Computation of Transonic Turbulent Flow for DLR-F6 Configuration using FEFLO

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Presented at the
2nd AIAA CFD Drag Prediction Workshop
June 21-22, 2003, Orlando, FL

Objective

- Continuing validation of FEFLO code for computing compressible turbulent flows on complex geometries.
- Testing robustness of FEFLO code on meshes generated by different mesh generators.

Overview

- FEFLO Description
- Computer Description
- Grid Description
- Test Cases 1 & 2
- Conclusions

FEFLO-SAIC Code (1)

- Hybrid formulation for solving Navier-Stokes equations
  - Finite volume for inviscid fluxes
  - Finite element for viscous fluxes
- Unstructured tetrahedral grids
- Turbulence modeling
  - Baldwin-Lomax model
  - Goldberg-Ramakrishnan model
  - Spalart-Allmaras model
  - _-_ model
- Parallelization
  - OpenMP

FEFLO-SAIC Code (2)

- **Spatial discretization for inviscid fluxes:**
  - Control volume:
    - Medium dual
    - Containment dual
  - **Numerical fluxes:**
    - vanLeer
    - AUSM+
    - HLLC
    - ROE
    - Godunov
  - **Reconstruction:**
    - Green-Gauss
    - Linear least-square
    - Consistent-mass
  - **Limiters:**
    - Van-Albada
    - Barth
    - Venkatakrishnan

FEFLO-SAIC Code (3)

- Temporal discretization:
  - Explicit:
    - Runge-Kutta
    - Residual smooth
  - Implicit:
    - Matrix-free LU-SGS
    - Matrix-free SGS
    - Matrix-free GMRES+LU-SGS

FEFLO features

- Single topological element→Simplicity
- Containment dual control volume→Accuracy
- Matrix-free implicit GMRES+LU-SGS→Speed and memory

Computer system description

- Name: NAVO IBM Cluster 1600
- Processor: 1.3 GHz Power 4
- Procs: 1184
- Nodes: 148
- Procs/node: 8
- Computer peak: 6.1 Tflops
- Memory/node: 8 Gbyte (144 nodes)
  64 Gbyte (4 nodes)

Grid Description (1)

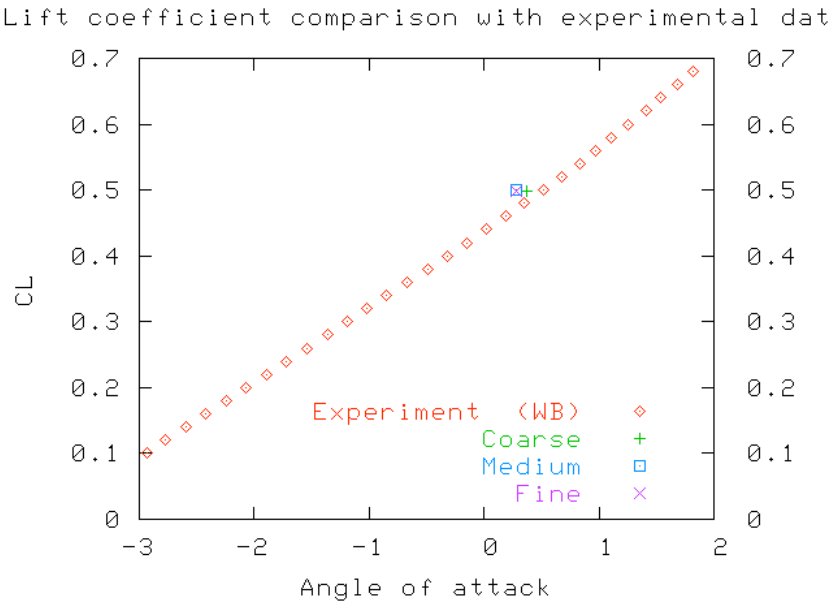
- Coarse grid: coarse grid by LARC
  - WB configuration:
    - Npoin=1,121,301, nelem=6,558,758, nboun=38,879,nface=77,754
  - WBNP configuration:
    - Npoin=1,827,470, nelem=10,715,204, nboun=58,803,nface=117,606
- Medium grid: coarse grid by Swansea
  - WB configuration: (59% more grid points than the coarse)
    - Npoin=1,779,420, nelem=10,504,337, nboun=57,009,nface=114,014
  - WBNP configuration: (32% more grid points than the coarse)
    - Npoin=2,419,388, nelem=14,304,595, nboun=70,580,nface=141,160
- Fine grid: coarse grid by DLR
  - WB configuration: (34% more grid points than the medium)
    - Npoin=2,390,716, nelem=13,977,040, nboun=93,663,nface=187,322
  - WBNP configuration: (52% more grid points than the medium)
    - Npoin=3,682,535, nelem=21,564,720, nboun=134,802,nface=269,7604

