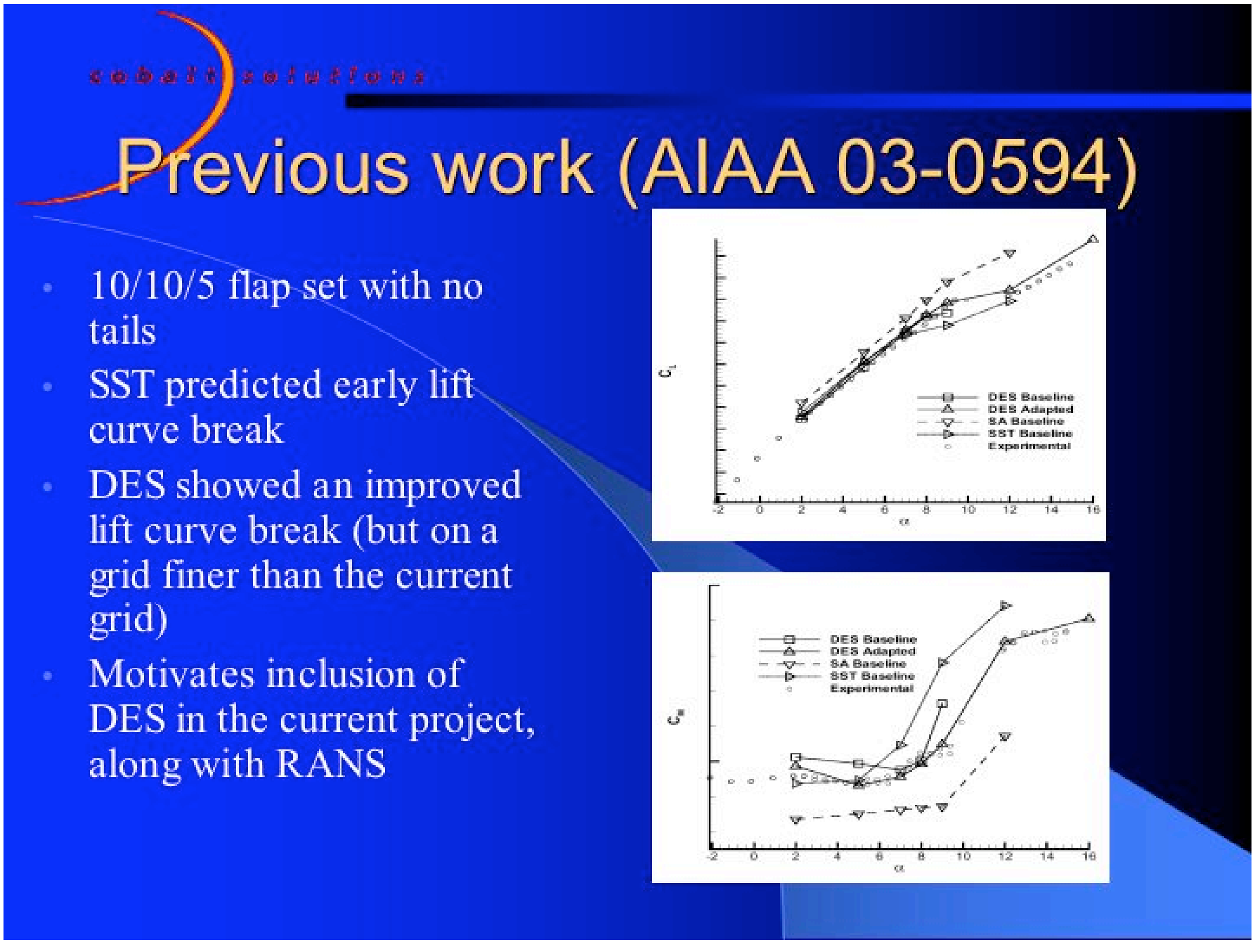
Previous work published at AIAA meeting in Reno 2003, and to be published in AIAA Journal of aircraft (FOM=Figure of Merit).



For DES, RANS is responsible for predicting boundary layer growth and separation. LES is responsible for predicting the geometry dependant turbulent flow features. Grid adaptation done using NASA Langley's RefineMesh program. Adaptation on time average of vorticity



DES results are time-averaged coefficients. Left axis removed to protect proprietary data.

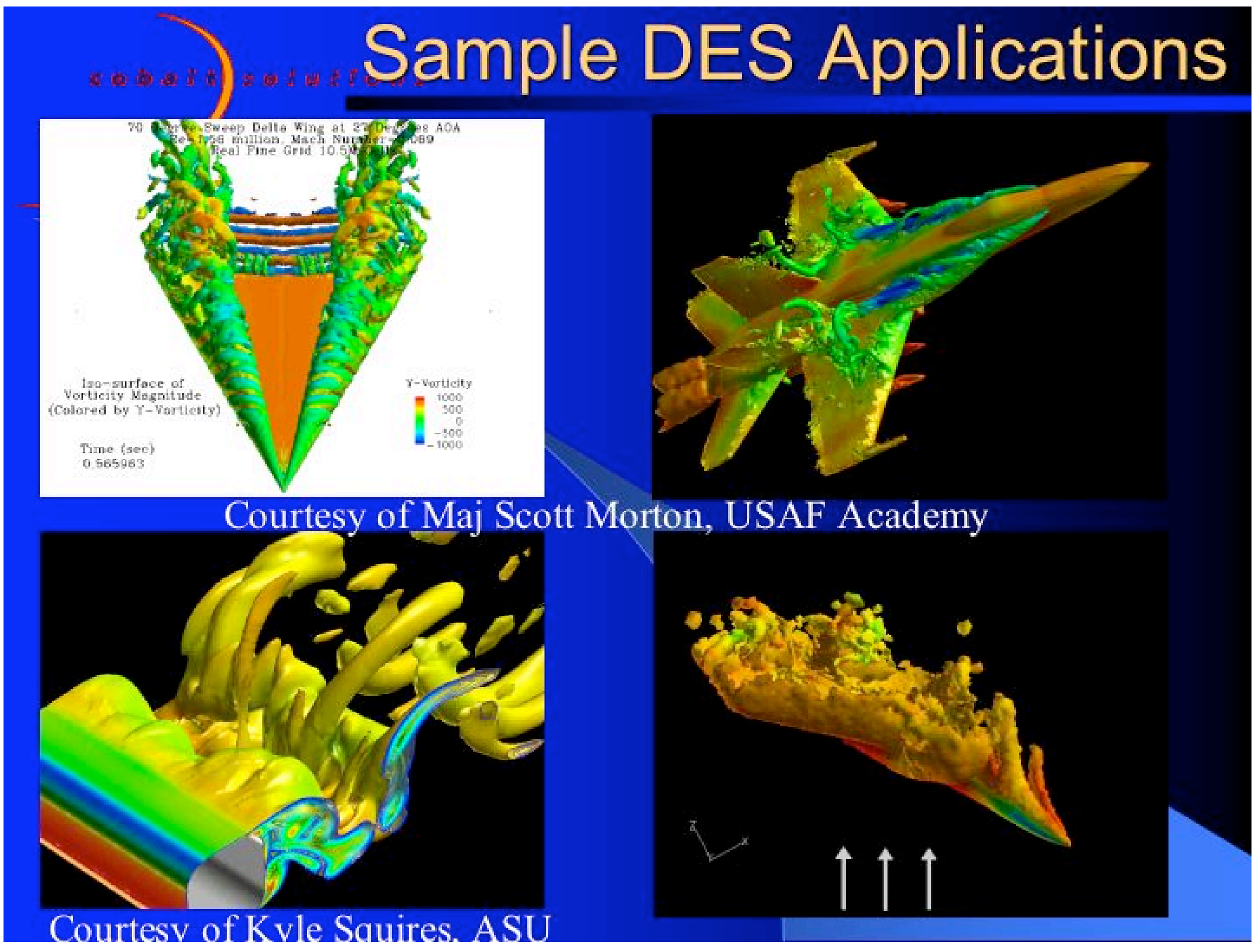


These DES projects represent a cross section of those done over the past few years using Cobalt.

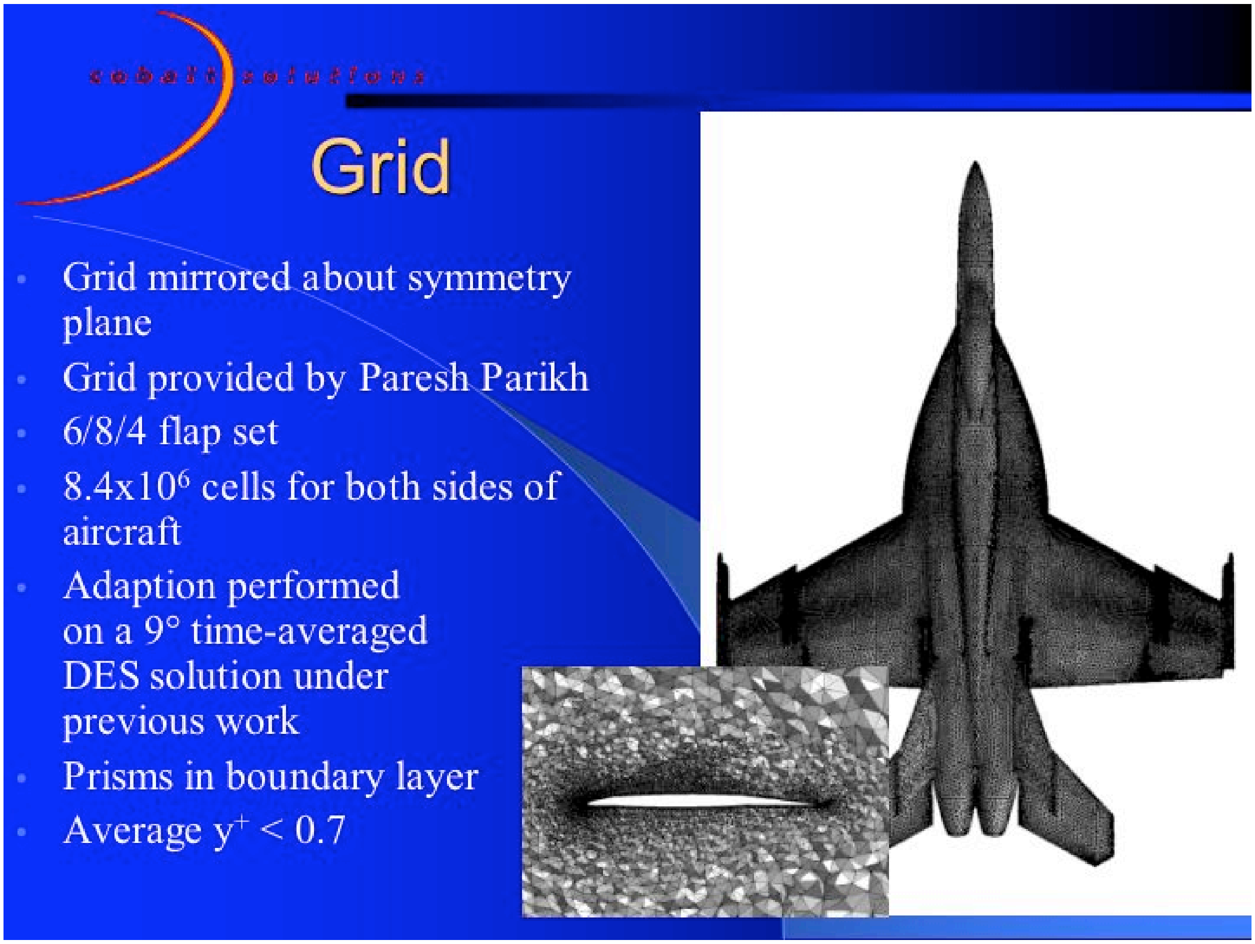
Delta wing vortex breakdown on a delta wing and the F-18C done by Major Scott Morton of the USAF Academy (Scott.morton@usafa.af.mil).

2-D forebody geometry by Kyle Squires (squires@asu.edu).

Prescribed spin of the F-15E by James Forsythe.

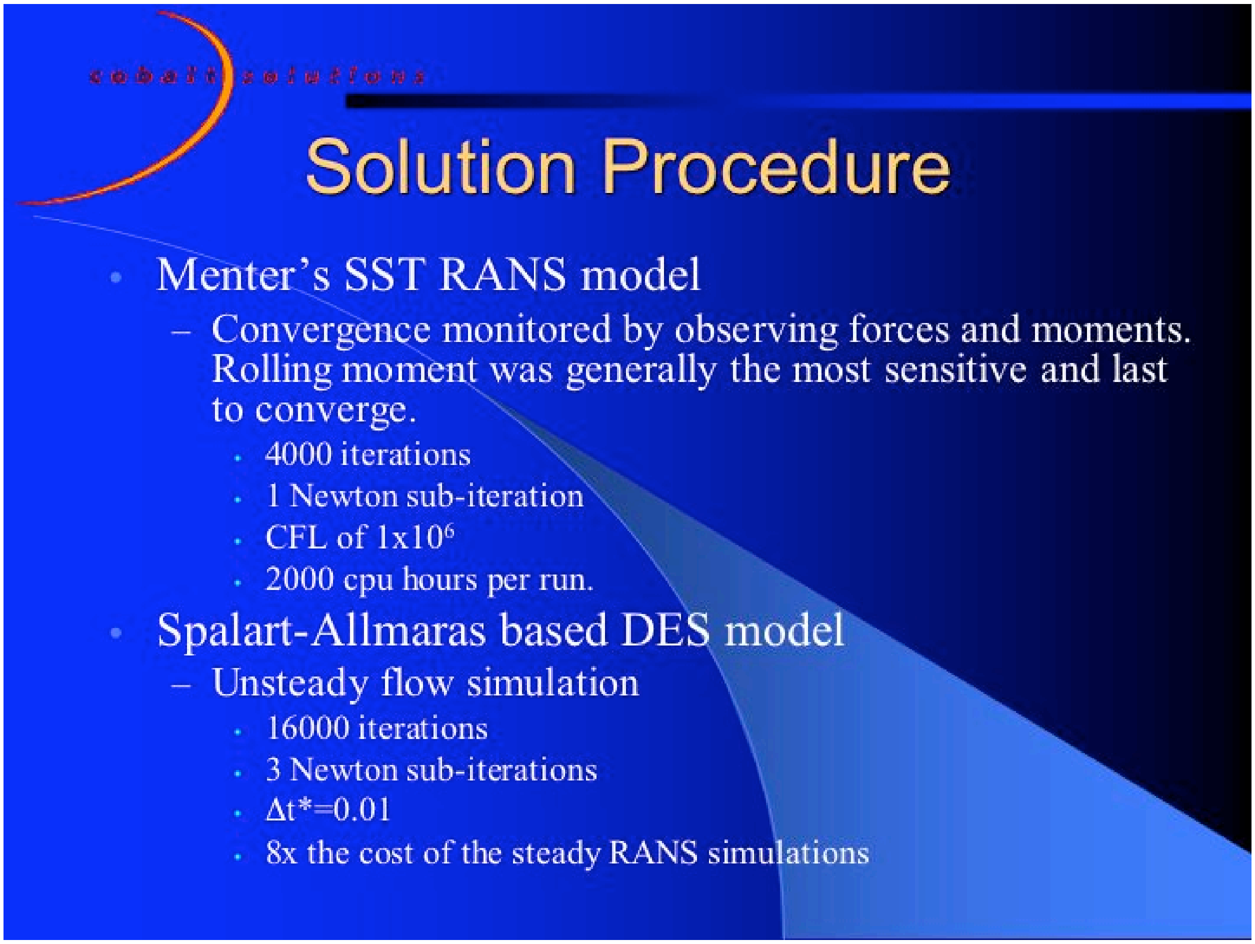


Prisms created using “Blacksmith” to recombine the tets in the boundary layer into prisms. Blacksmith is a Cobalt grid utility.

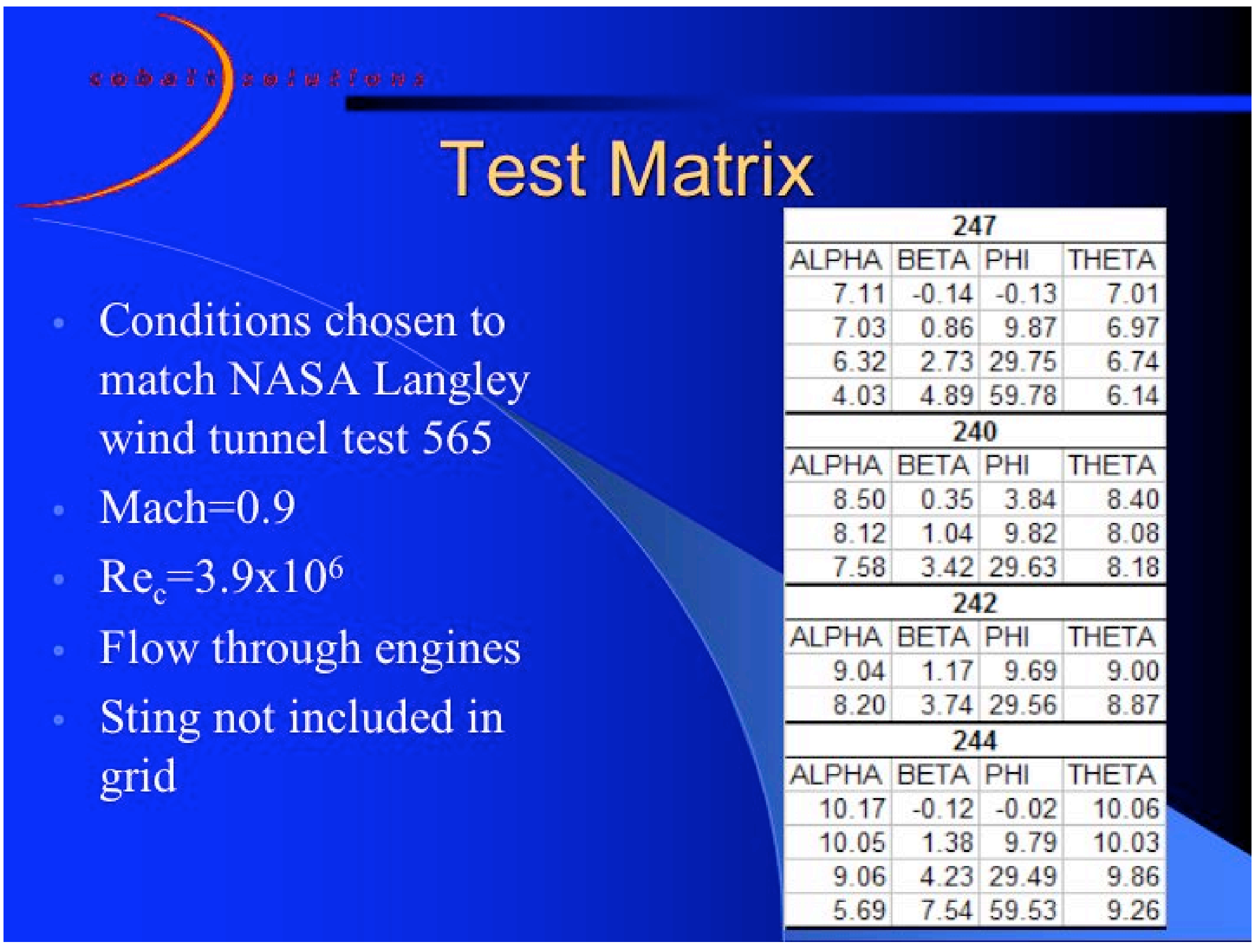


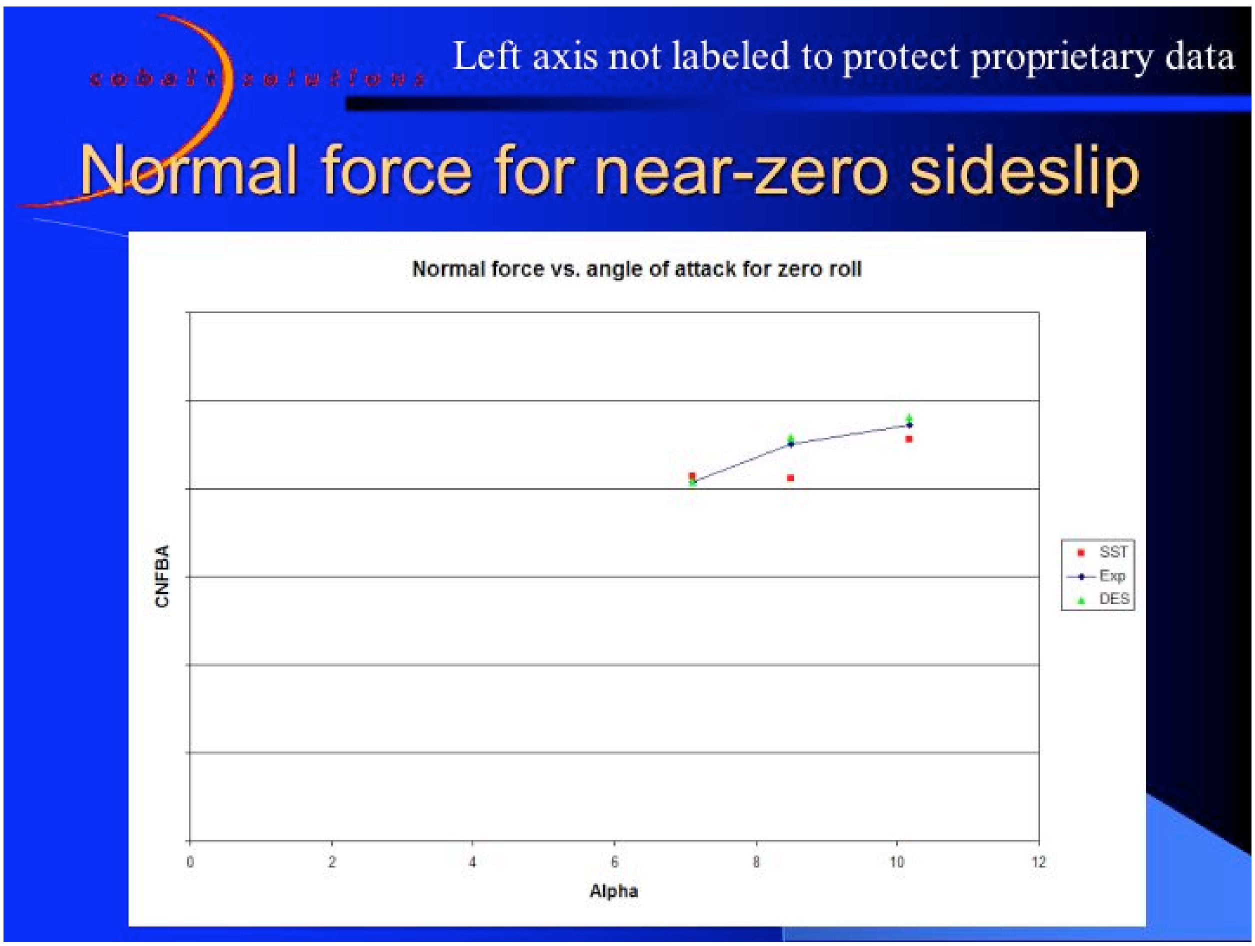
The following are non-moving cases – but can be unsteady (for DES)

CPU hours based on a Compaq ES45. Timestep for DES non-dimensionalized by chord and freestream velocity.