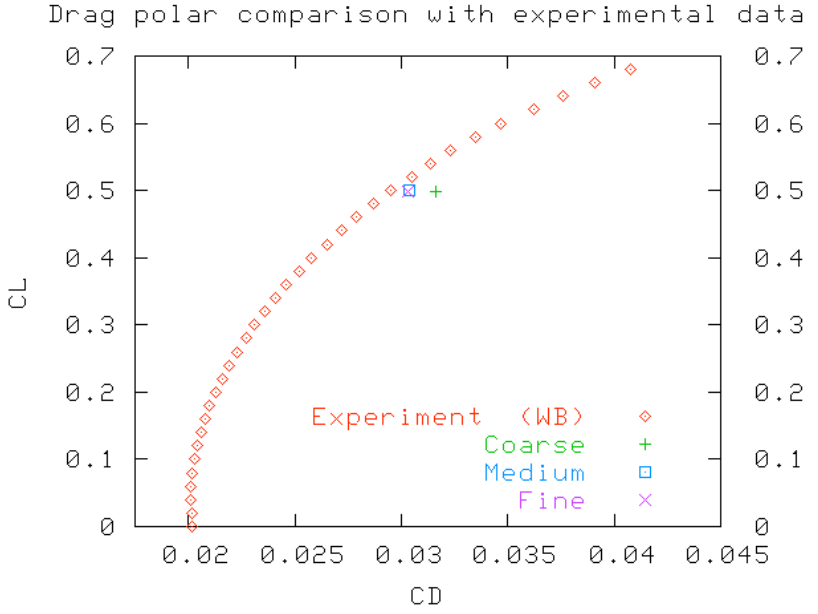
Grid Descriptions (2)

- Test the robustness of FEFLO on grids generated by different grid generators.
- ``Free'' computer resources available to us do not allow us to run big memory job (<8Gbytes) in a timely fashion.
- All except fine WBNP mesh were run using less than 8Gbytes, and most test cases took less than 12 hours of CPU.

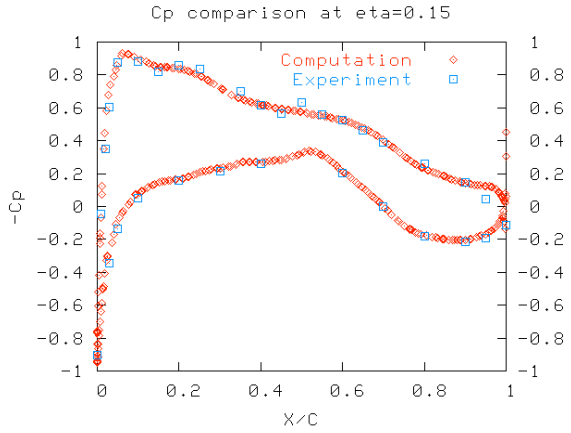
Test case 1: Wing/body Configuration

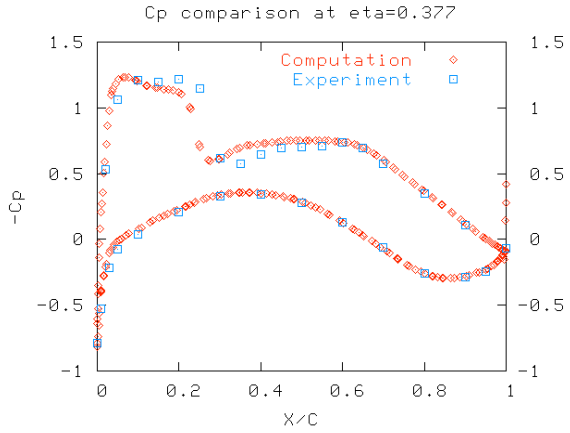
GRID SIZE	MACH	ALPHA	CL_TOT	CT_TOT	CD_PR	CD_SF	CM_TOT
1,121,301	0.75	0.376	0.499	0.03165	0.01873	0.01292	-0.1244
1,779,420	0.75	0.28	0.500	0.03038	0.01775	0.01263	-0.1281
2,390,716	0.75	0.275	0.499	0.03034	0.01803	0.01231	-0.1332