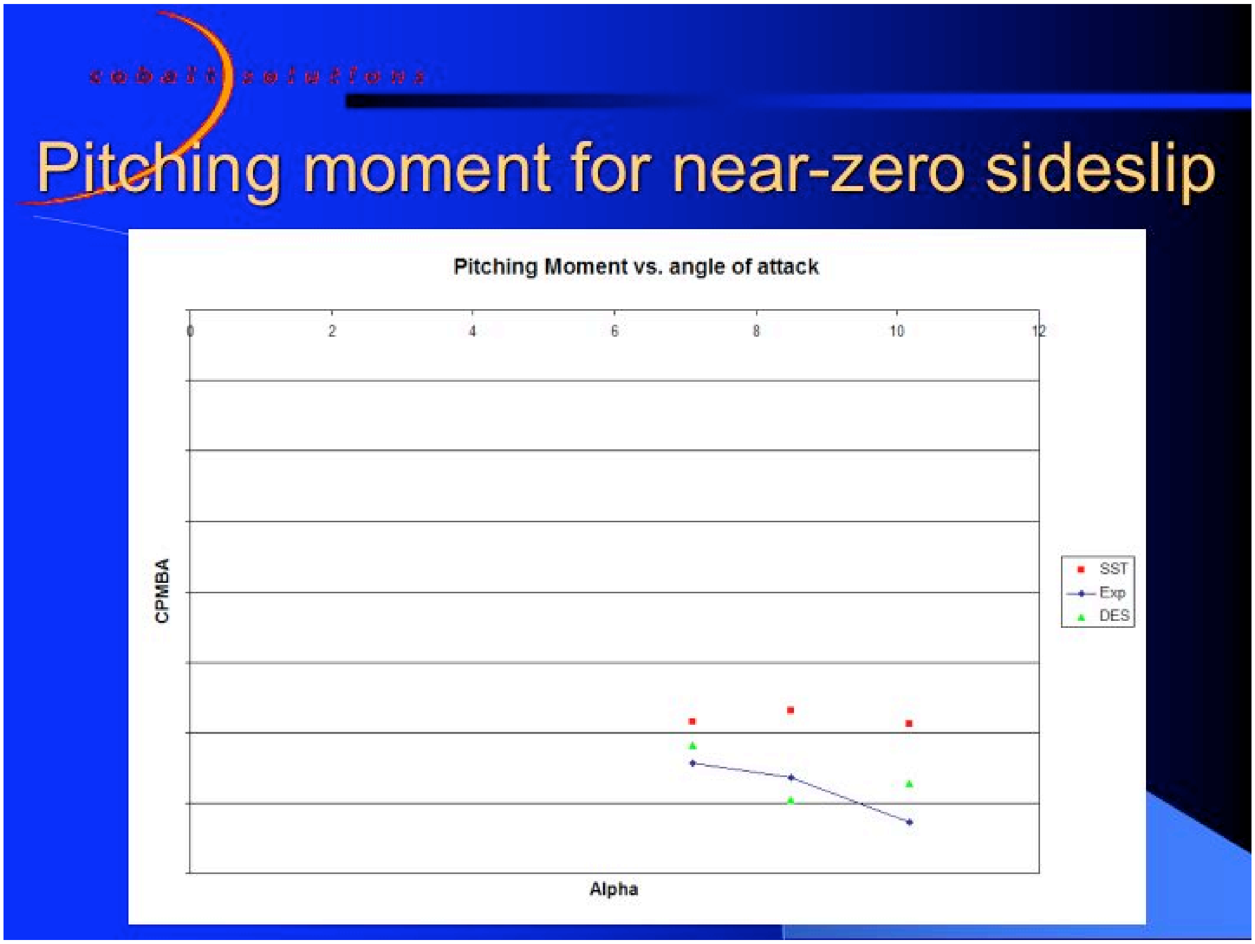


Model was set to a given pitch angle (theta), then rolled about the longitudinal axis (phi). This resulted in a decrease of alpha, and an increase in beta as phi increased. The CFD was performed at the given alphas and betas, which were corrected in the wind tunnel data for wall effects.

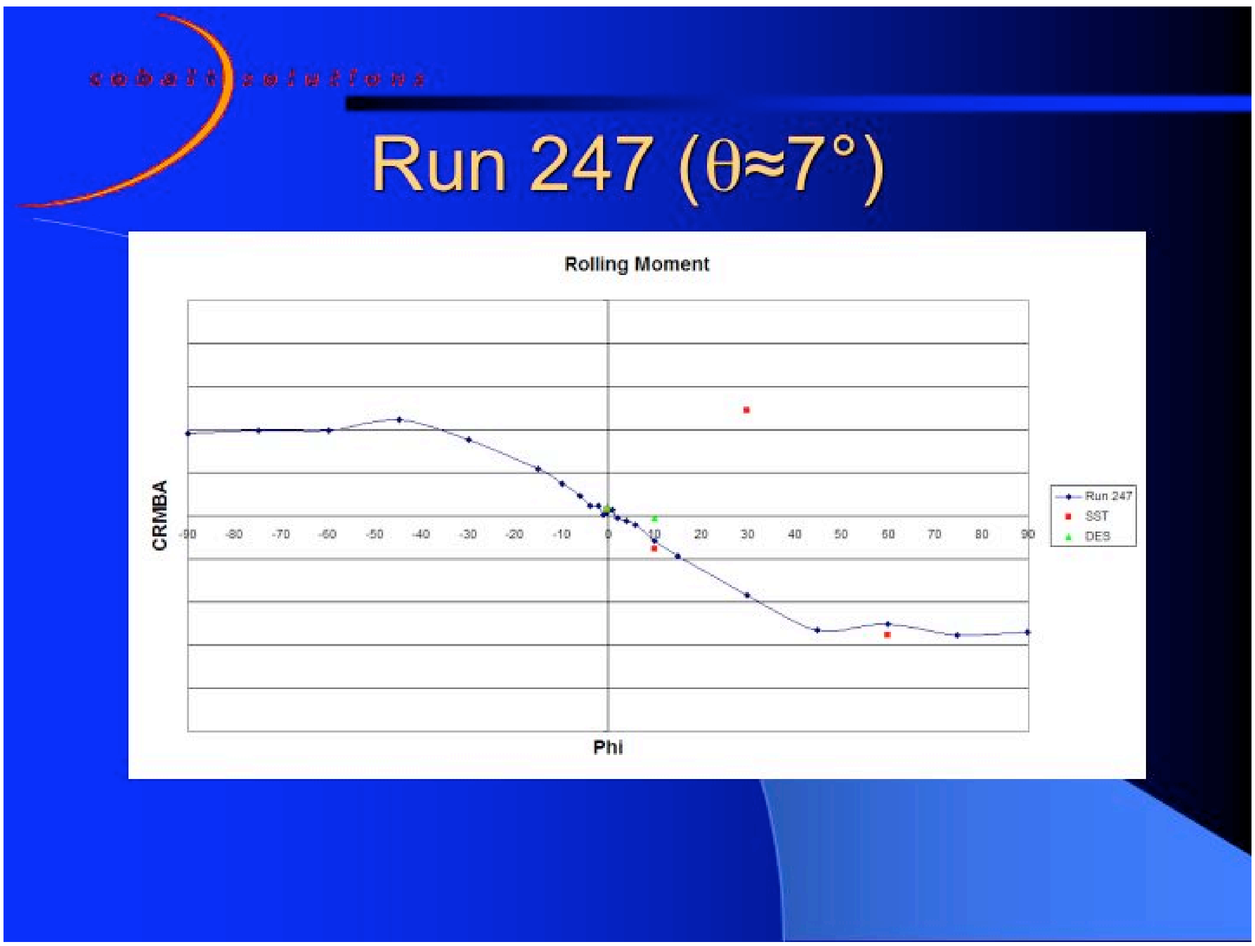




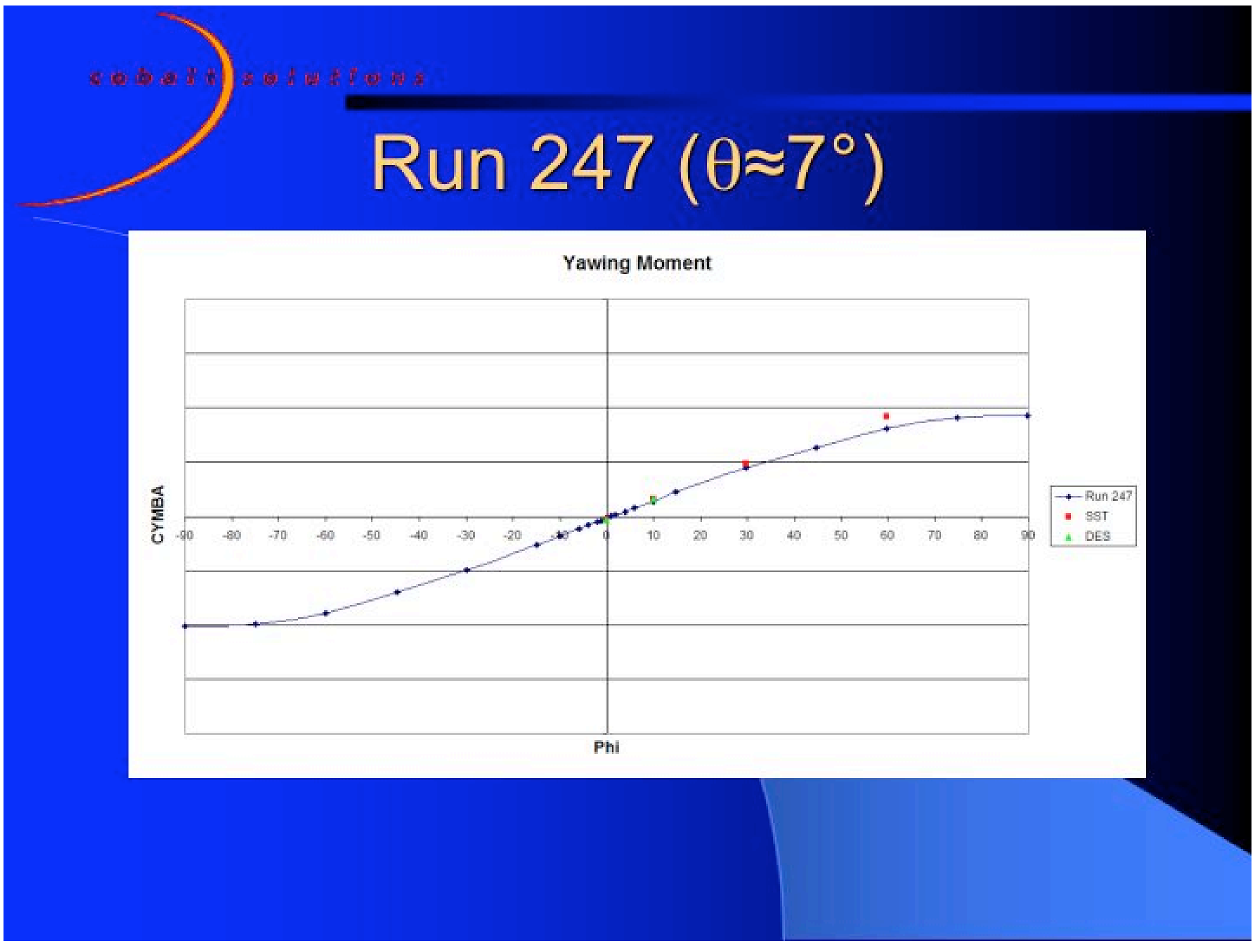
cobalt solutions
Left axis not labeled to protect proprietary data
Normal force for near-zero sideslip
Normal force vs. angle of attack for zero roll
CNFBA
0
2
4
6
8
10
12
Alpha
SST
Exp
DES


cobalt solutions
Pitching moment for near-zero sideslip
Pitching Moment vs. angle of attack
0
2
4
6
8
10
12
CPMBA
Alpha
SST
Exp
DES

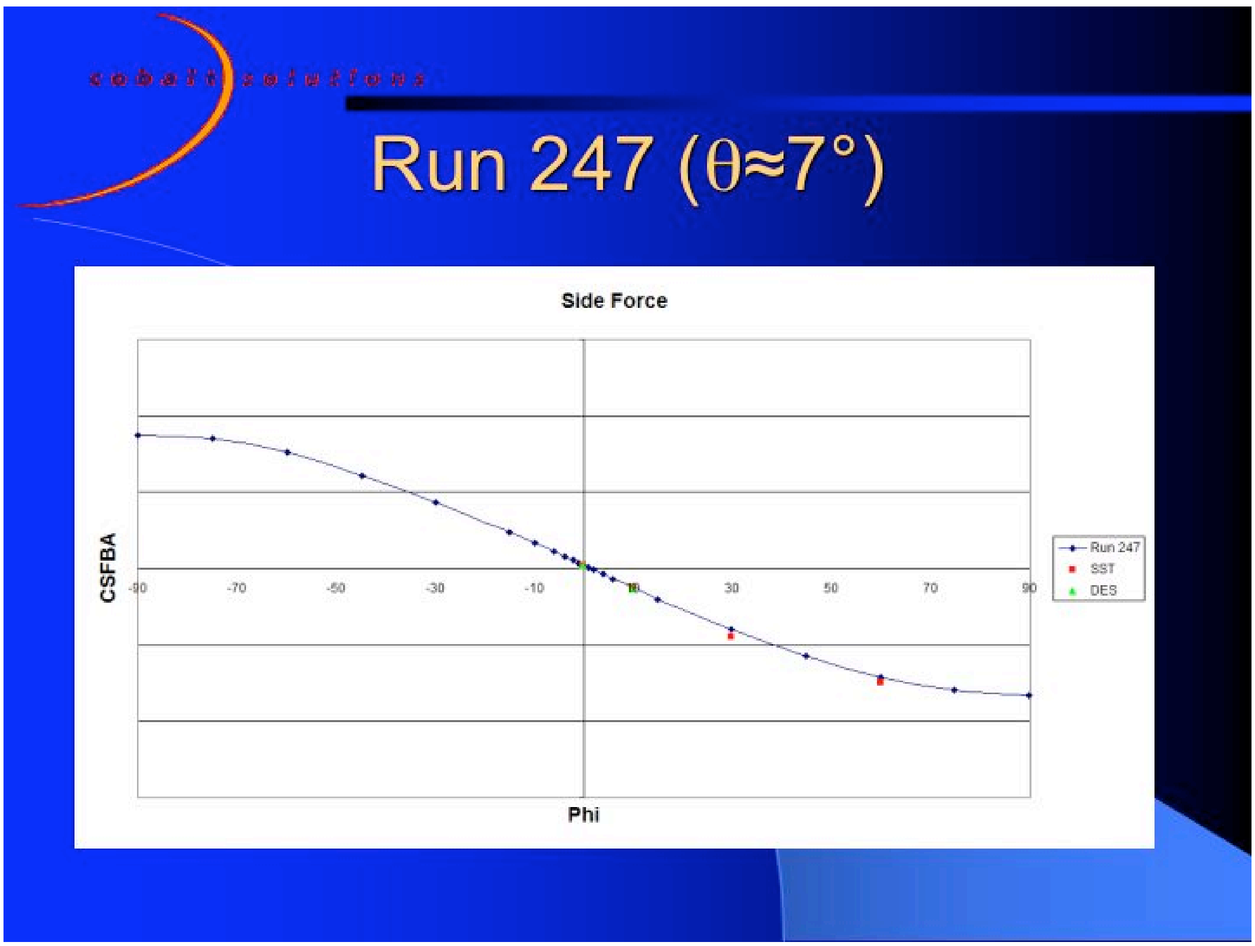
Note reversal of rolling moment for phi=30 using SST.



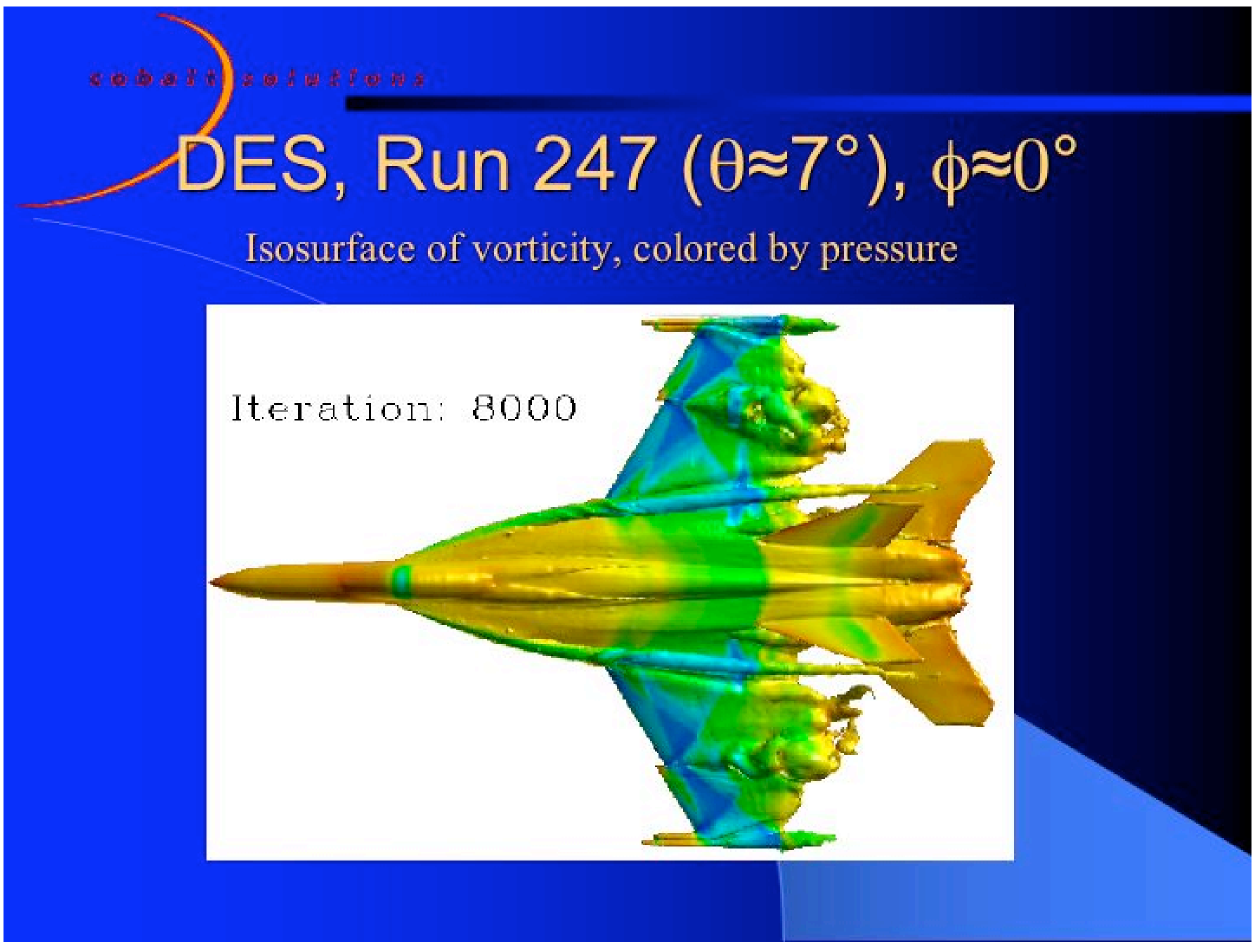
Yawing moment well predicted – as with all cases.



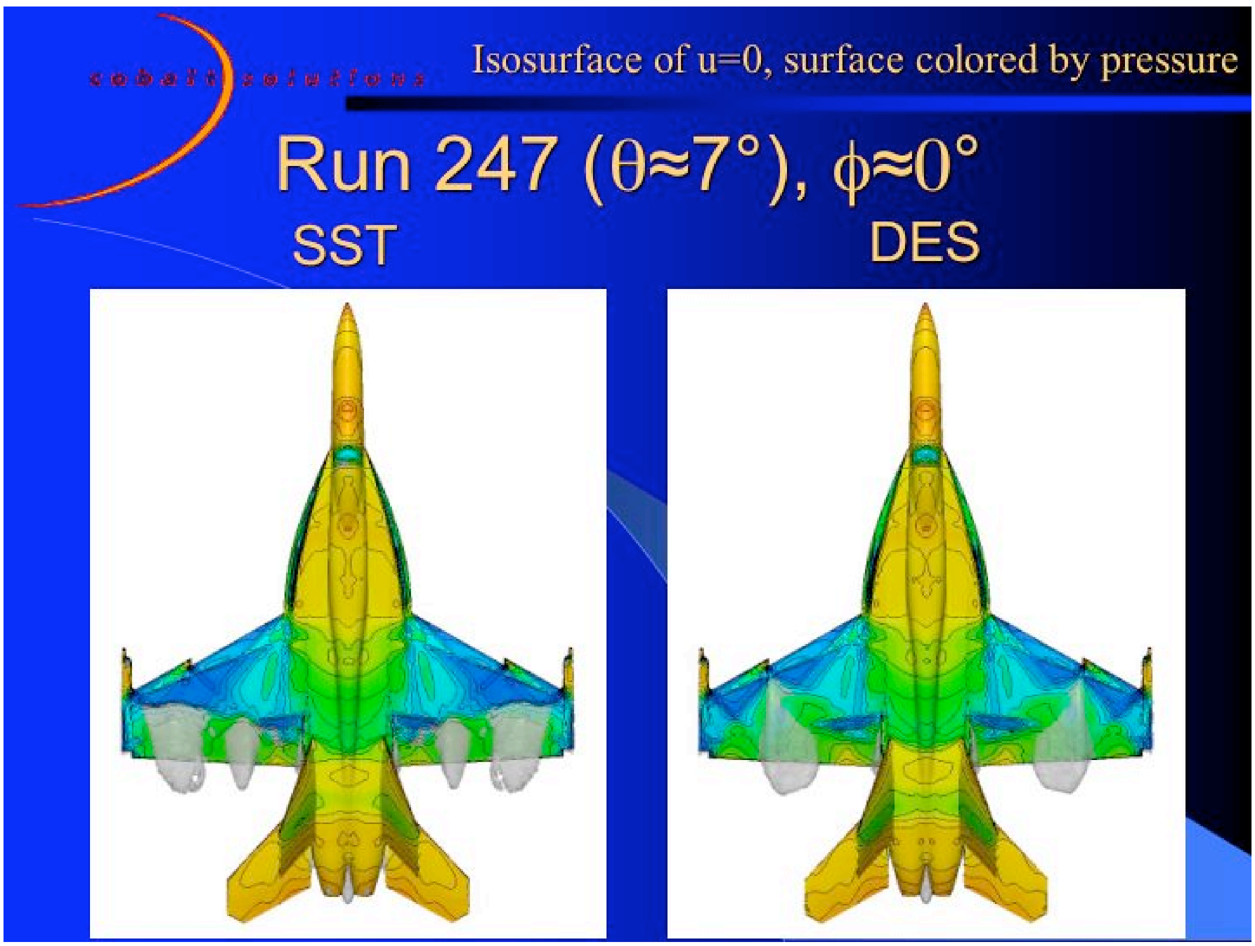
Side force well predicted – as with all cases.

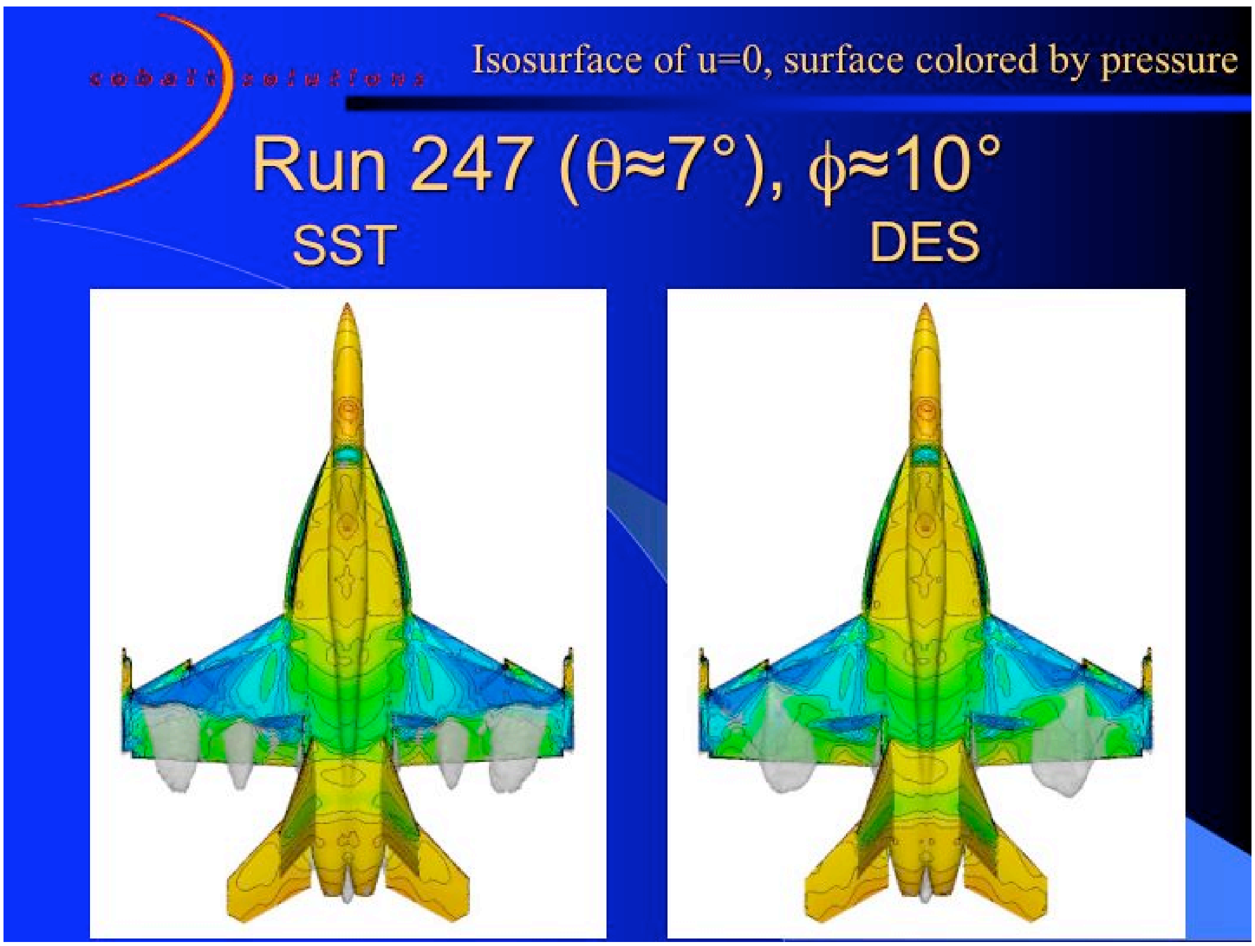


Shock retreating off trailing edge of leading edge flap.

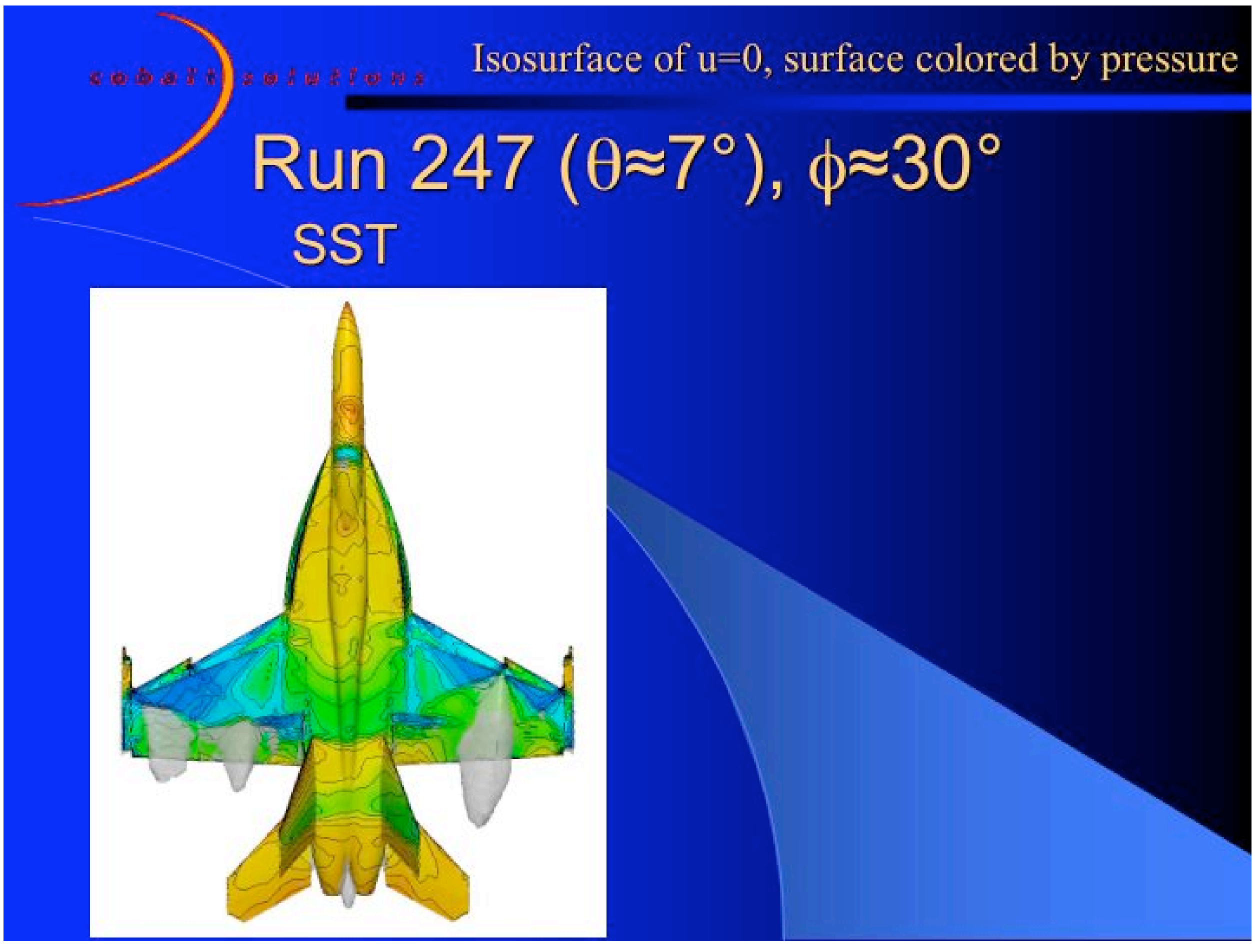


DES isosurface looks like separation is at trailing of leading edge flap. But it moves back from there unsteadily. This leads to the blue low pressure in the separation bubble (since it is not always separated).

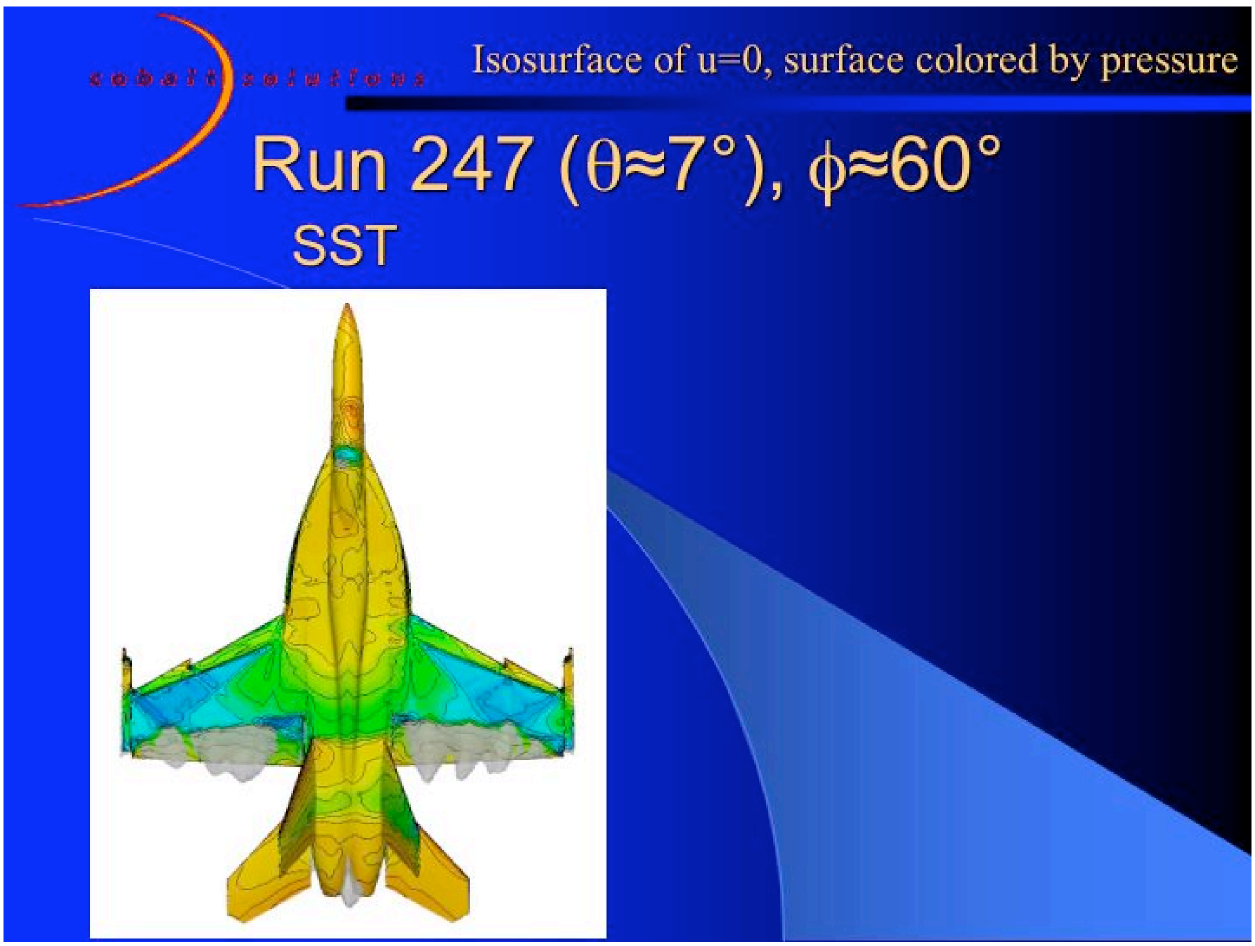



cobalt solutions
Isosurface of u=0, surface colored by pressure
Run 247 (θ≈7°), φ≈10°
SST
DES

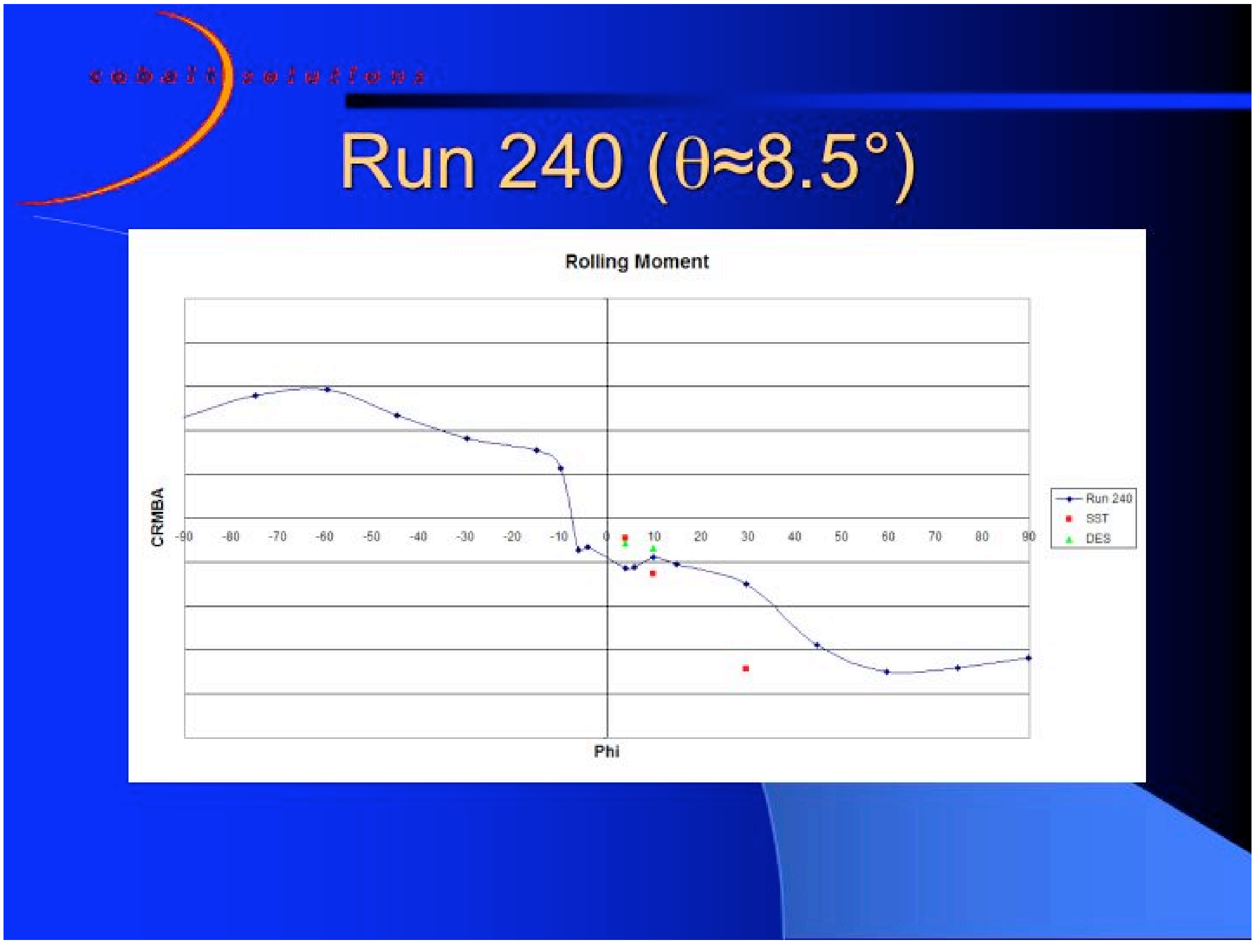
The separation moving forward on the right wing is the cause for the roll moment reversal.



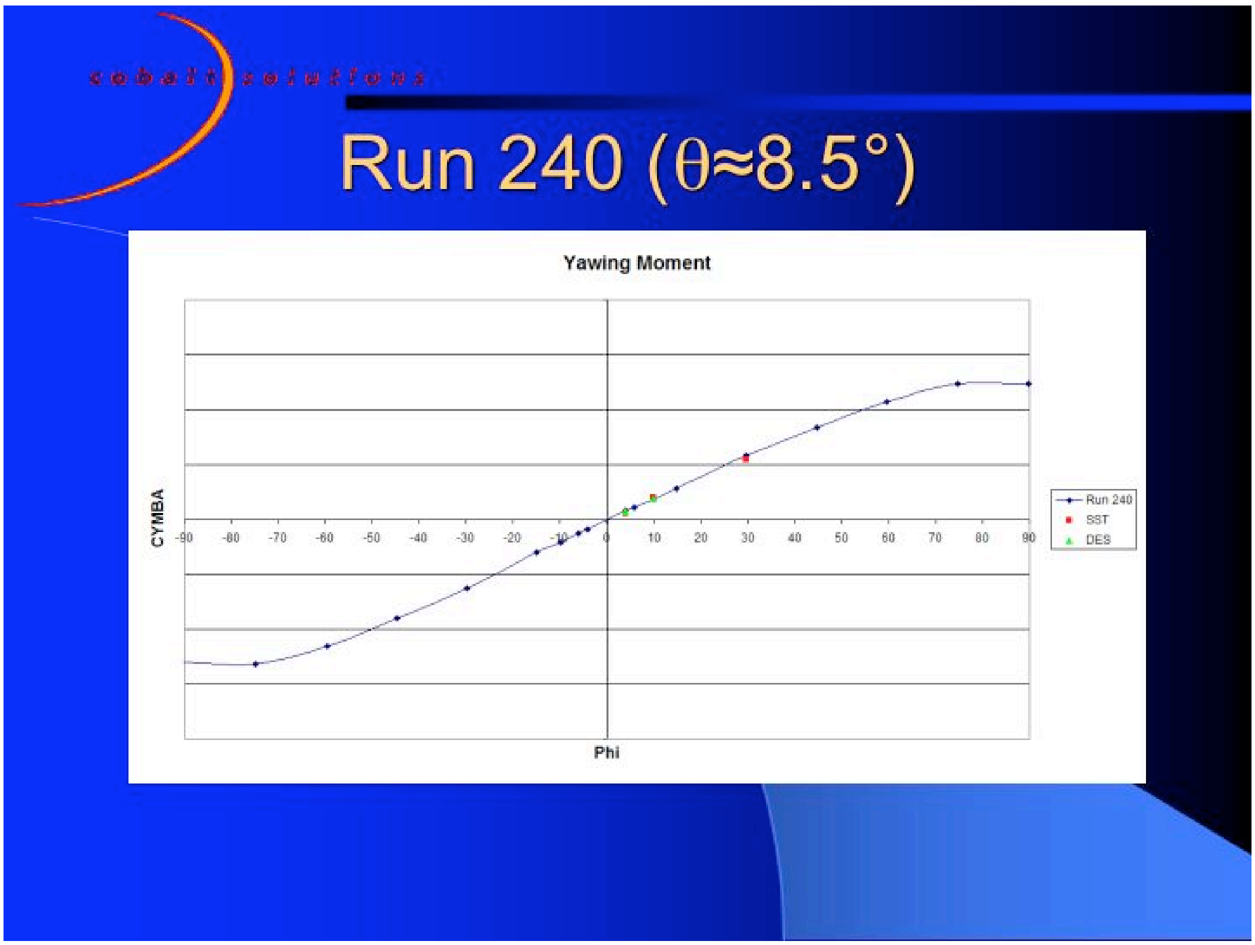
At this high phi, the alpha is reduced so much that the flow remains attached until the trailing edge of the wing.



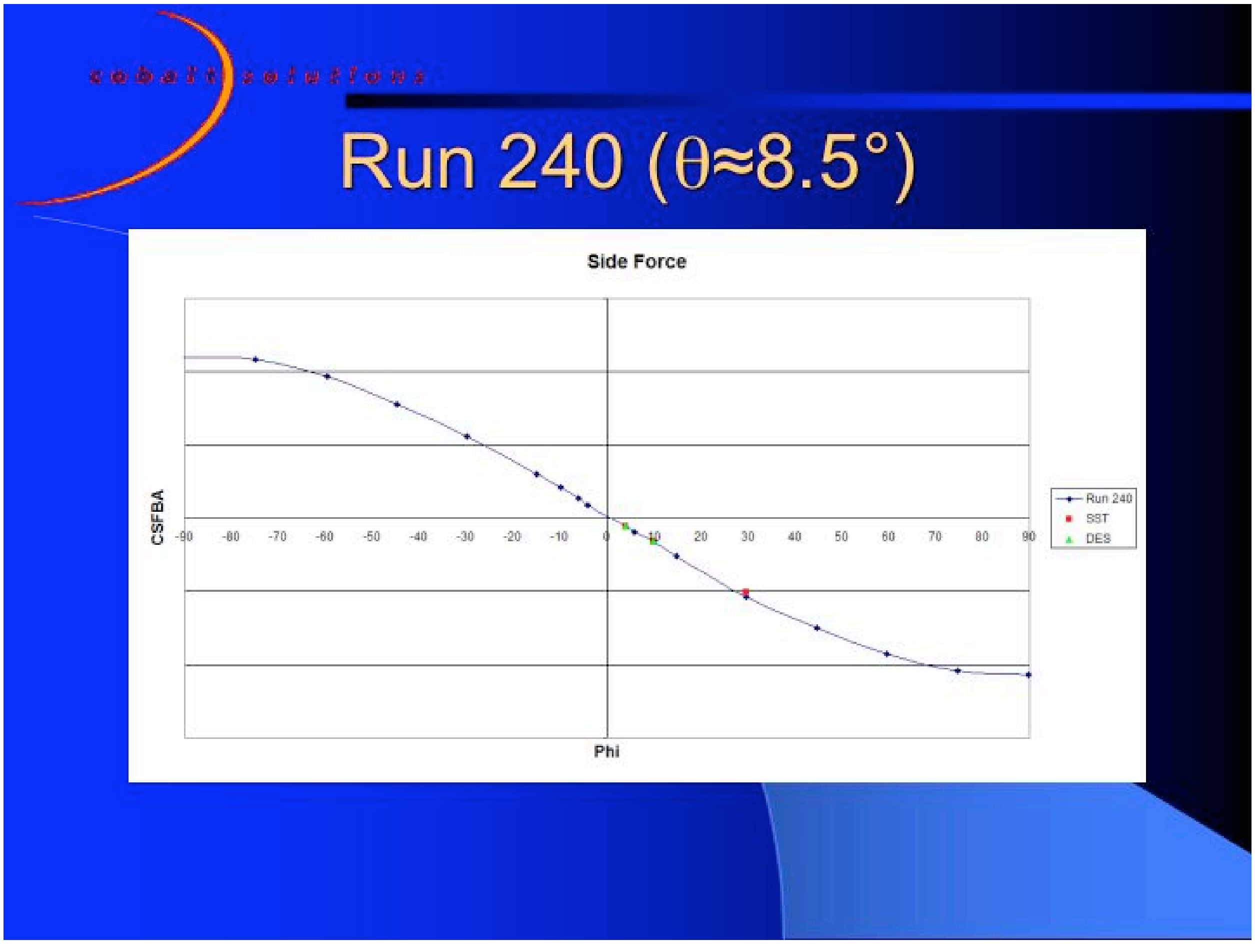
Note asymmetries in wind tunnel data. Decrease in lateral stability derivative picked up with DES.