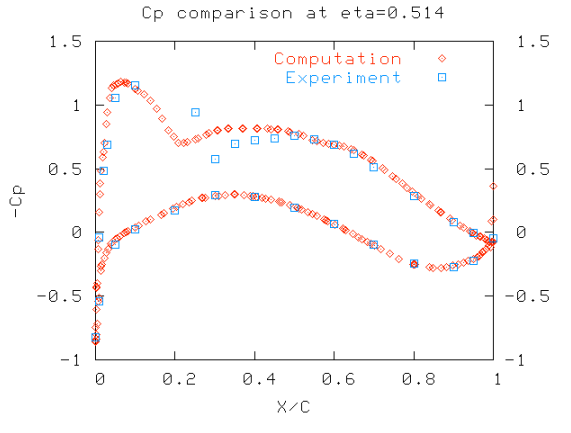


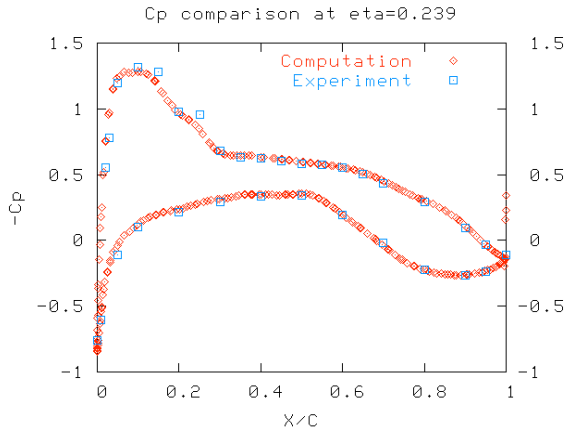


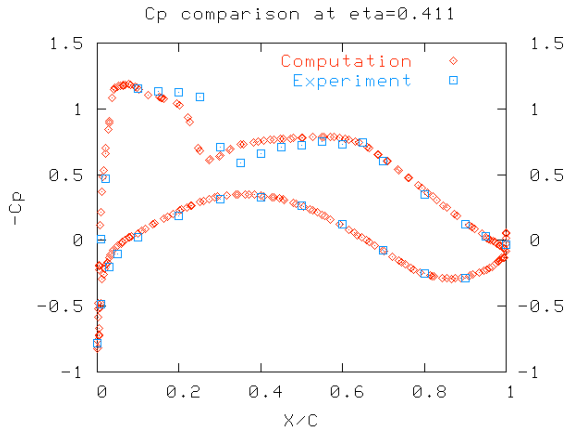
Comparison of Cp with experimental data for wing/body configuration

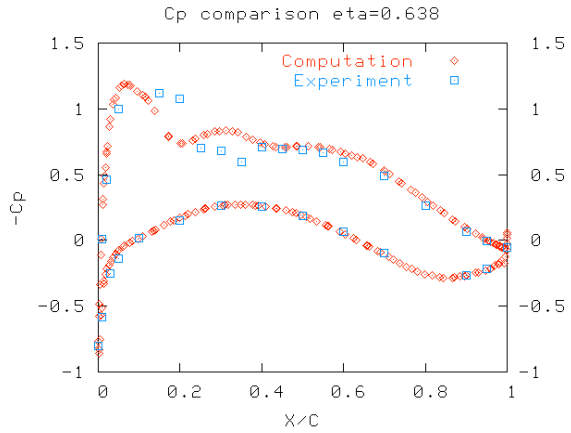


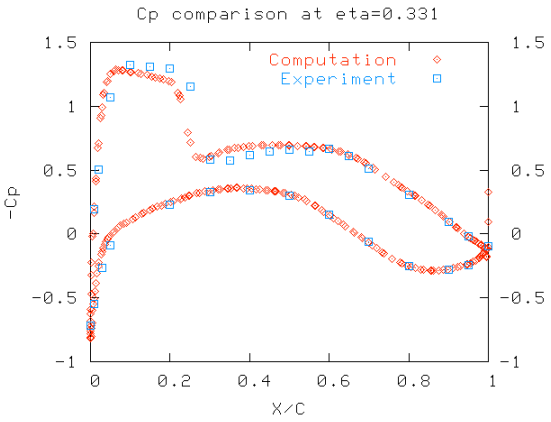


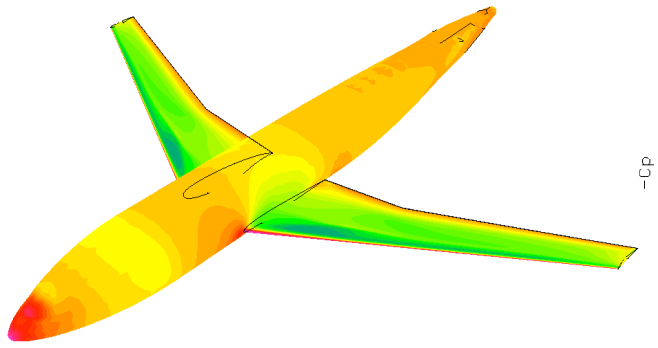


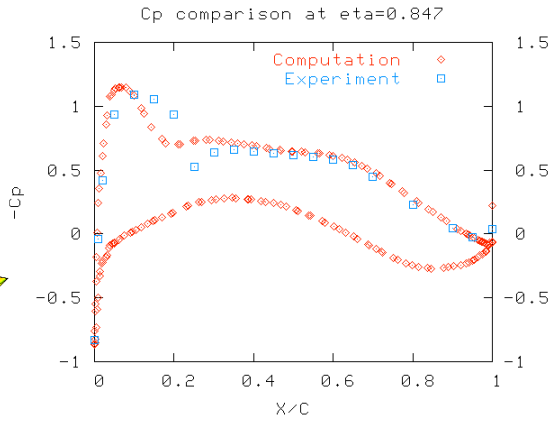






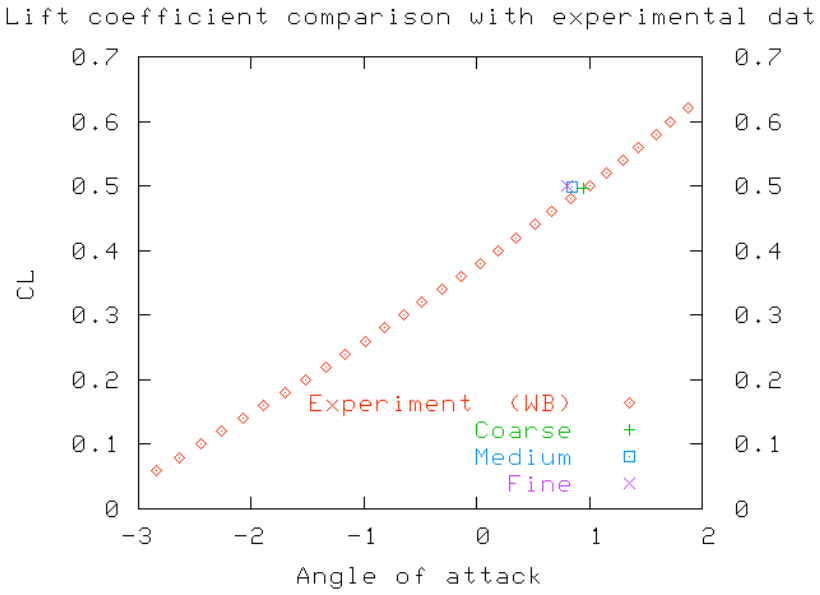


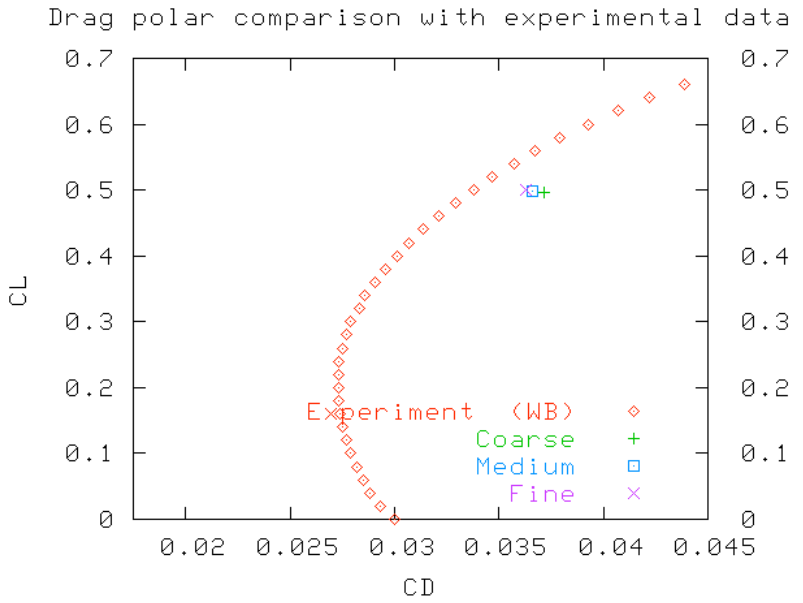




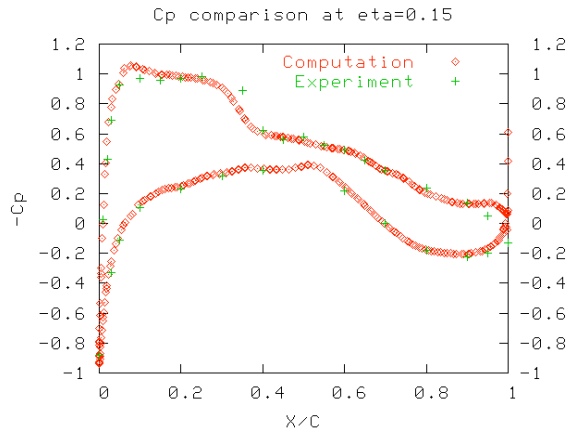
Test case 1: Wing/body/pylon/nacelle Configuration

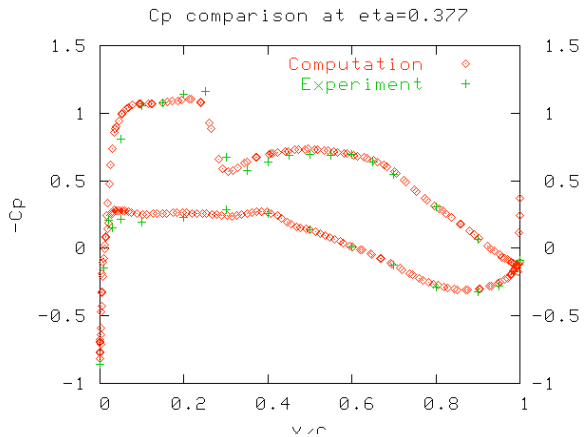
GRID SIZE	MACH	ALPHA	CL_TOT	CT_TOT	CD_PR	CD_SF	CM_TOT
1,827,470	0.75	0.950	0.497	0.03719	0.02161	0.01558	-0.1205
2,419,388	0.75	0.843	0.498	0.03658	0.02062	0.01596	-0.1216
3,682,535	0.75	0.800	0.501	0.03631	0.02081	0.01550	-0.1242