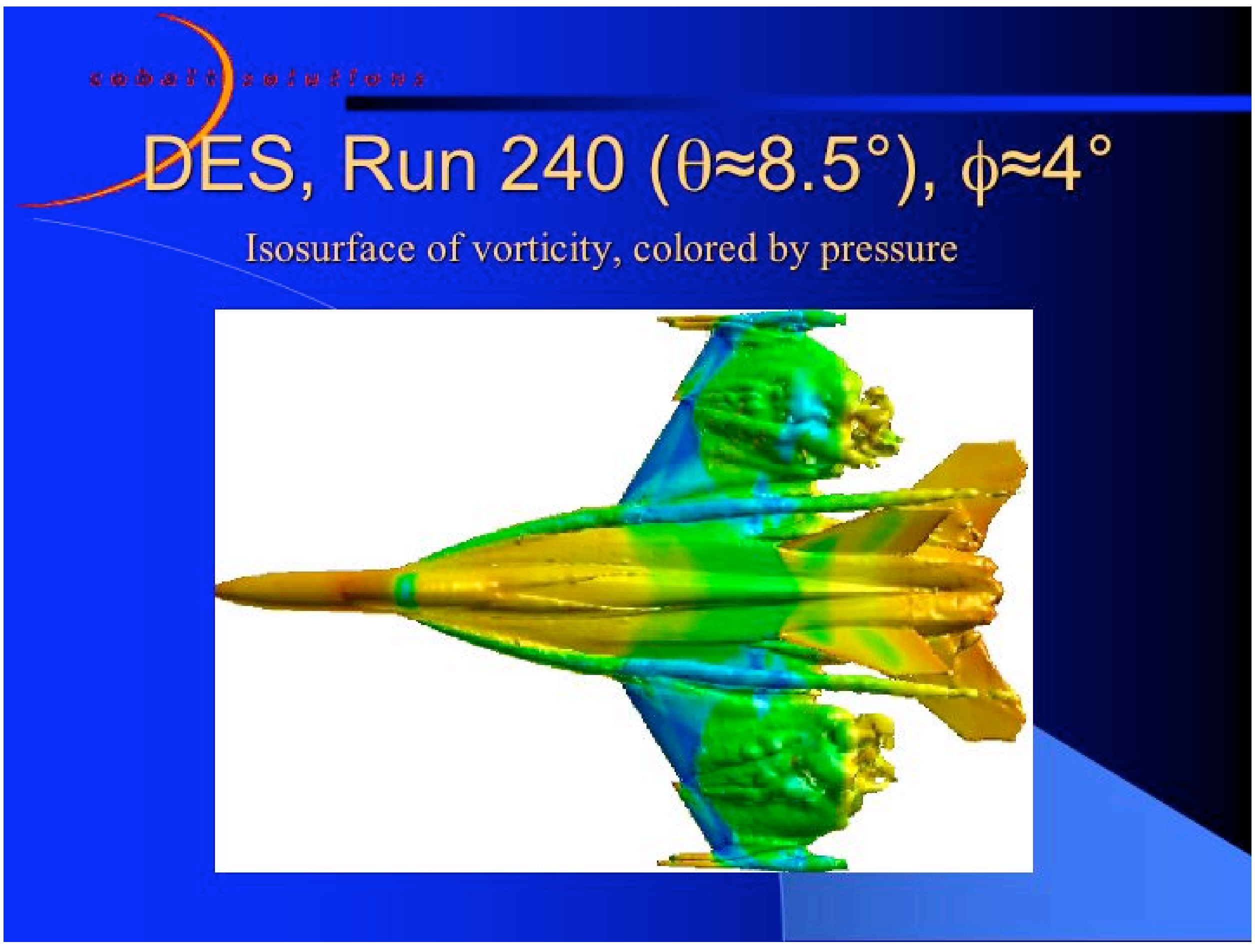
Good agreement for yawing moment, as with all cases – this is likely due to the attached flow at the tail, which is easily predicted.

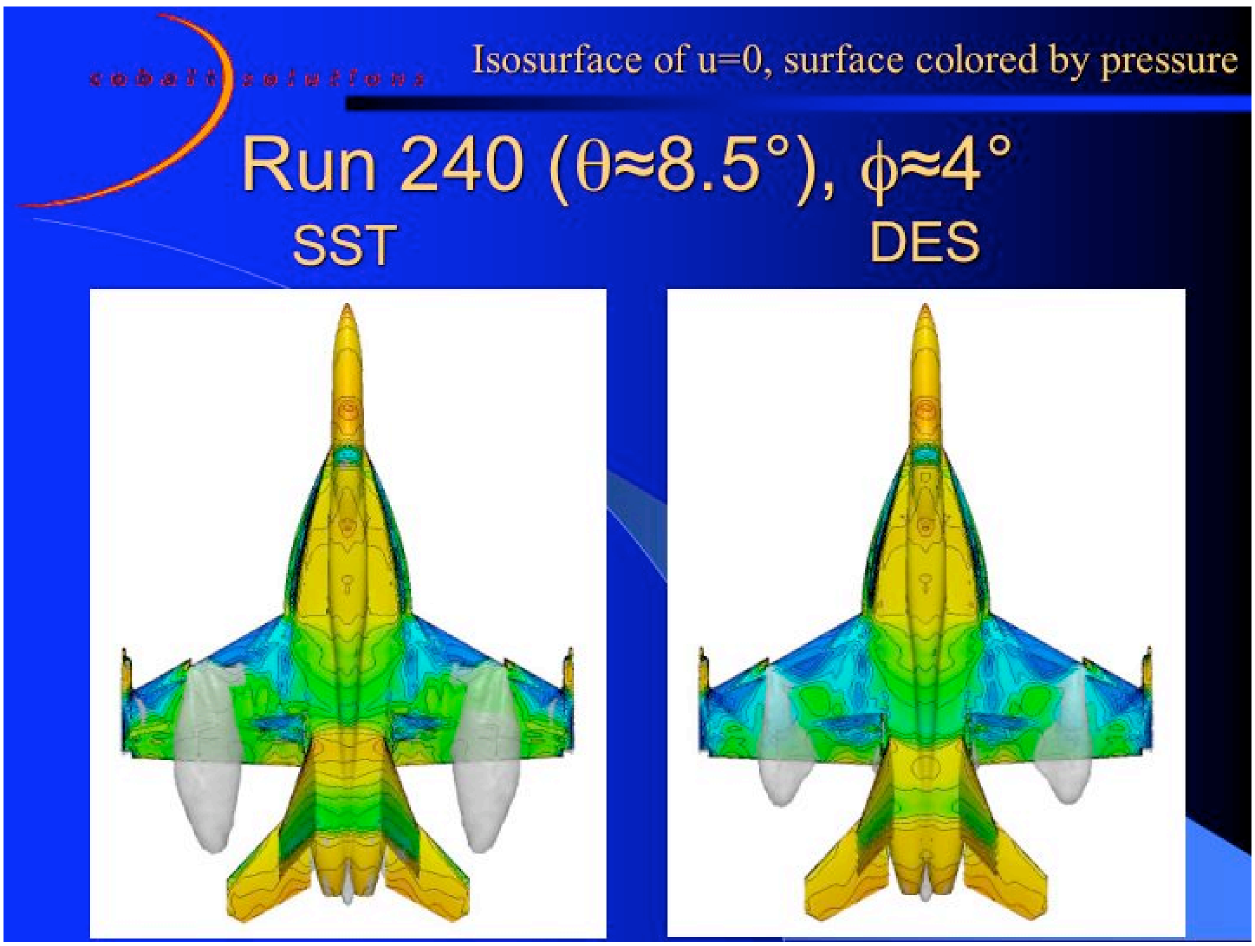


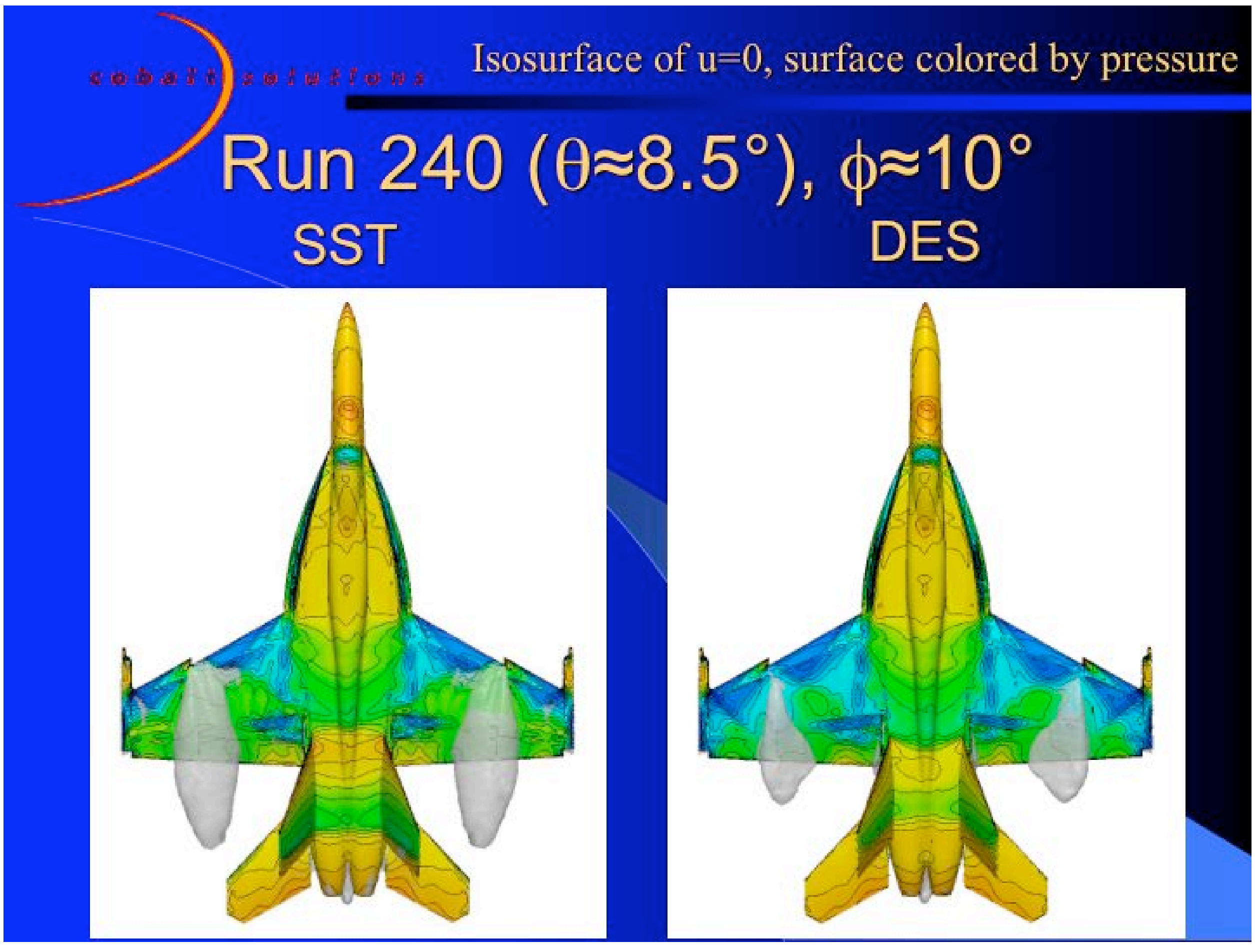
Good agreement for side force, as with all cases – this is likely due to the attached flow at the tail, which is easily predicted.

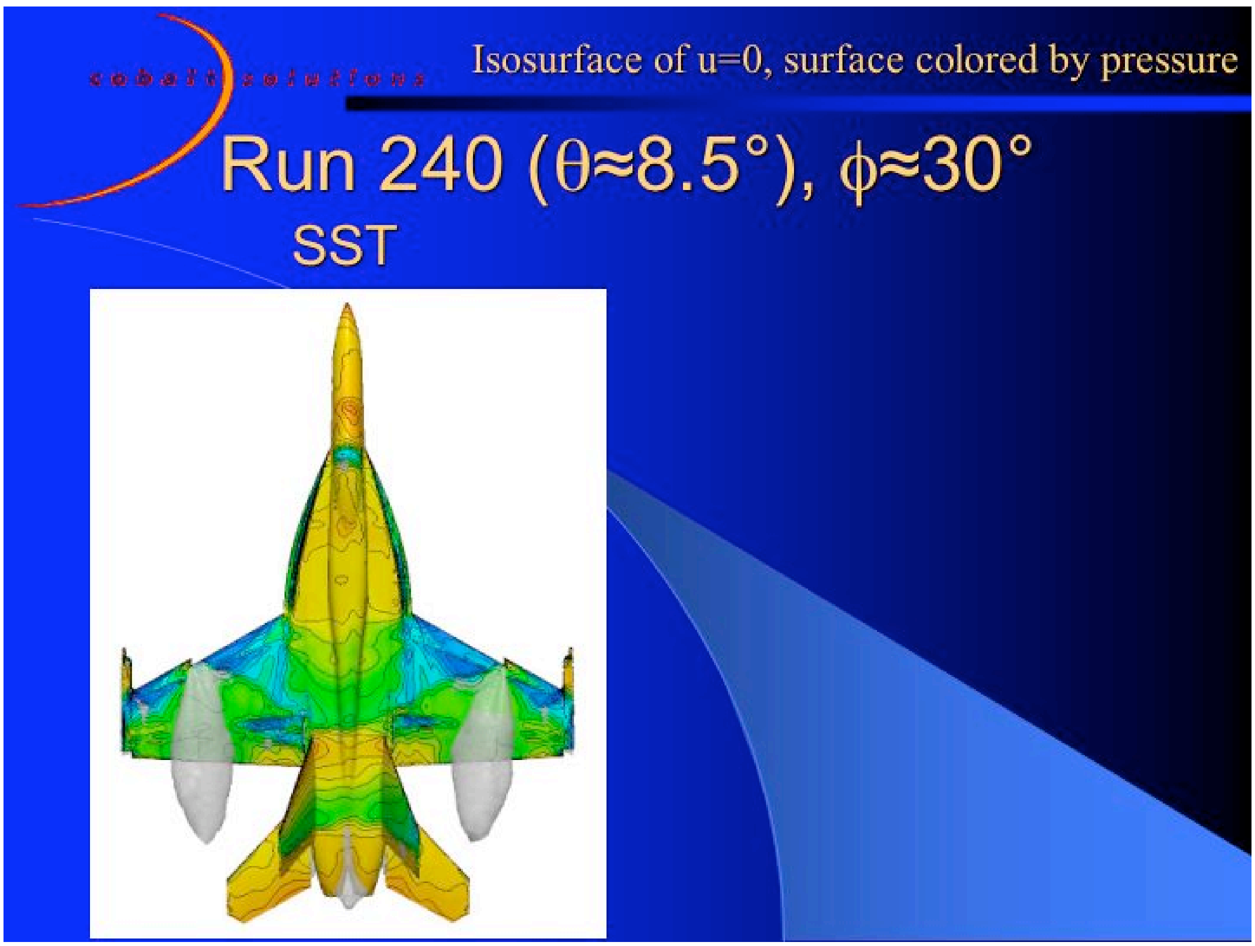


Separation is making it onto the leading edge of the leading edge flap.



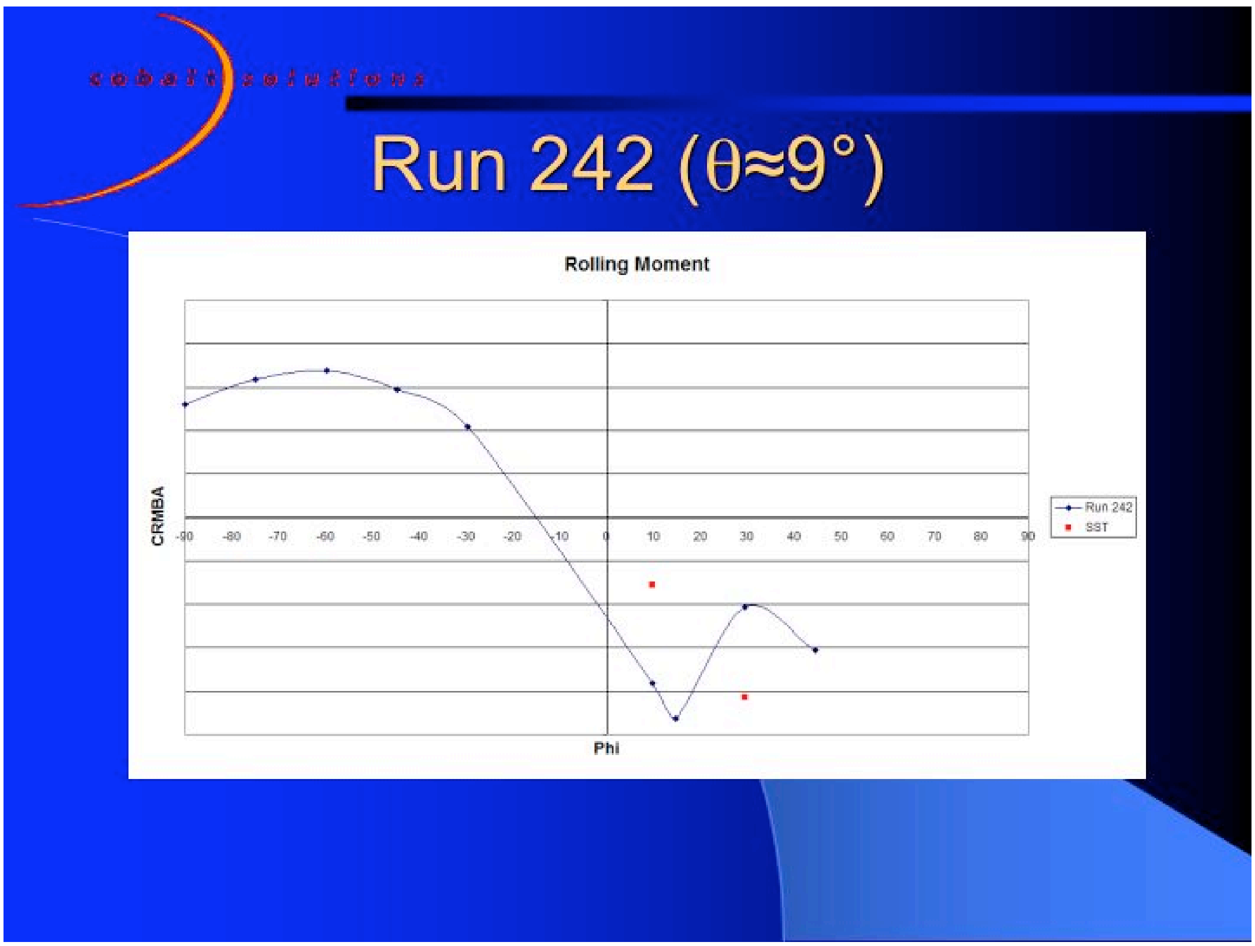

cobalt solutions
Isosurface of u=0, surface colored by pressure
Run 240 (θ≈8.5°), φ≈4°
SST
DES


cobalt solutions
Isosurface of u=0, surface colored by pressure
Run 240 (θ≈8.5°), φ≈10°
SST
DES

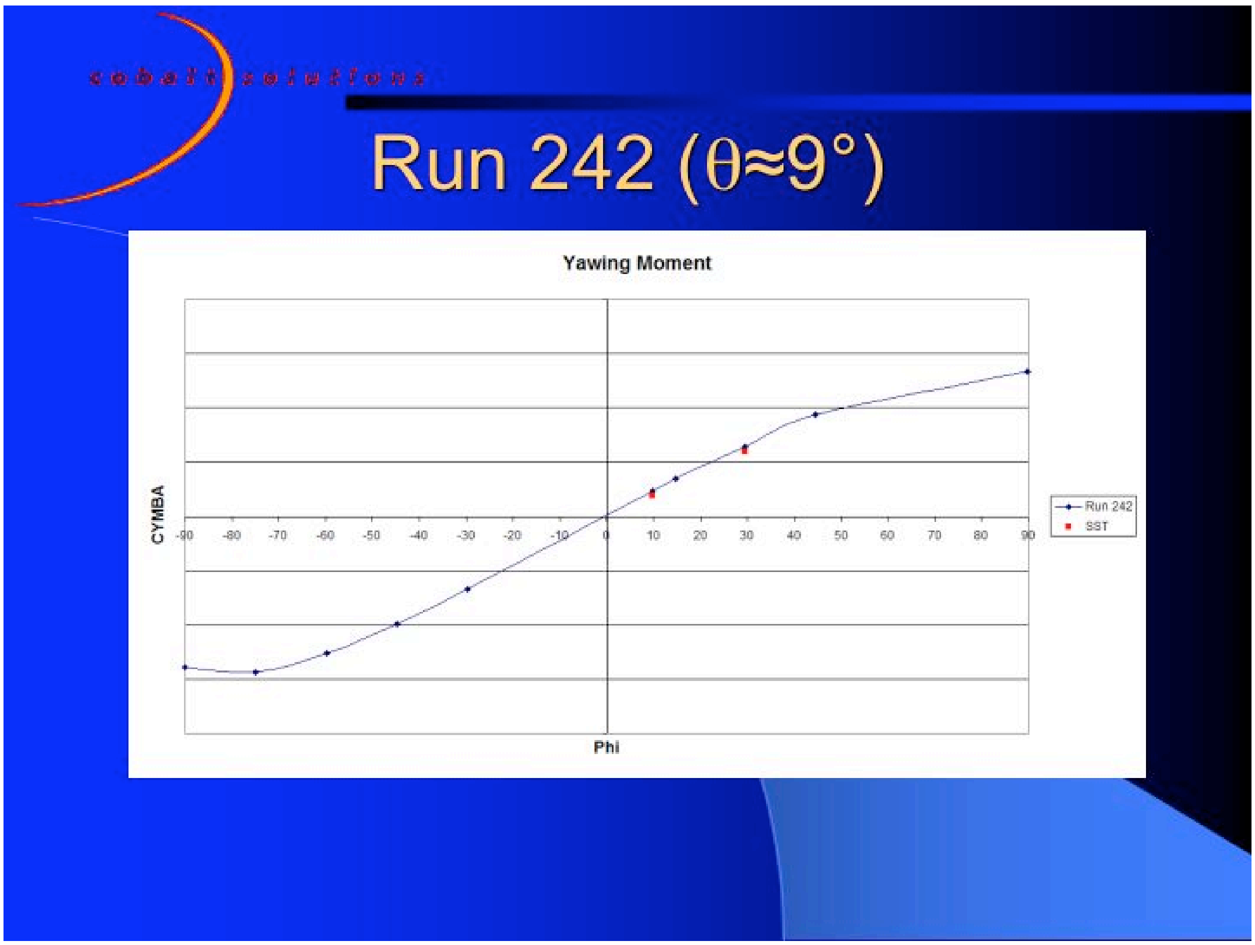


cobalt solutions
Isosurface of u=0, surface colored by pressure
Run 240 (θ≈8.5°), φ≈30°
SST

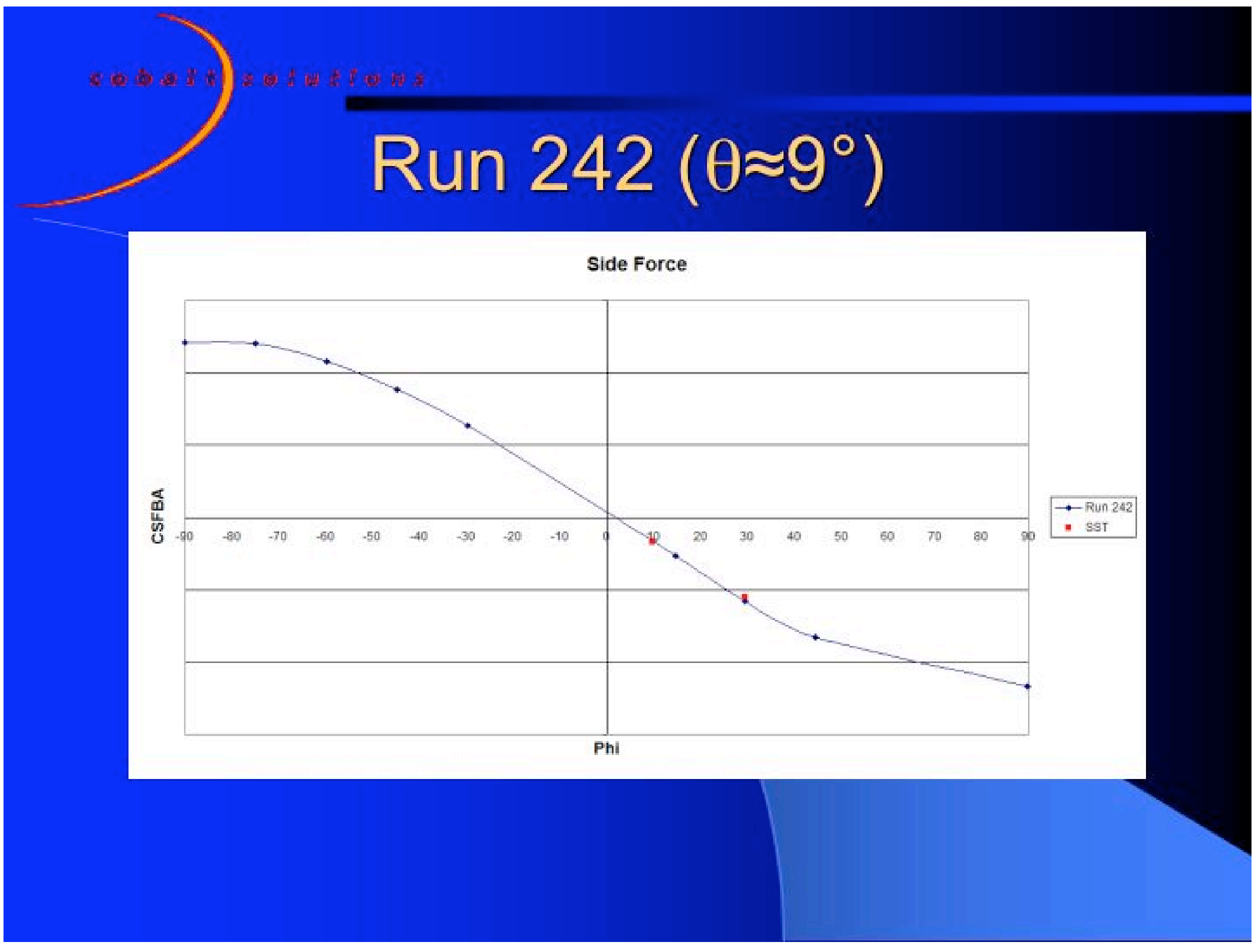
Large asymmetries in wind tunnel data. Around this angle there was difficulty in testing, since model dynamics became significant.



Good agreement for yawing moment, as with all cases.



Good agreement for side force, as with all cases.

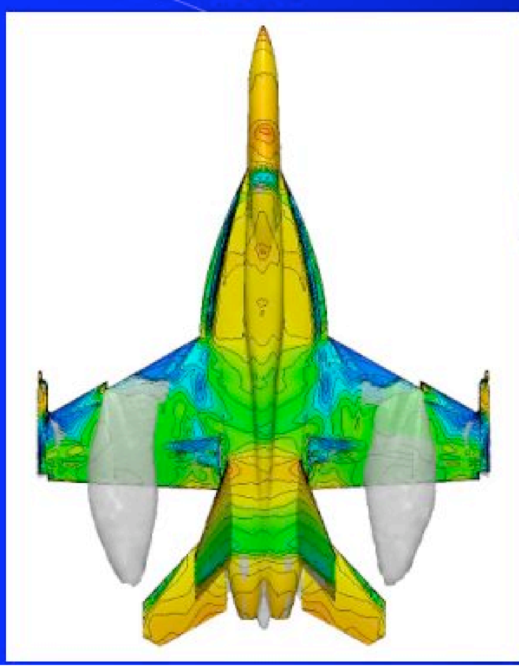


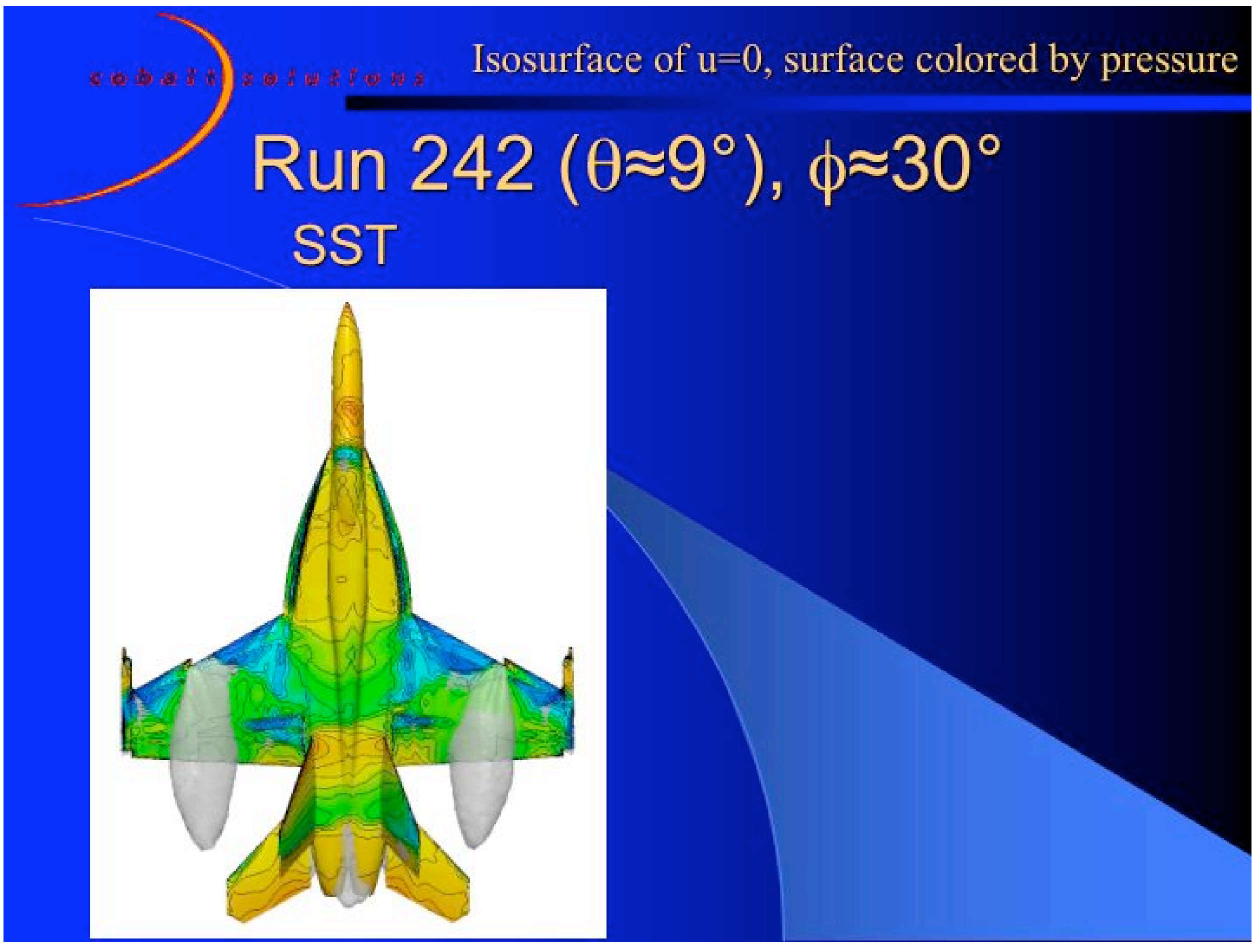
cobalt solutions

Isosurface of u=0, surface colored by pressure

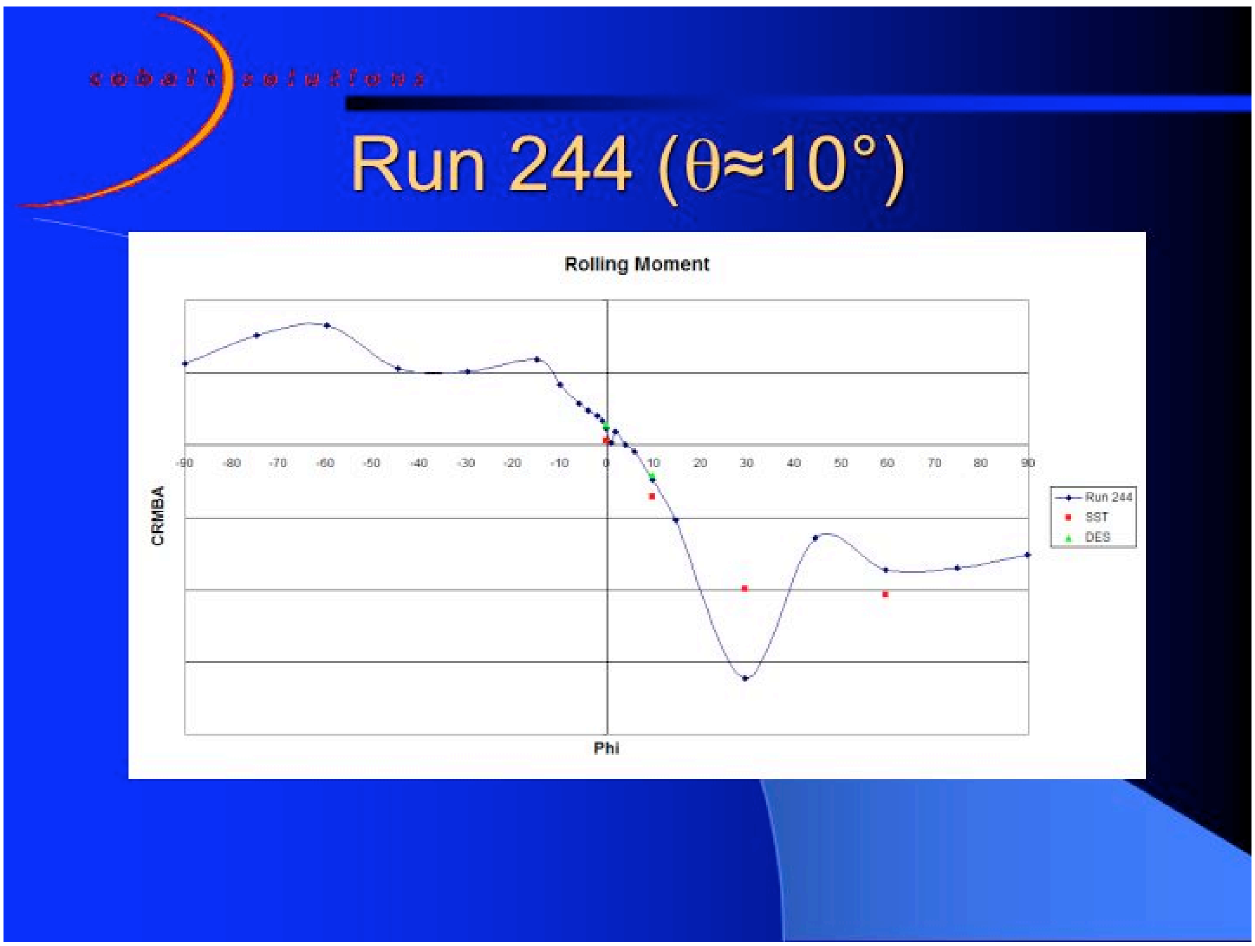
Run 242 ($\theta \approx 9°$), $\phi \approx 10°$

SST

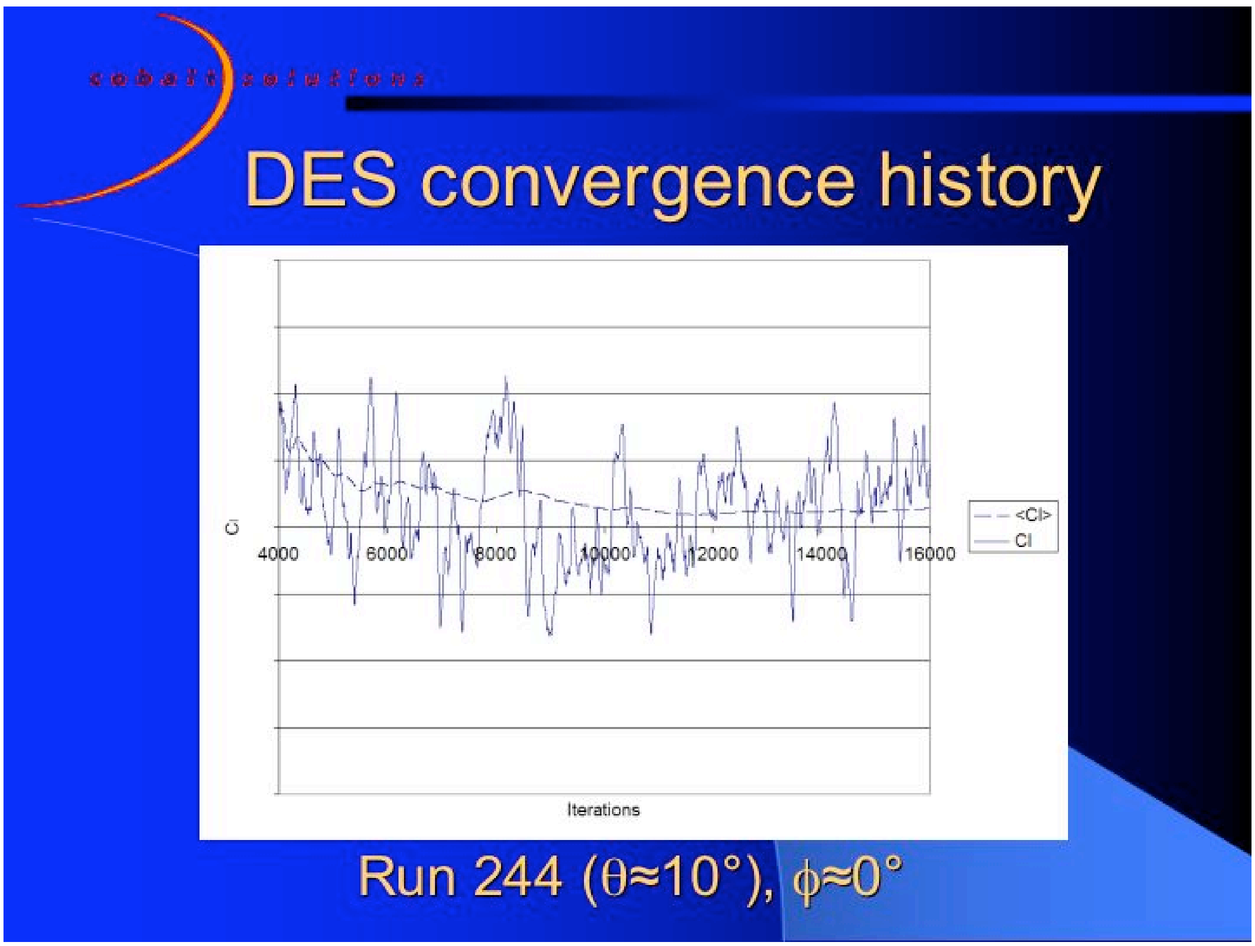


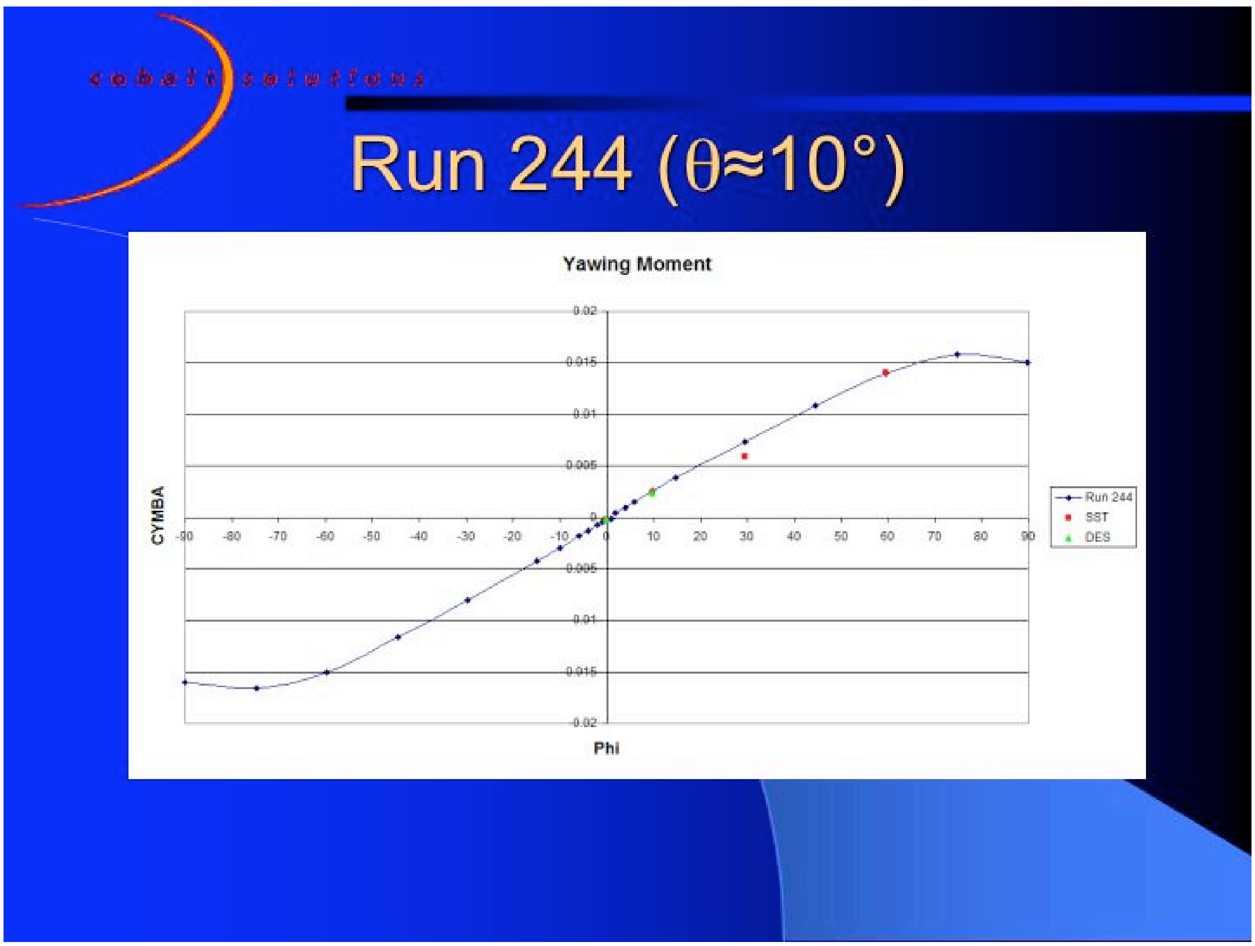

cobalt solutions
Isosurface of u=0, surface colored by pressure
Run 242 (θ≈9°), φ≈30°
SST

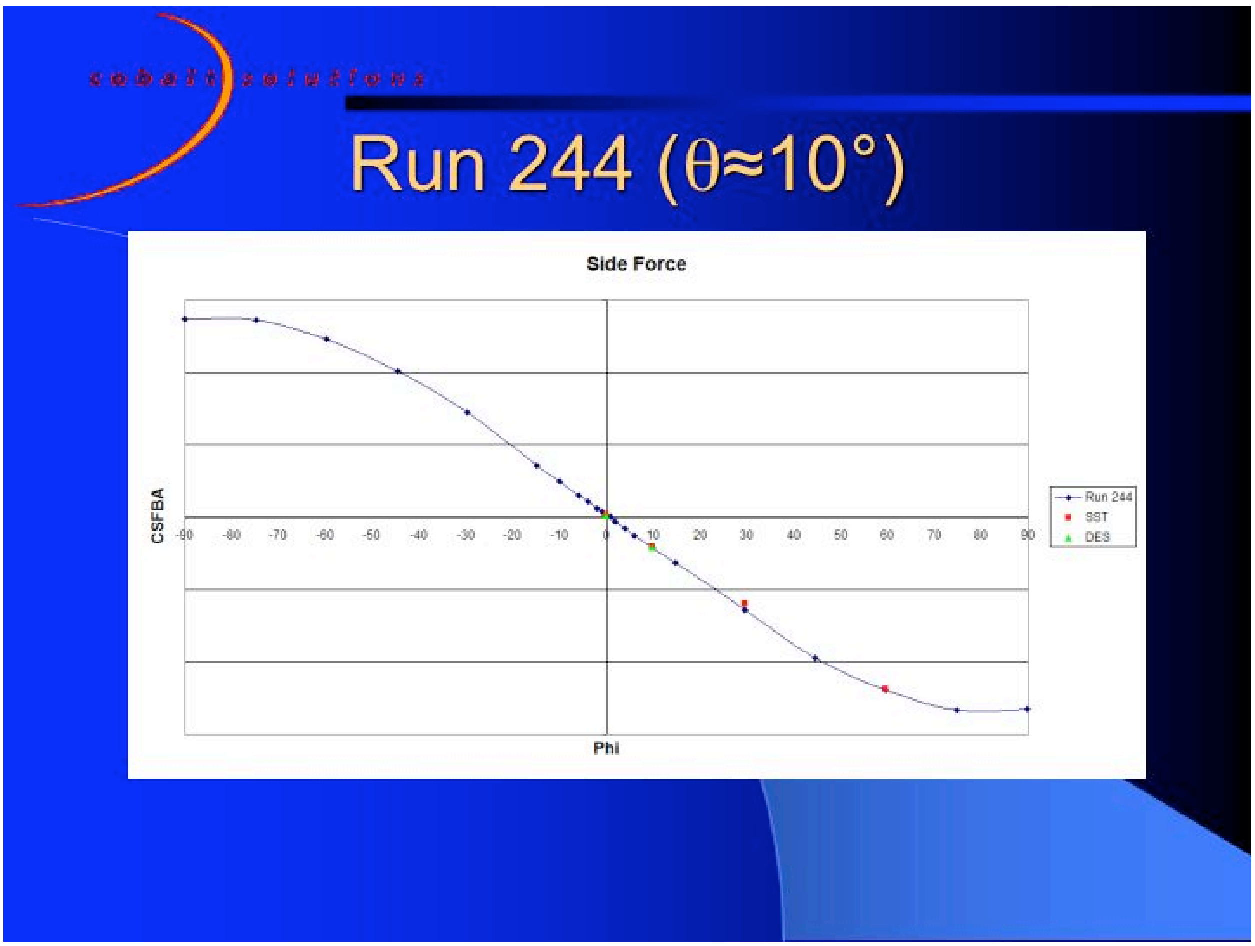
Rolling moment offset predicted by DES – is the sample size large enough?