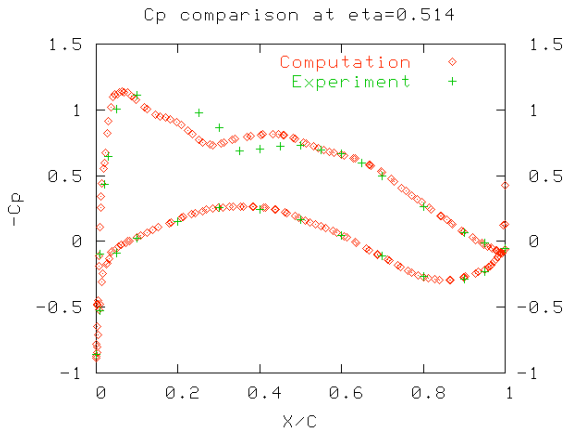


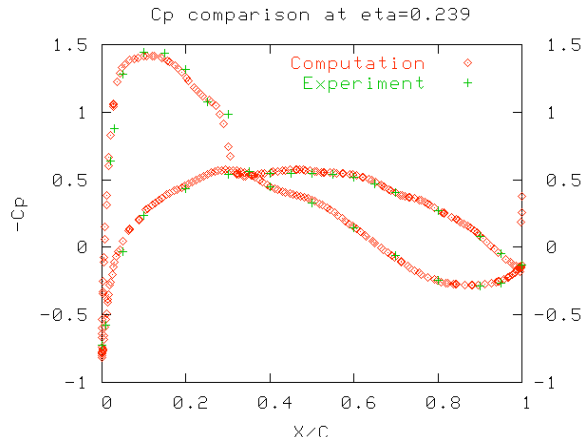


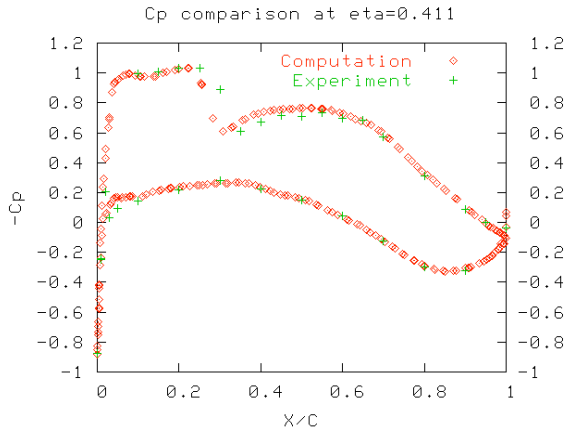
Comparison of Cp with experimental data for wing/body/pylon/nacelle configuration