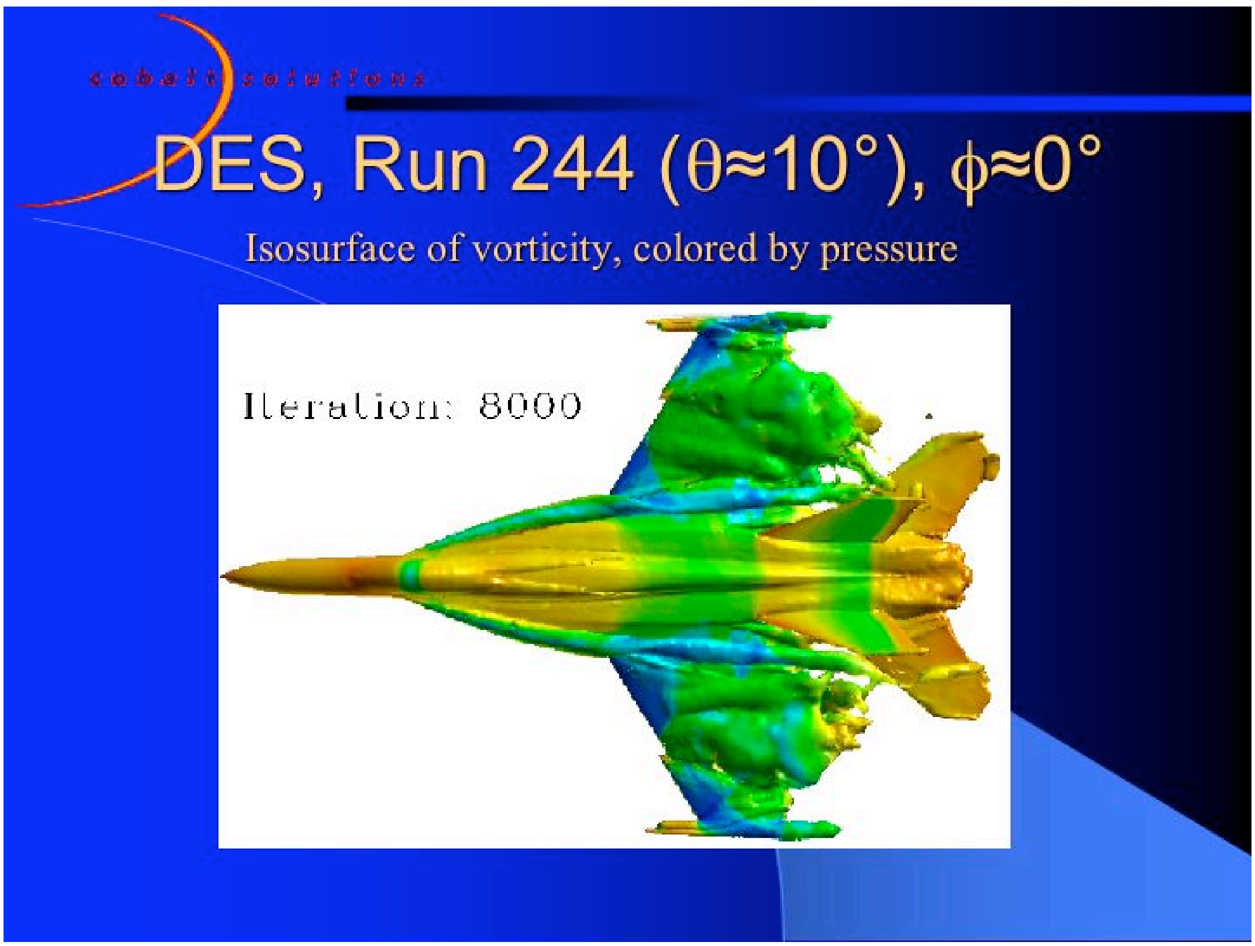
Looks like enough samples have been taken to well define rolling moment. However more might change the time-averaged rolling moment some.

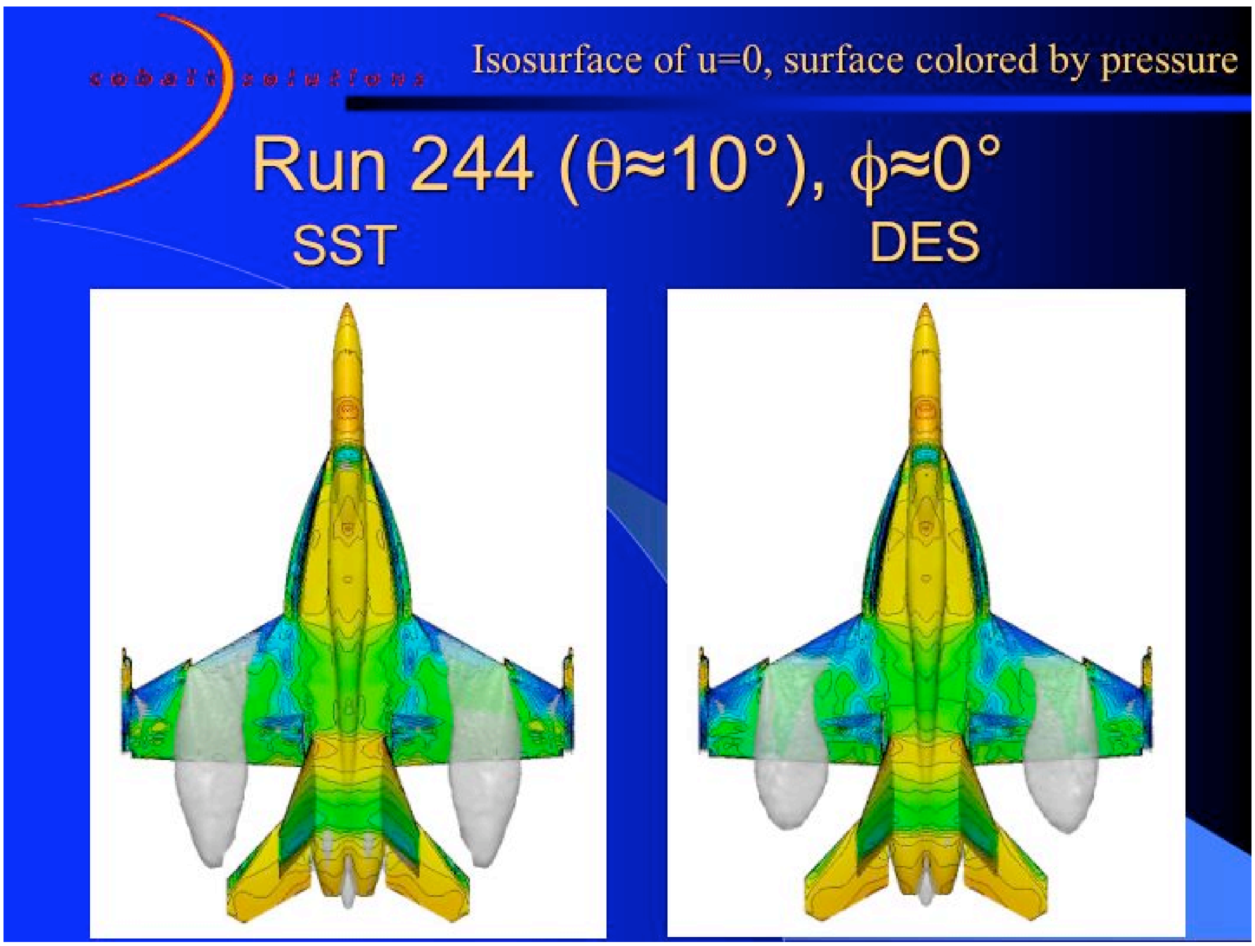


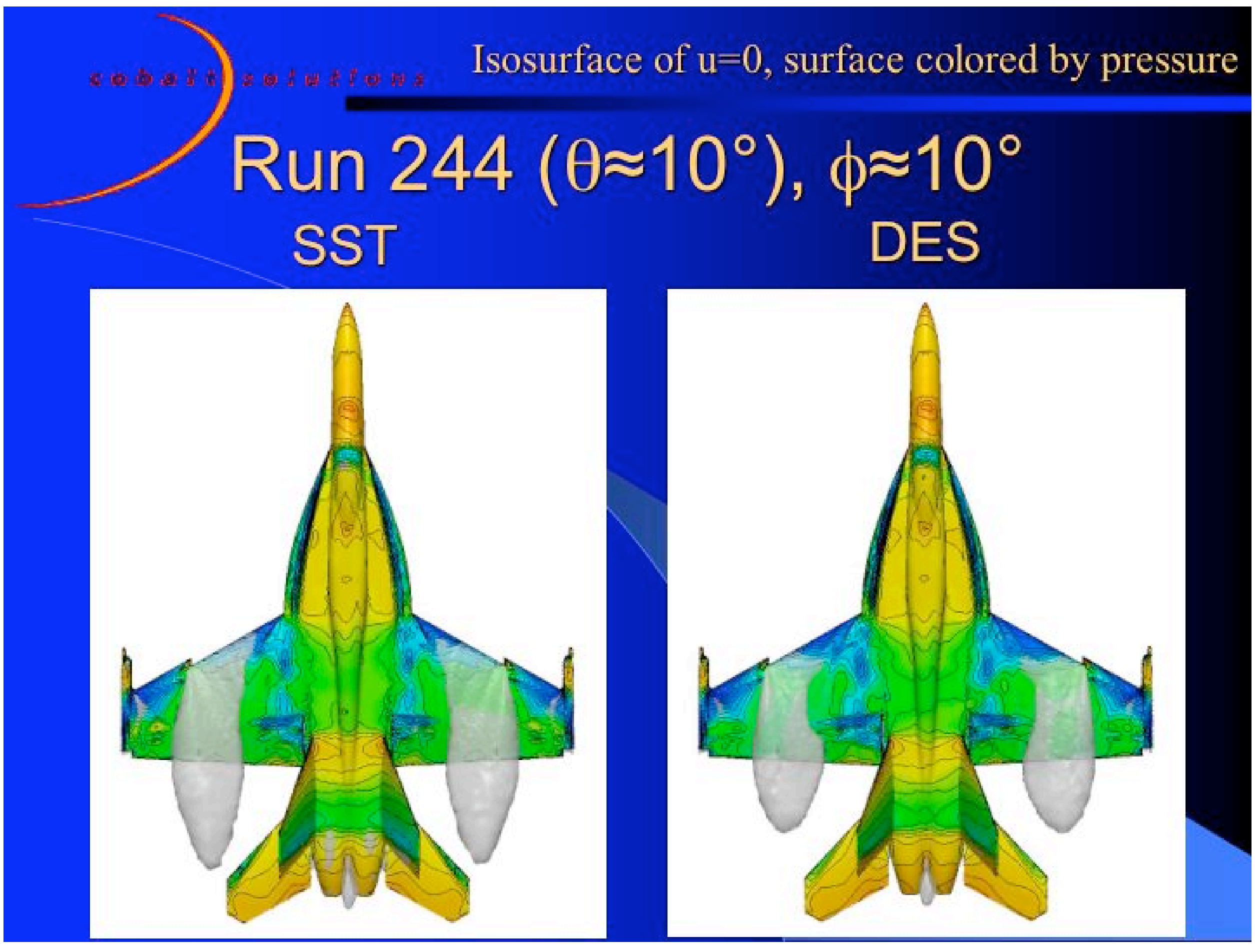

cobalt solutions
Run 244 (θ≈10°)
Yawing Moment
CYMBA
Phi
Run 244
SST
DES

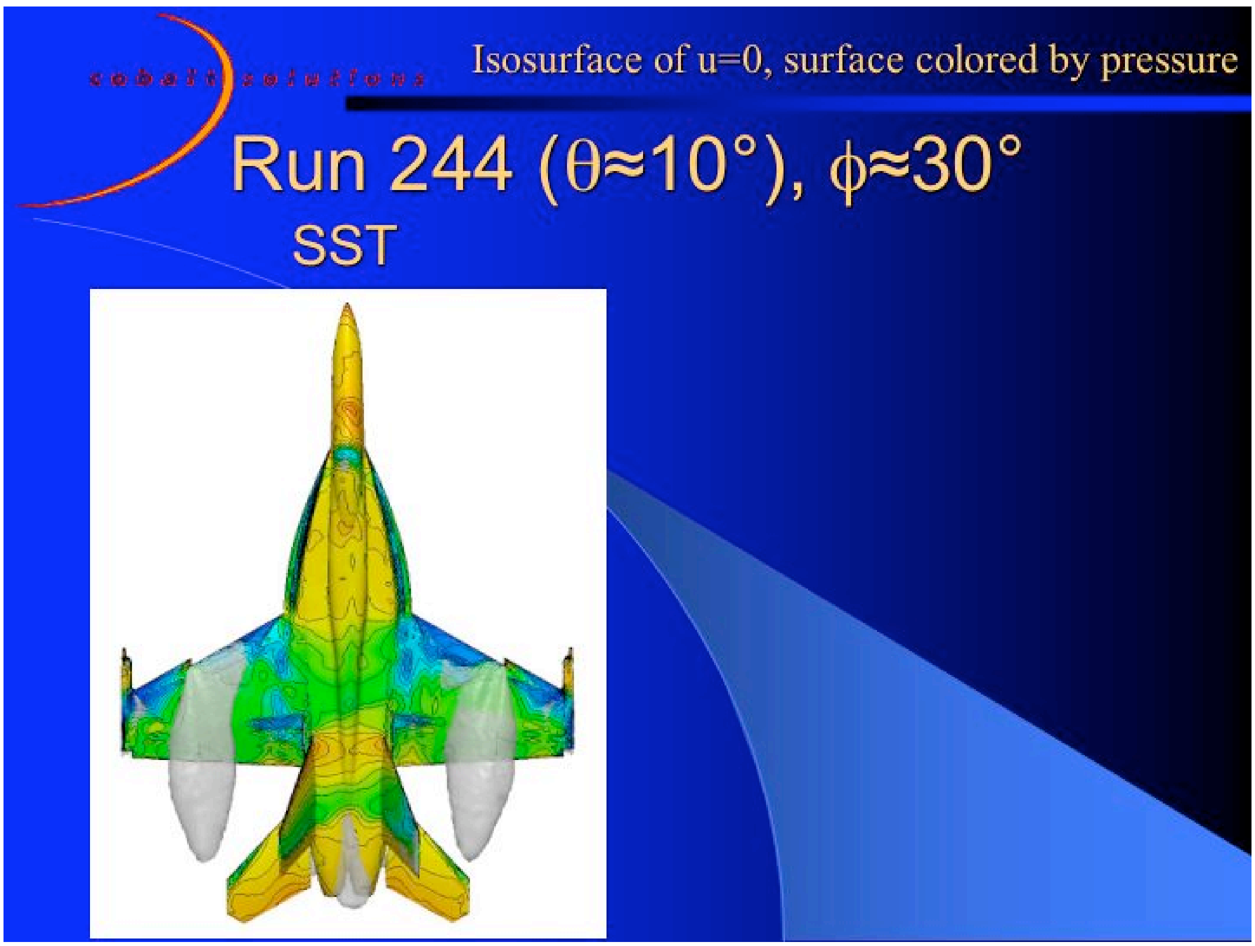

cobalt solutions
Run 244 (θ≈10°)
Side Force
CSFBA
Phi
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
Run 244
SST
DES

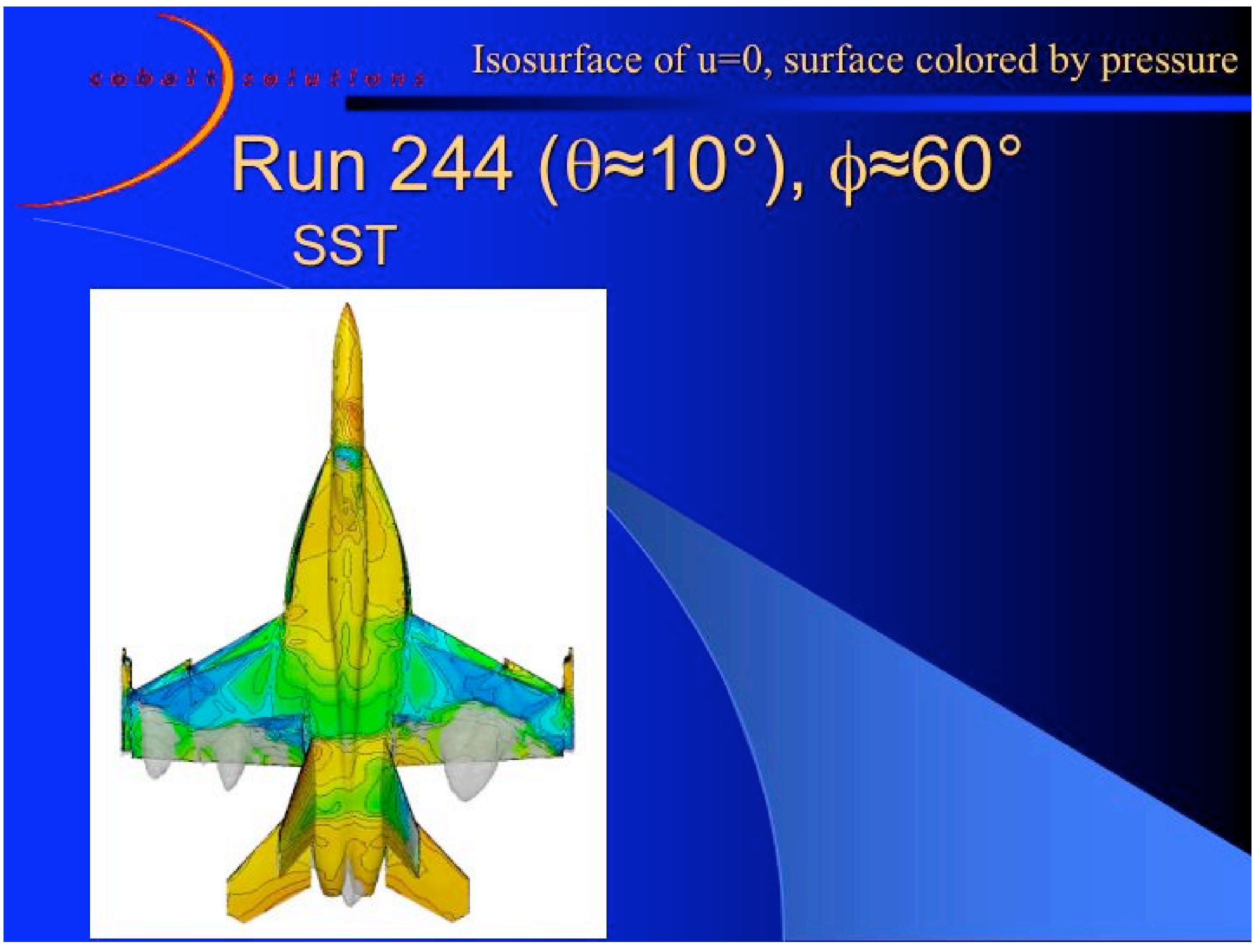
Unsteadiness now is due to separation moving from leading to trailing edge of the leading edge flap.




cobalt solutions
Isosurface of u=0, surface colored by pressure
Run 244 (θ≈10°), φ≈0°
SST
DES

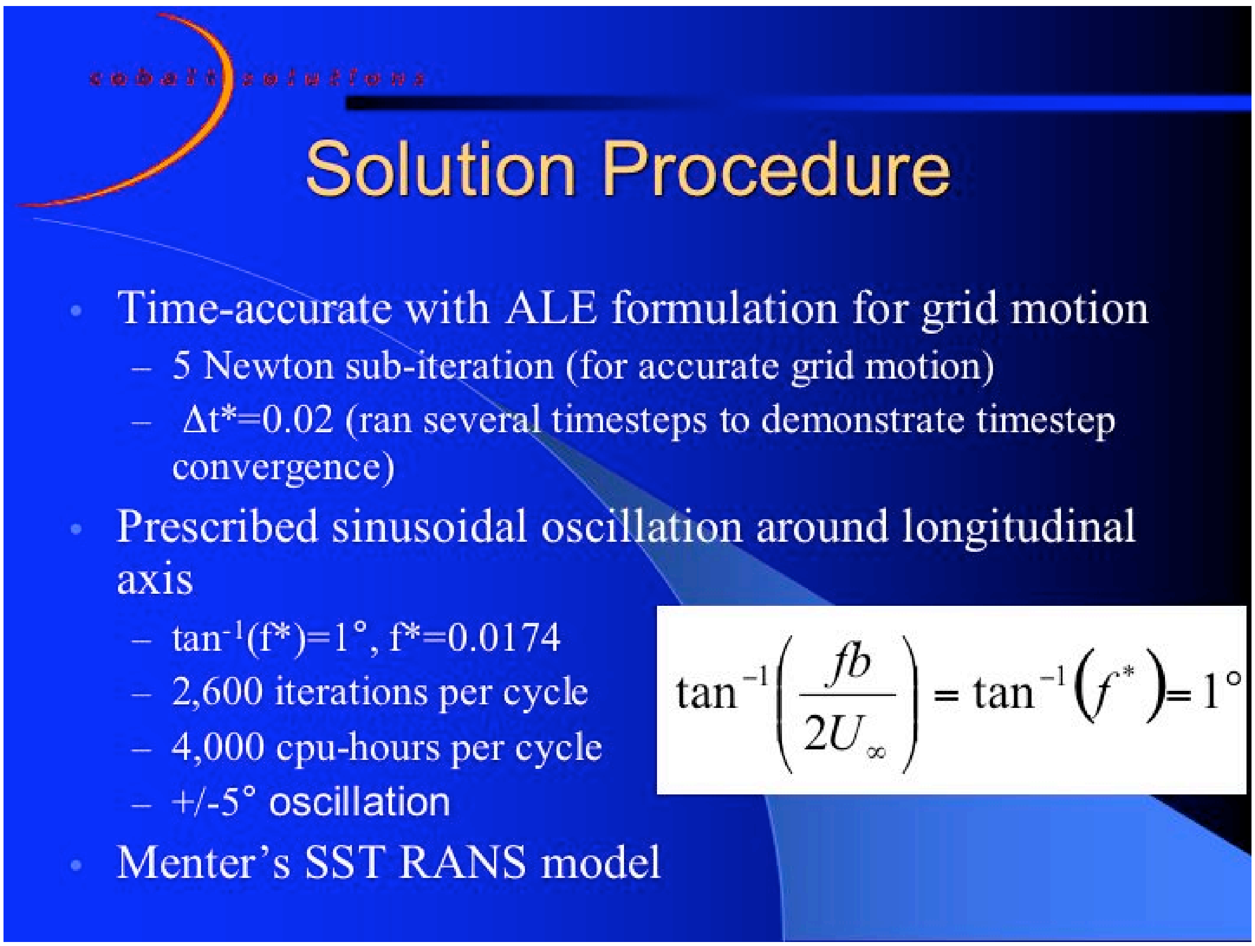

cobalt solutions
Isosurface of u=0, surface colored by pressure
Run 244 (θ≈10°), φ≈10°
SST
DES


cobalt solutions
Isosurface of u=0, surface colored by pressure
Run 244 (θ≈10°), φ≈30°
SST

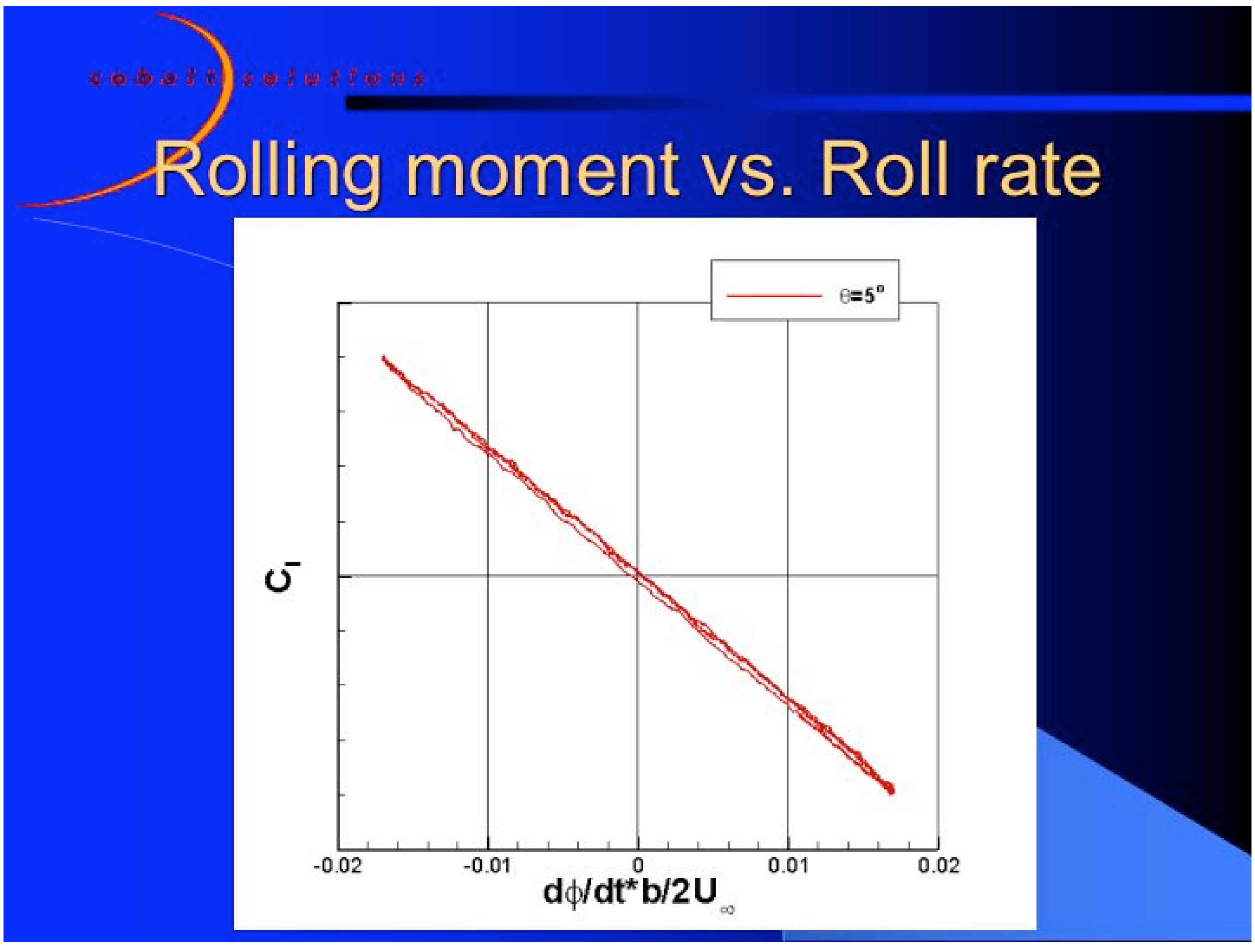

cobalt solutions
Isosurface of u=0, surface colored by pressure
Run 244 (θ≈10°), φ≈60°
SST

Oscillating Cases

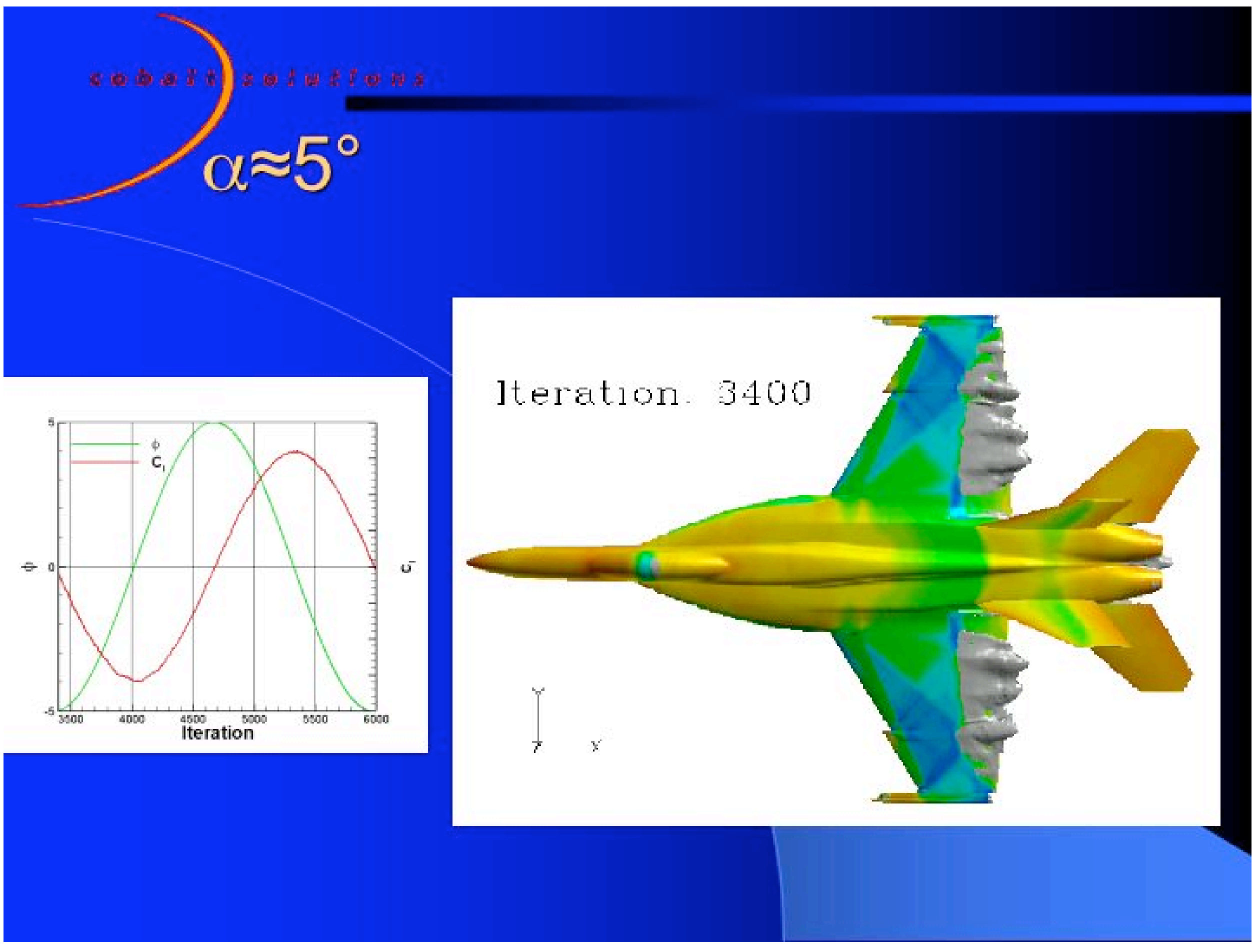
ALE = Arbitrary Eulerian/Lagrangian.



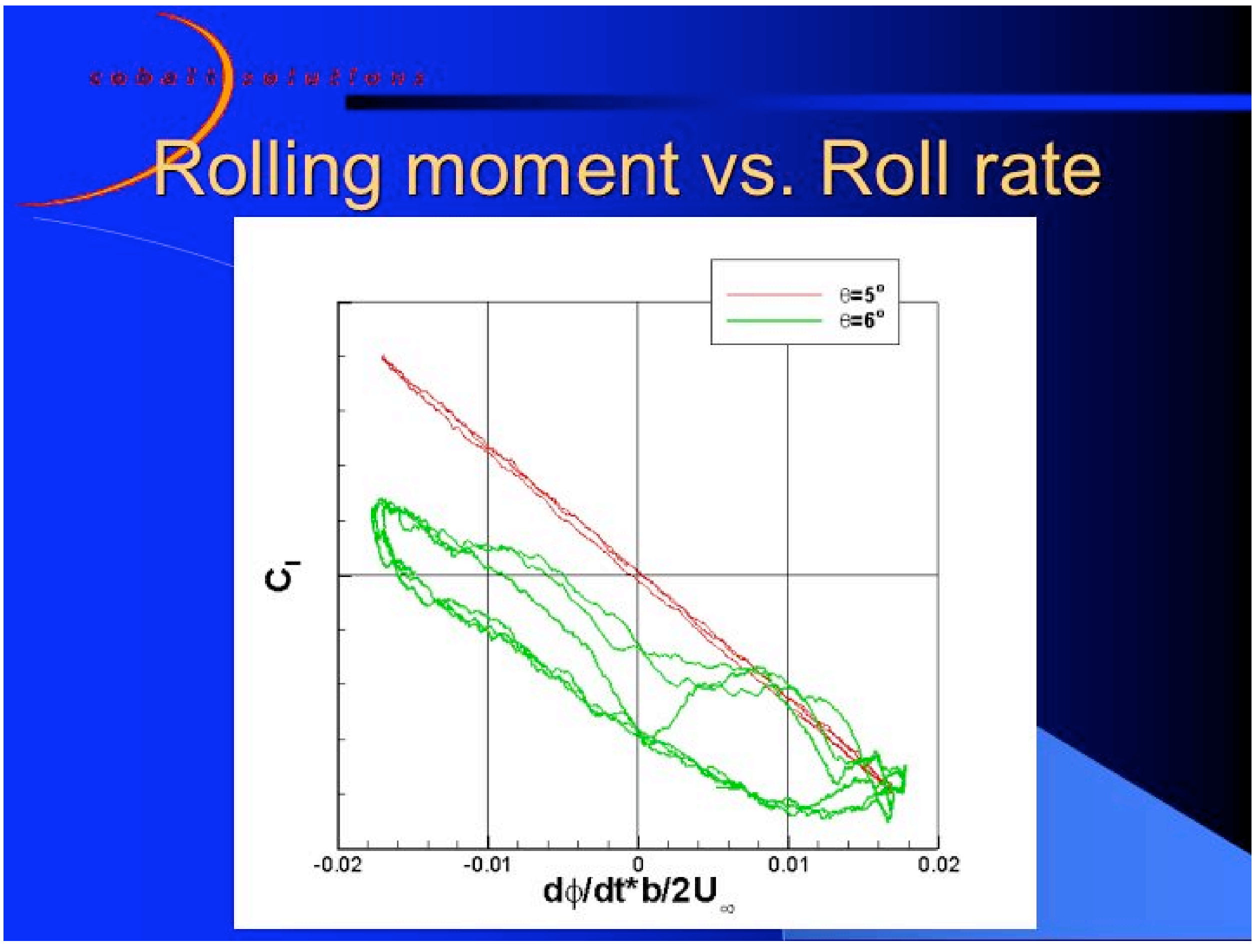
Linear and well behaved. Stable roll damping.



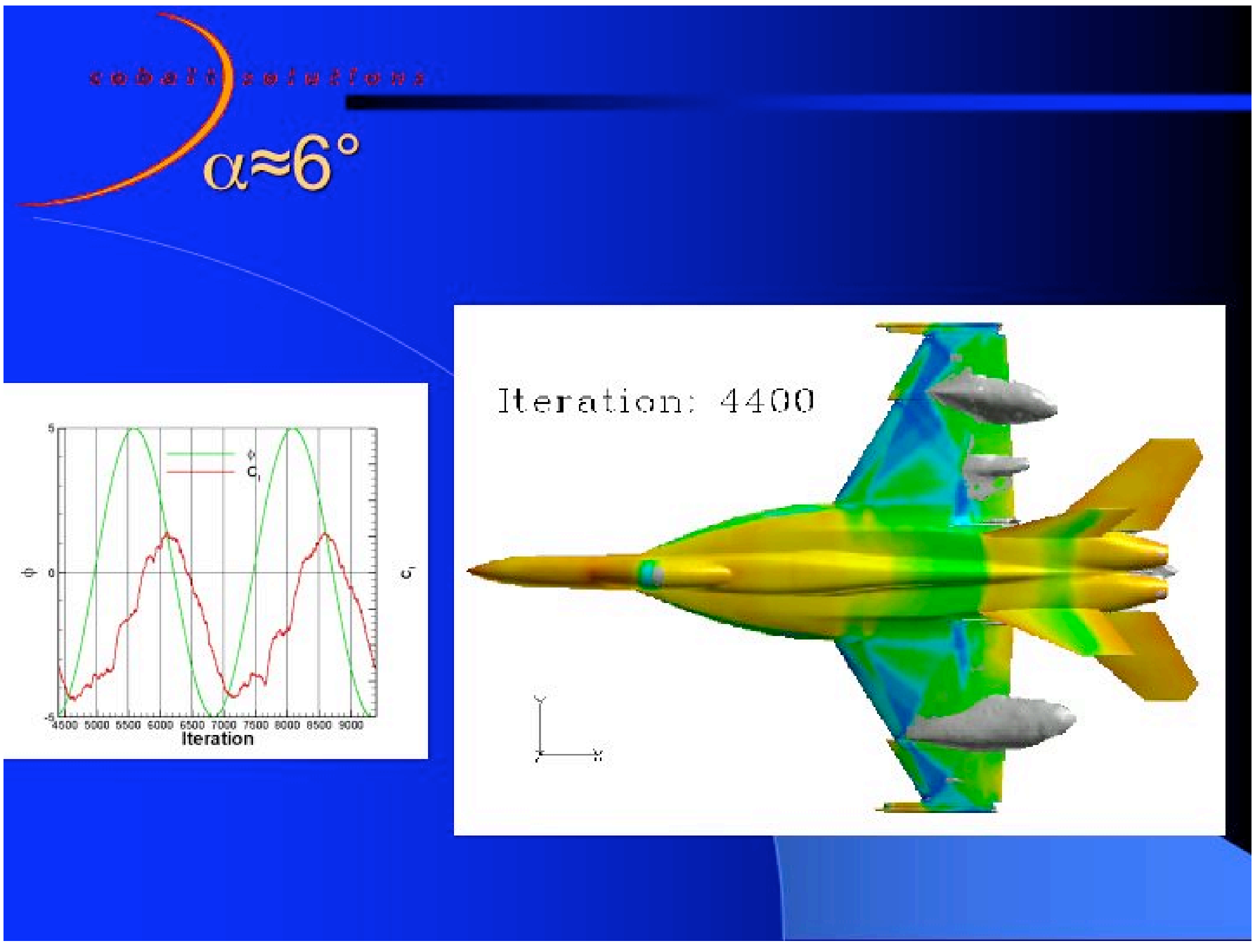
Separation at trailing edge – flow well behaved.



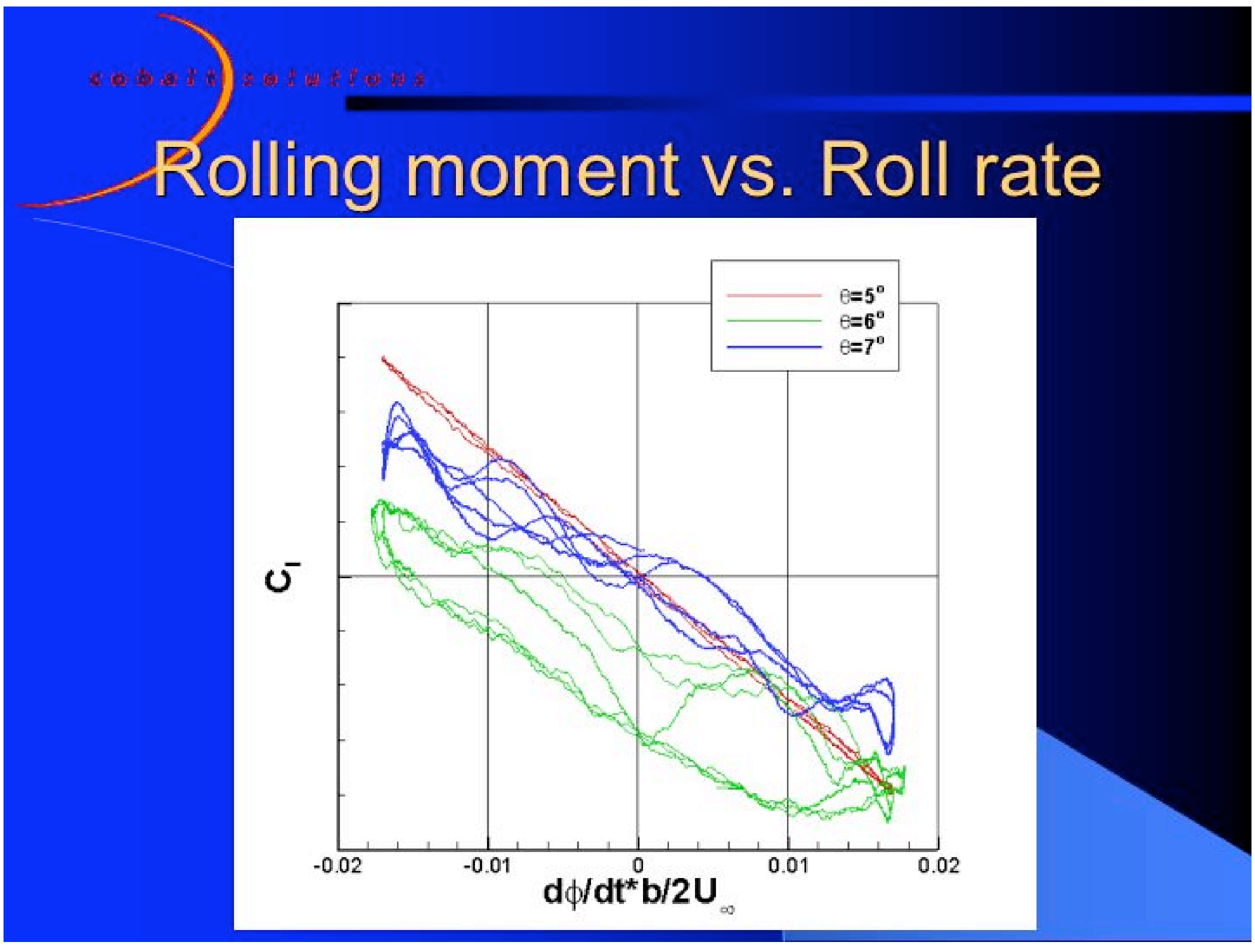
Large rolling moment offset. Several cycles run with varied timestep, but offset remained.

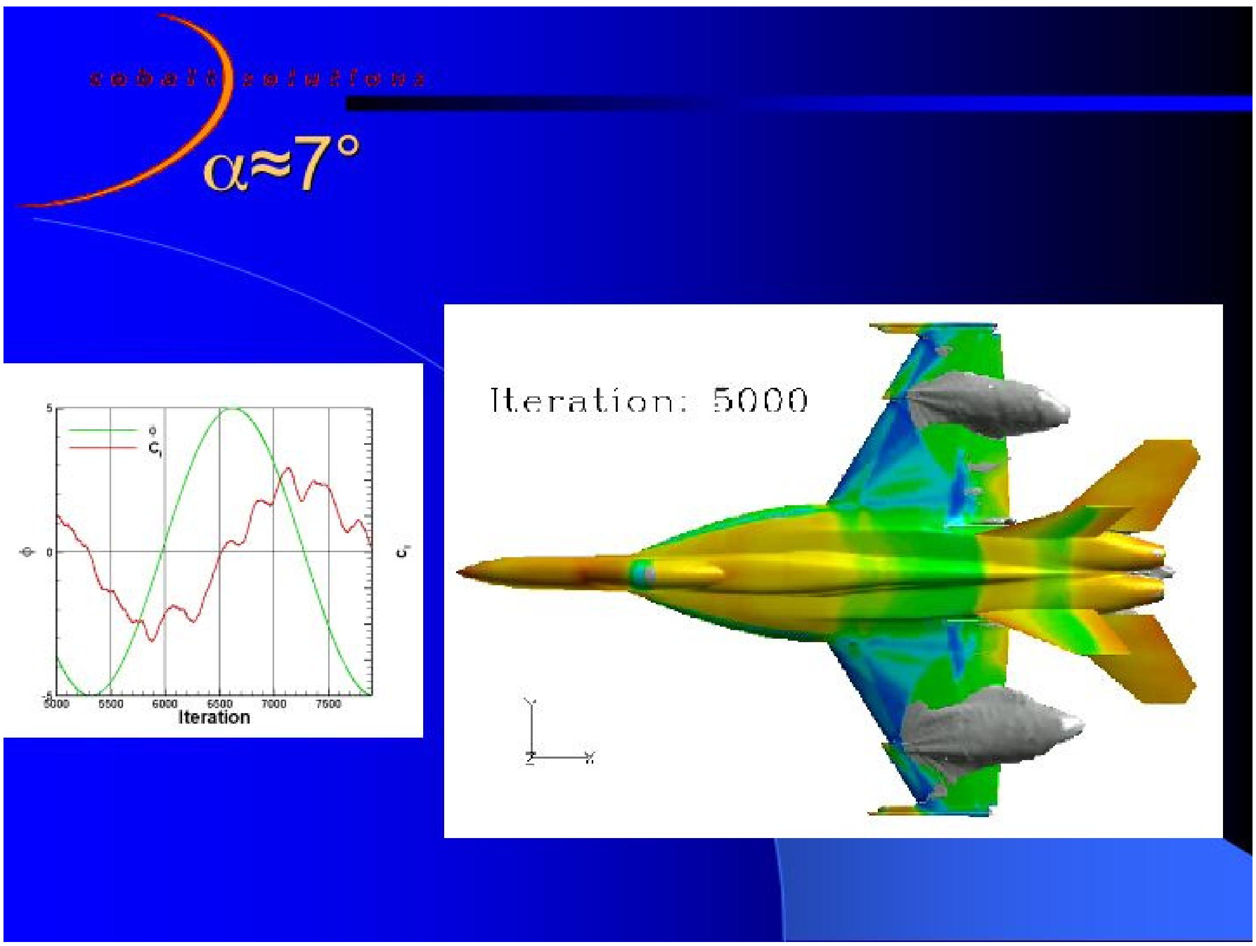


Offset due to differences in separation location. Hysterisis?