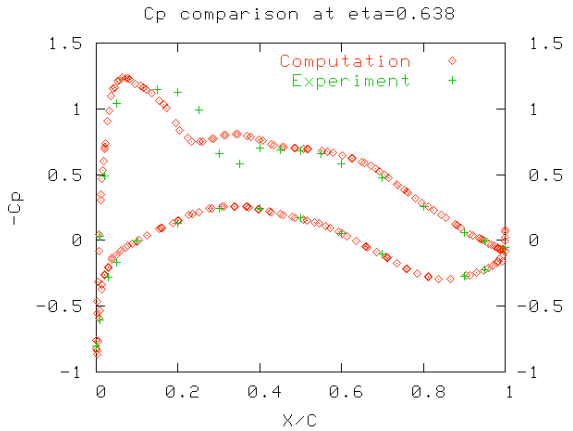


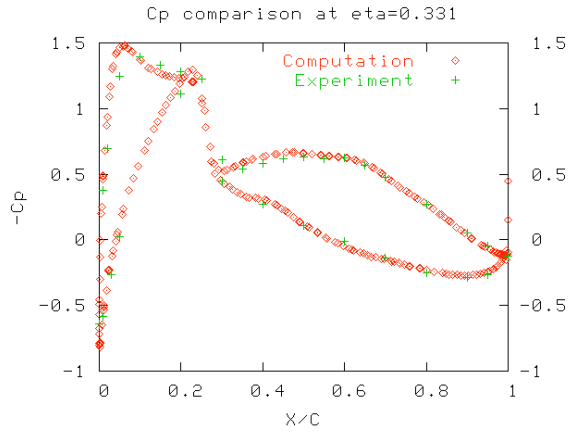


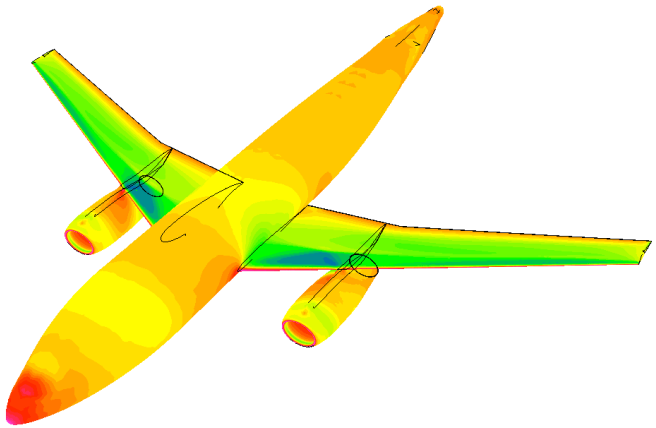


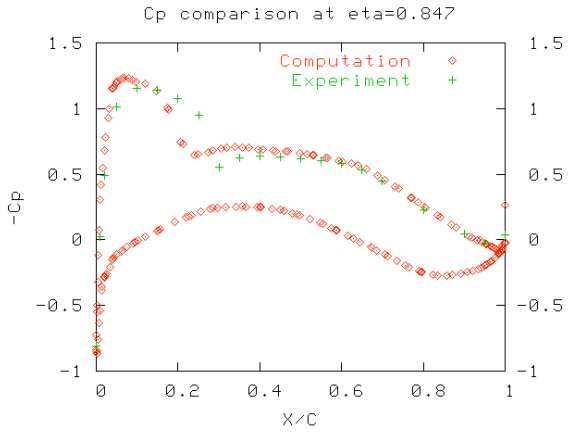












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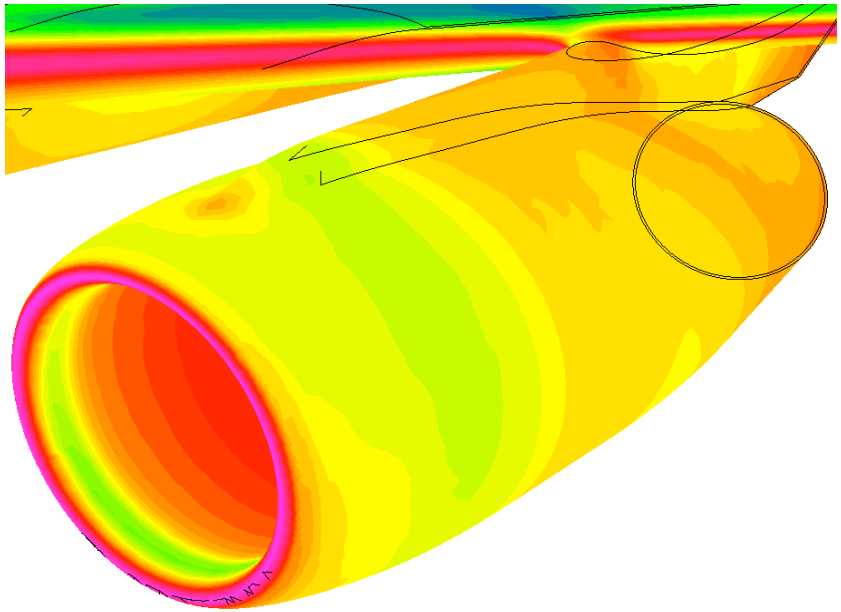
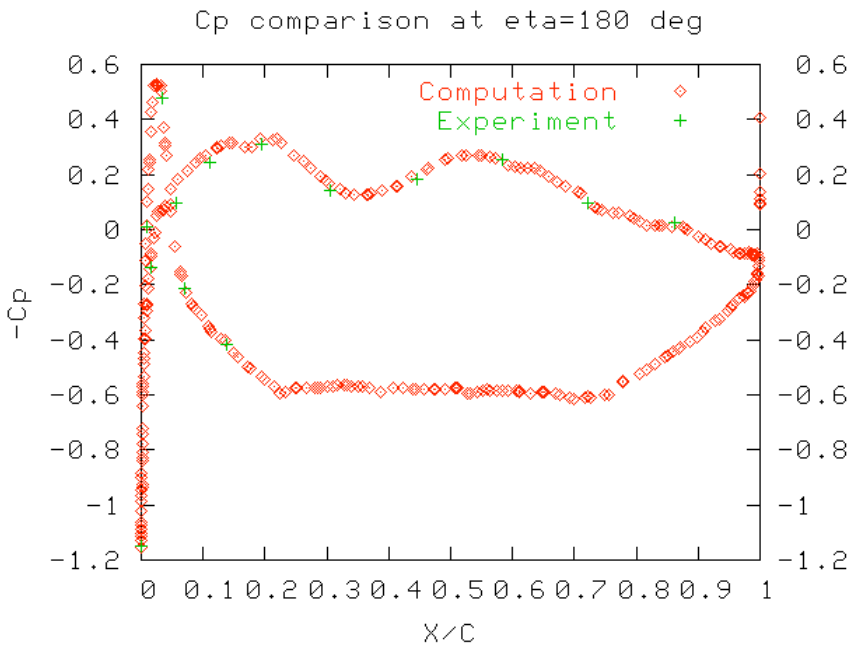
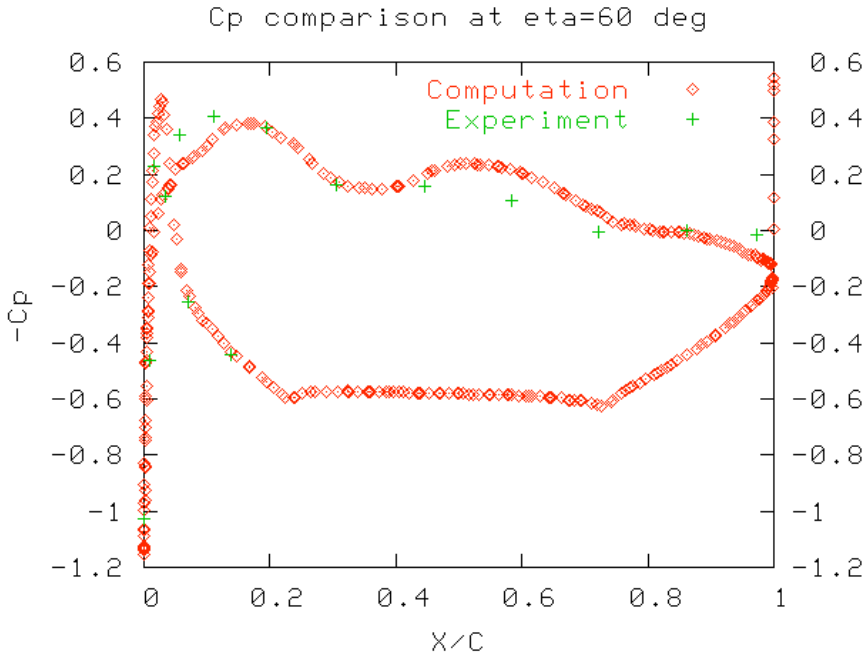
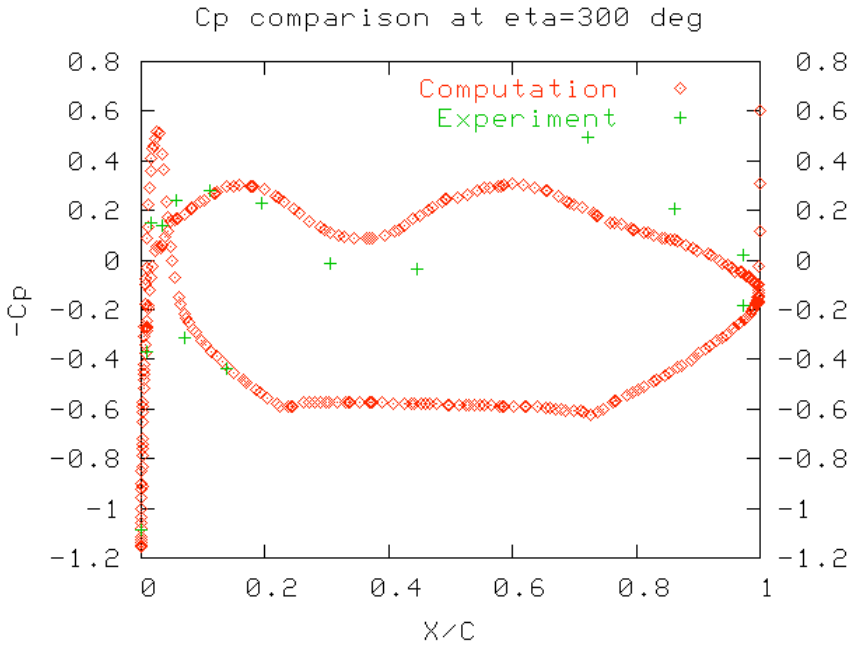
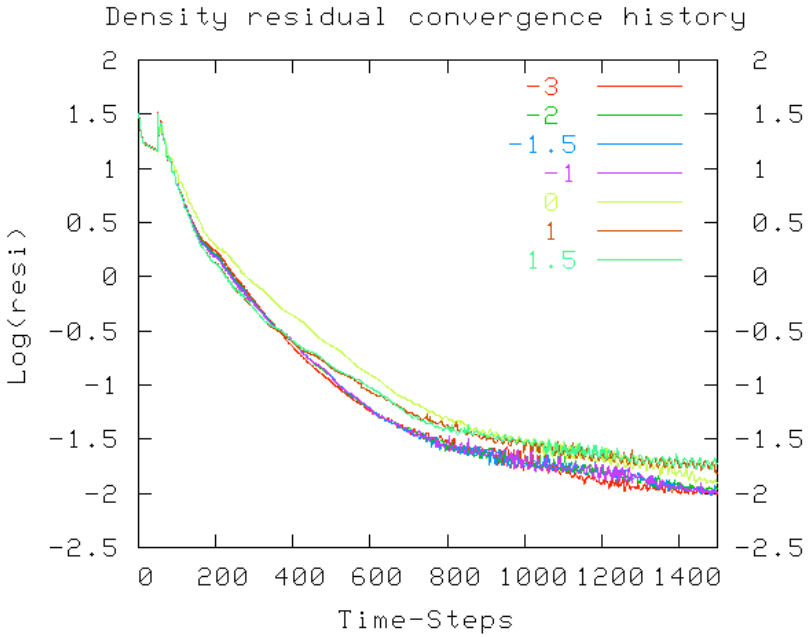