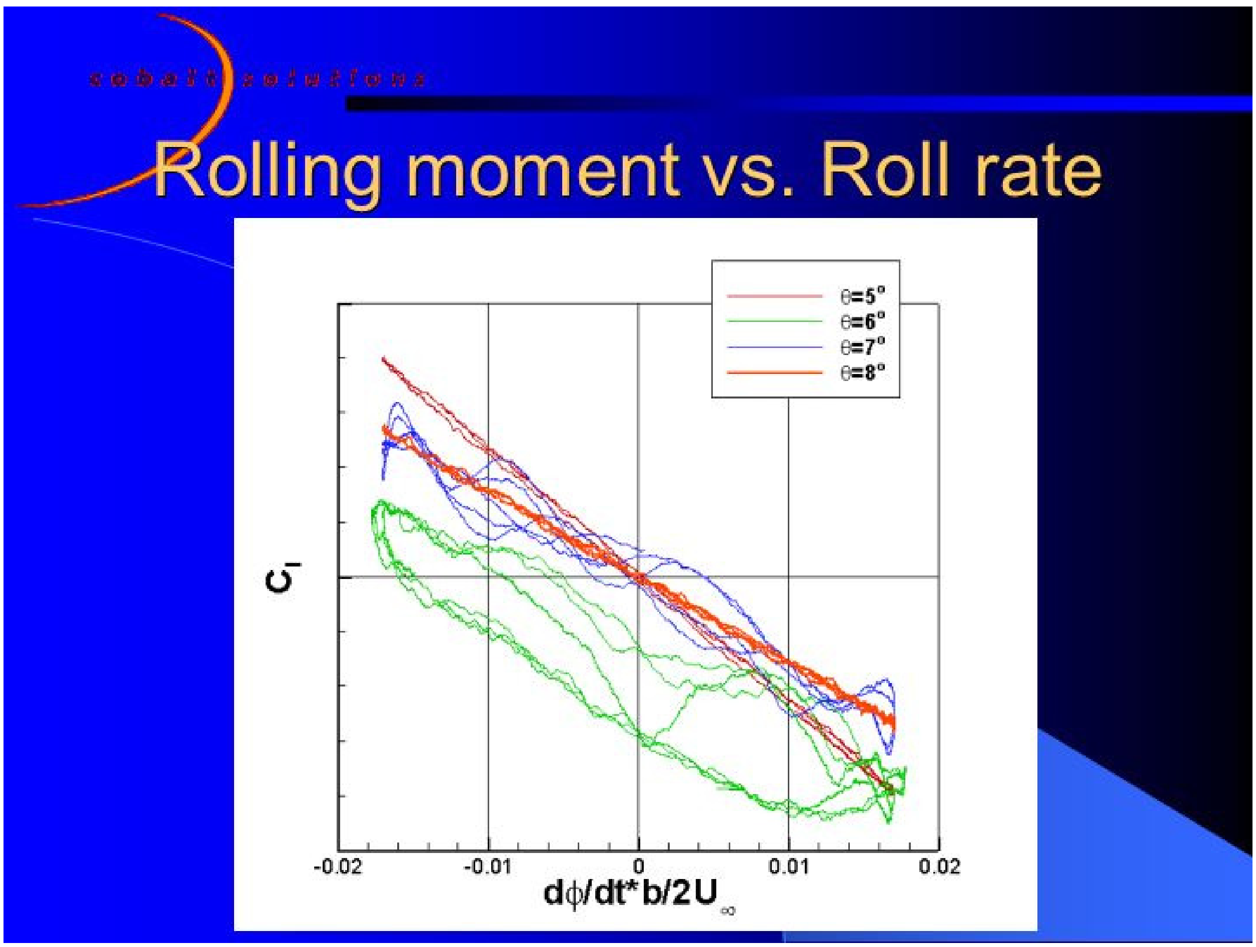


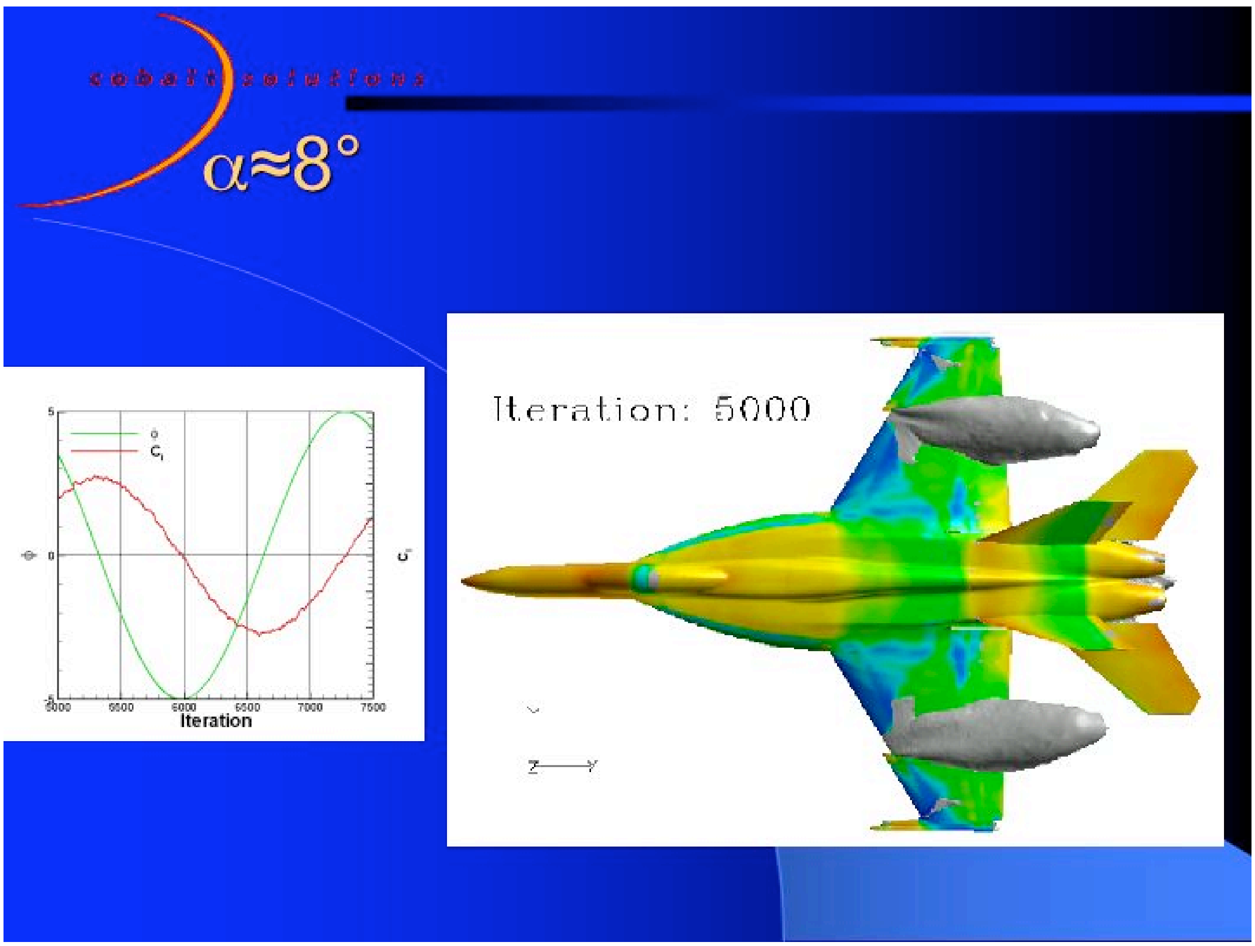
Slightly chaotic behavior, but linear and stable roll damping.

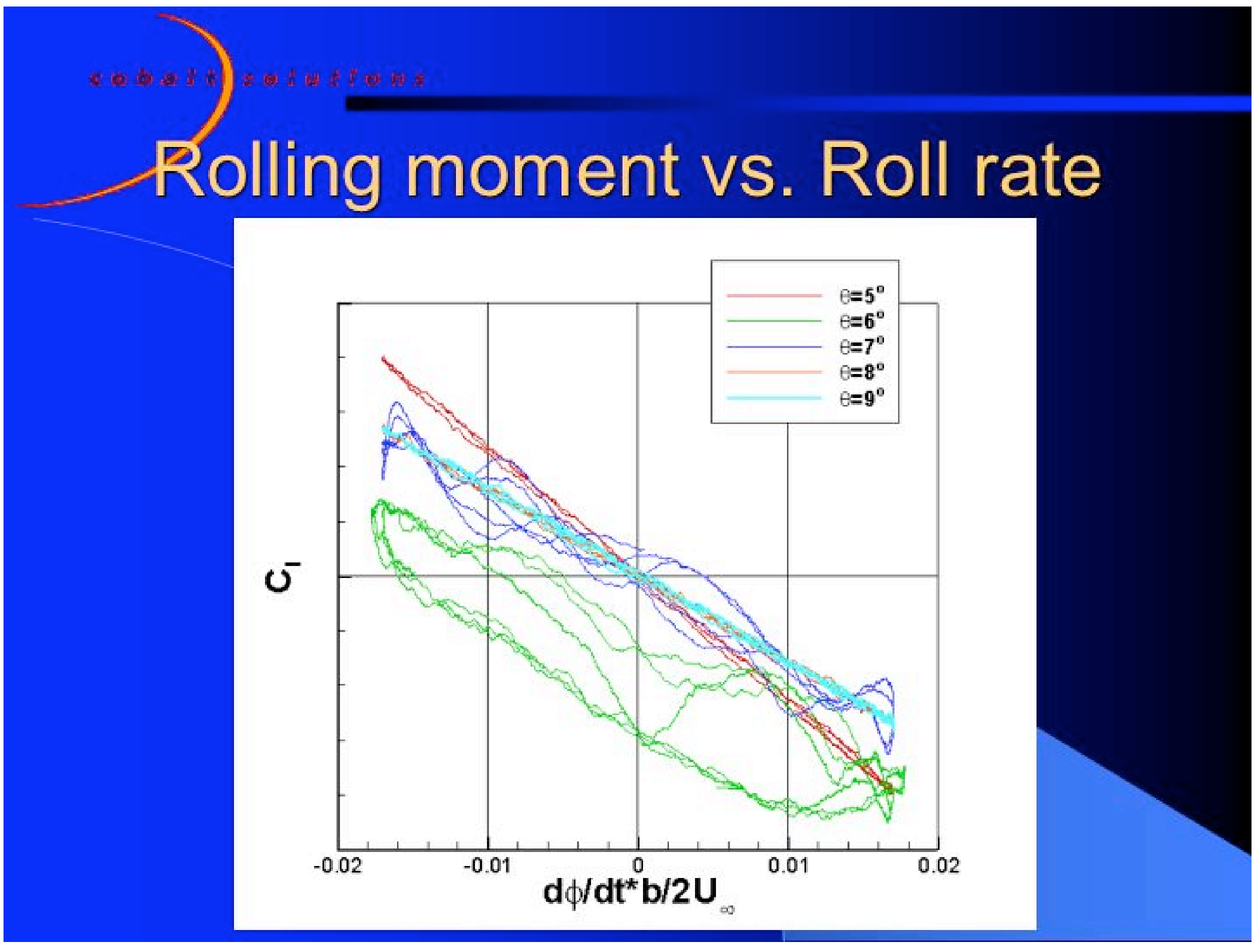


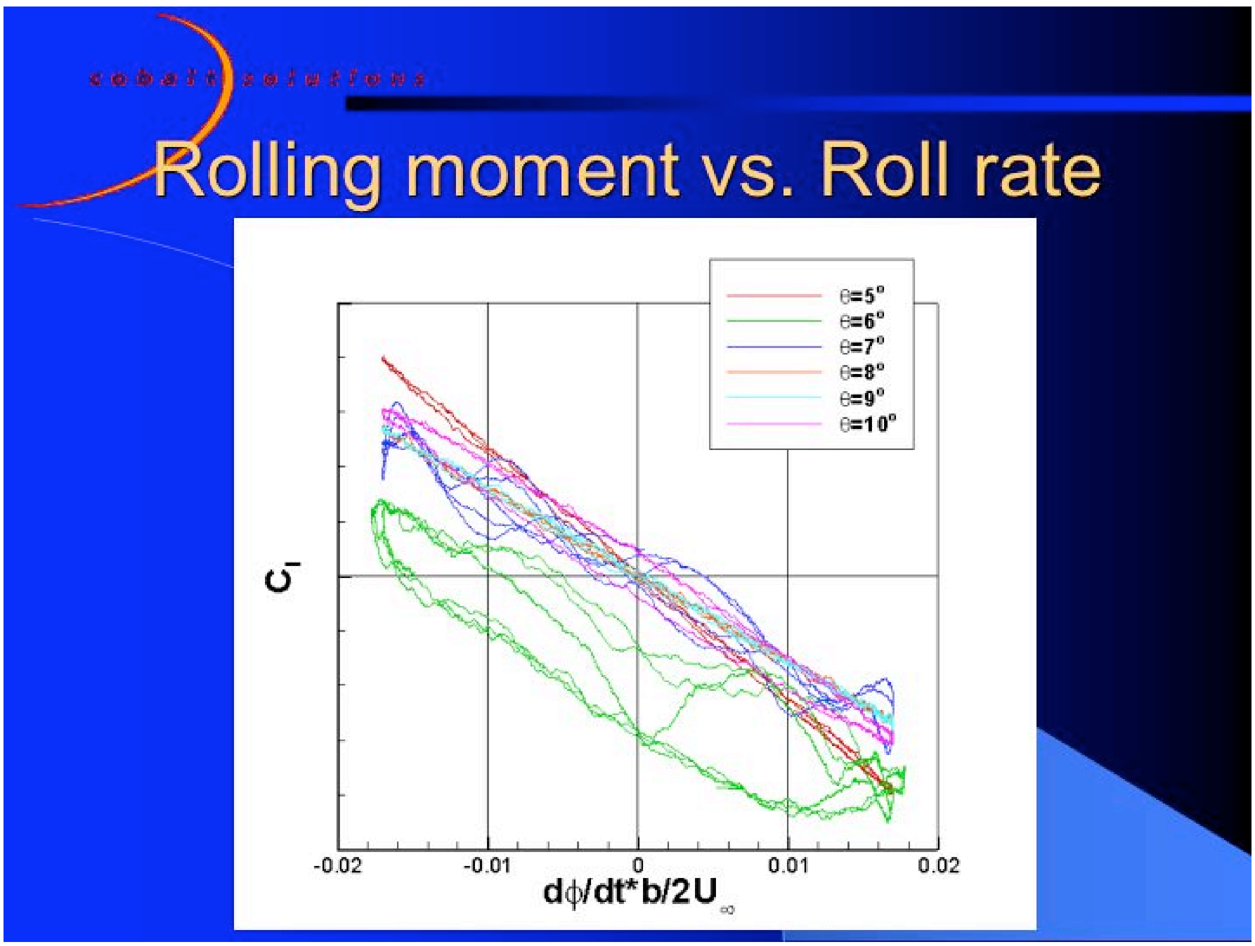

cobalt solutions
α≈7°
Iteration: 5000
φ
C_l
Iteration
5000
5500
6000
6500
7000
7500

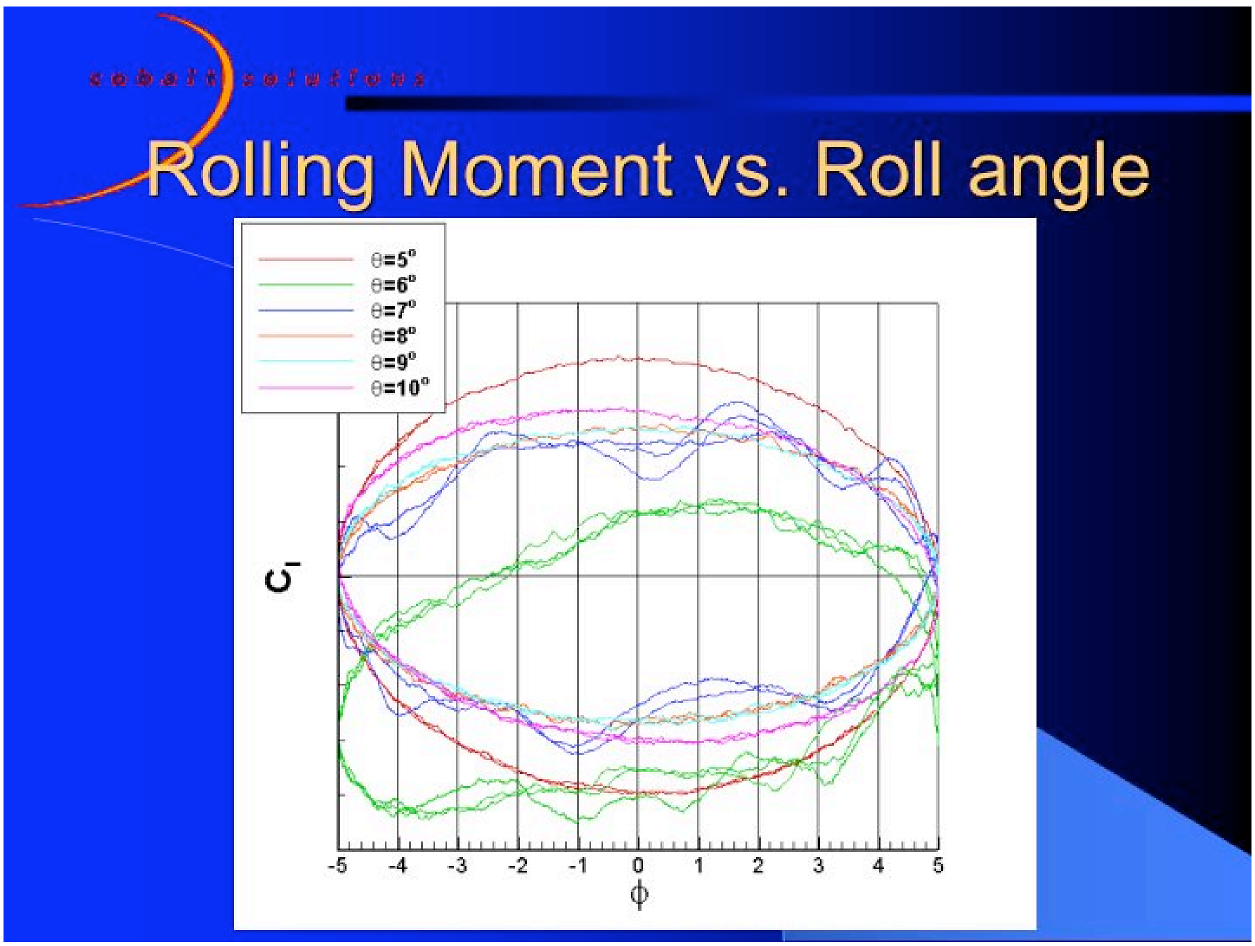
Positive roll damping. Note lowered slope – due to lower lift curve slope once shock moves forward on the wing.



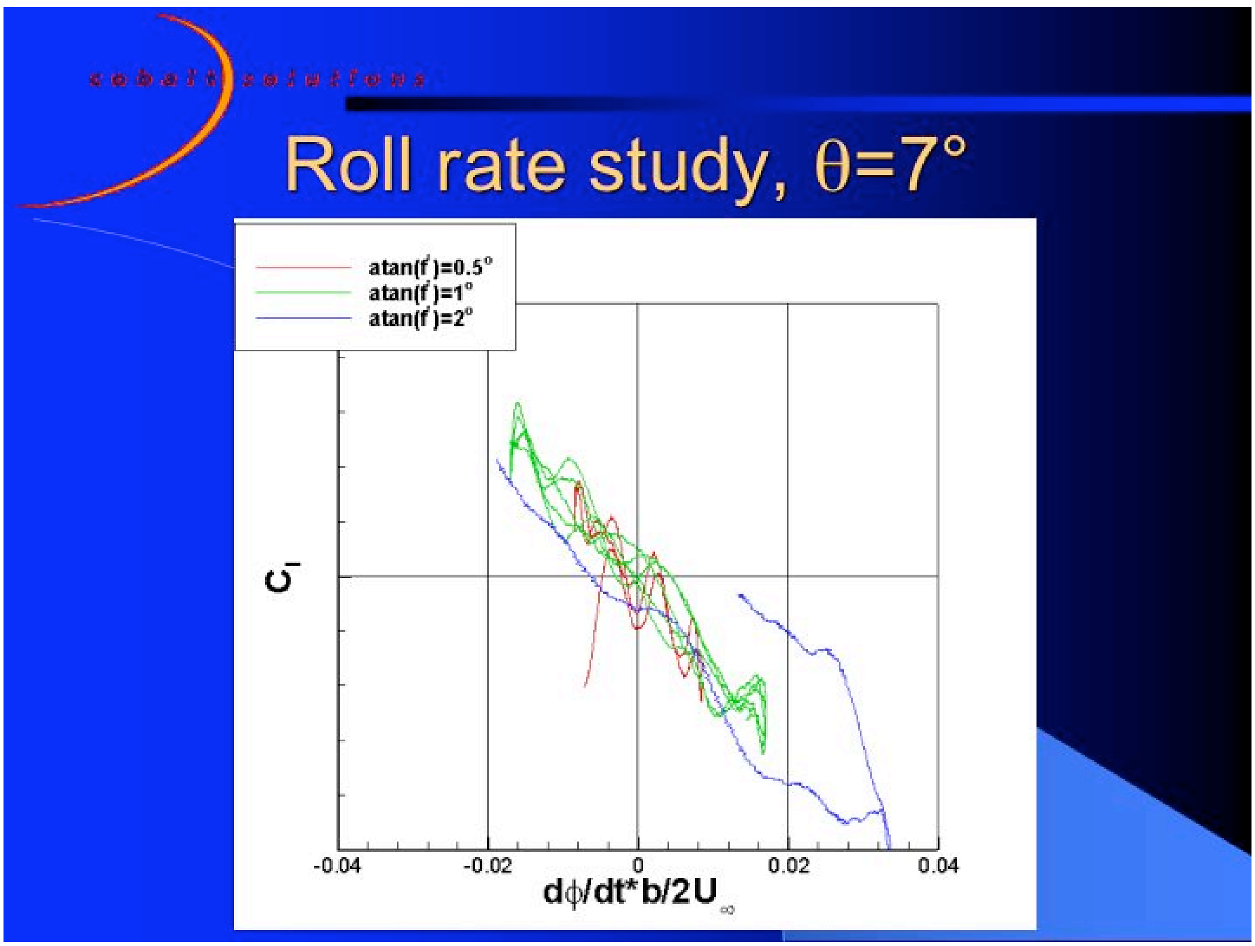

cobalt solutions
α≈8°
Iteration: 5000
Iteration
5000
5500
6000
6500
7000
7500


cobalt solutions
Rolling moment vs. Roll rate
θ=5°
θ=6°
θ=7°
θ=8°
θ=9°
C_l
-0.02
-0.01
0
0.01
0.02
$d\phi/dt*b/2U_\infty$


cobalt solutions
Rolling moment vs. Roll rate
θ=5°
θ=6°
θ=7°
θ=8°
θ=9°
θ=10°
C_l
-0.02
-0.01
0
0.01
0.02
$d\phi/dt^*b/2U_\infty$


cobalt solutions
Rolling Moment vs. Roll angle
θ=5°
θ=6°
θ=7°
θ=8°
θ=9°
θ=10°
C_l
-5
-4
-3
-2
-1
0
1
2
3
4
5
φ

Study still underway – not enough samples. Looking at dependence of roll damping on roll rate.



cobalt solutions

Conclusions

- RANS and DES applied to predict static stability derivatives in roll in AWS regime
  - DES showed better lift and moment predictions
  - Yawing moments and side force well predicted by both methods
  - Rolling moment more sensitive (both for CFD and wind tunnel)
- Prescribed rolls used to look at roll damping (RANS only)
  - All cases were stable in roll, but in AWS regime had more chaotic behavior. For one angle there was a significant rolling moment offest
  - Comparison to experiments still ongoing
- Continuing work
  - DES of prescribed rolls
  - More iterations on varying roll rate