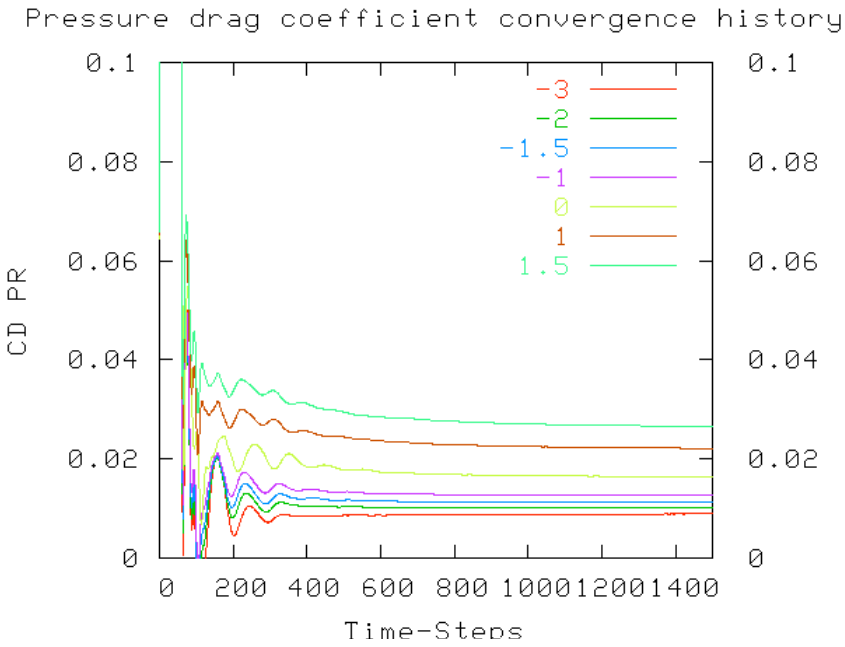


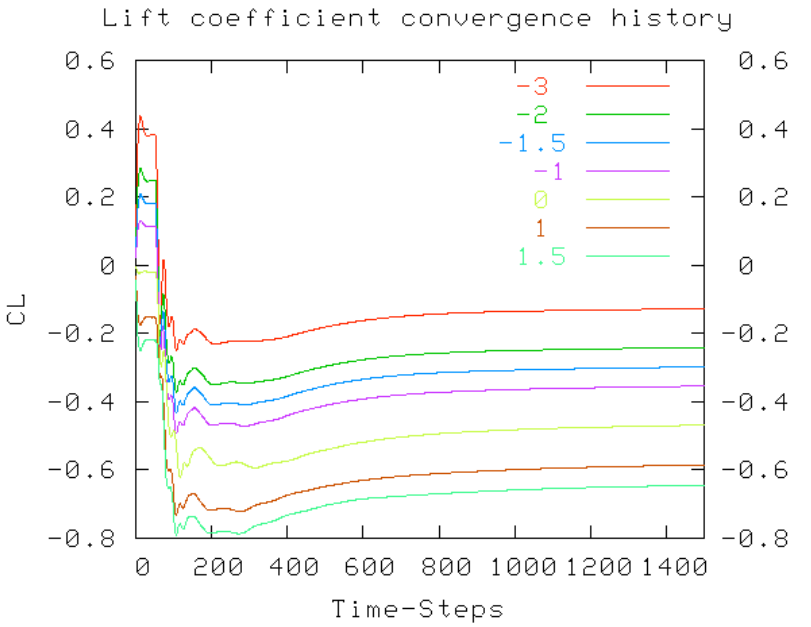


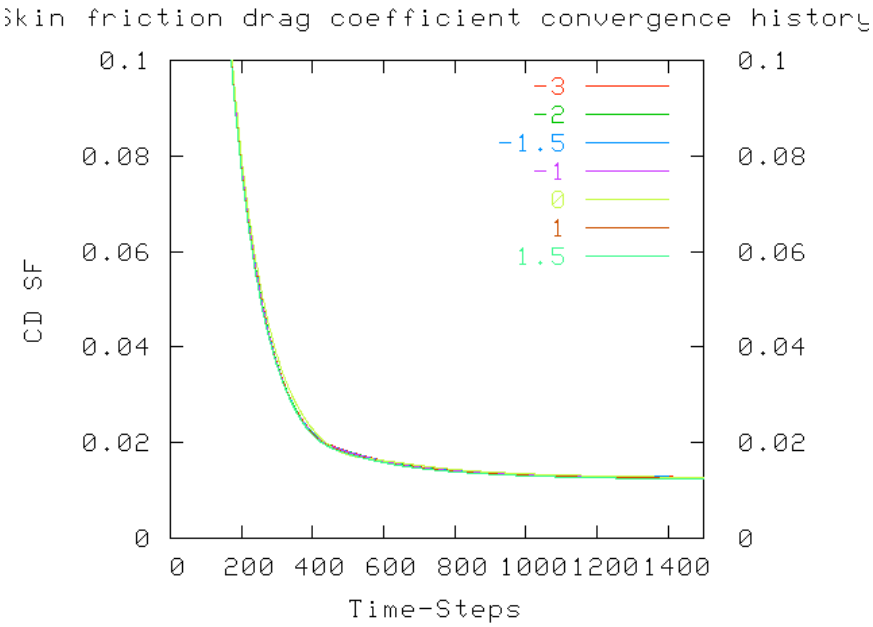


Test case 2: Convergence history for wing/body configuration









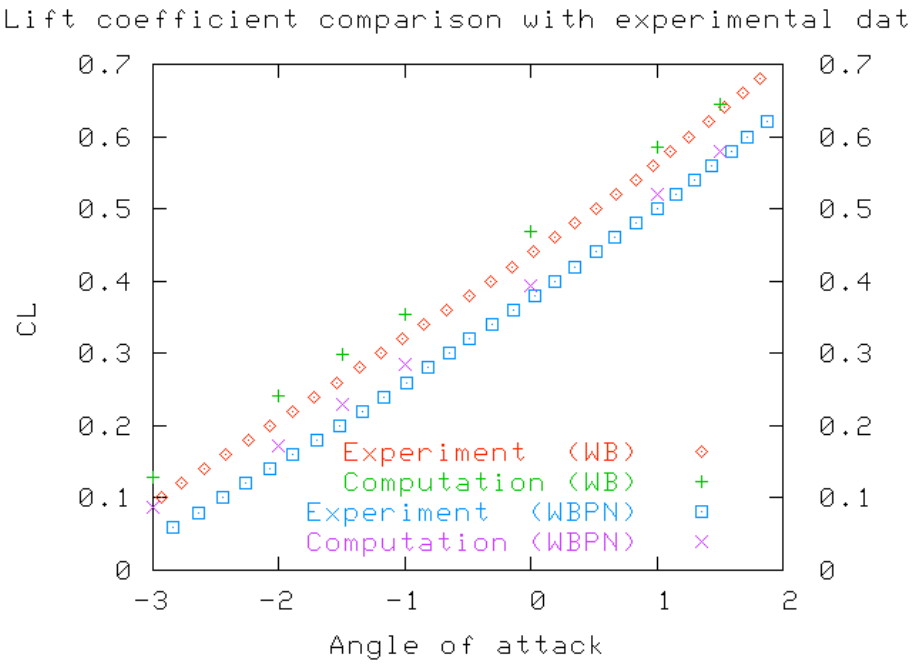
Test case 2: Wing/body Configuration

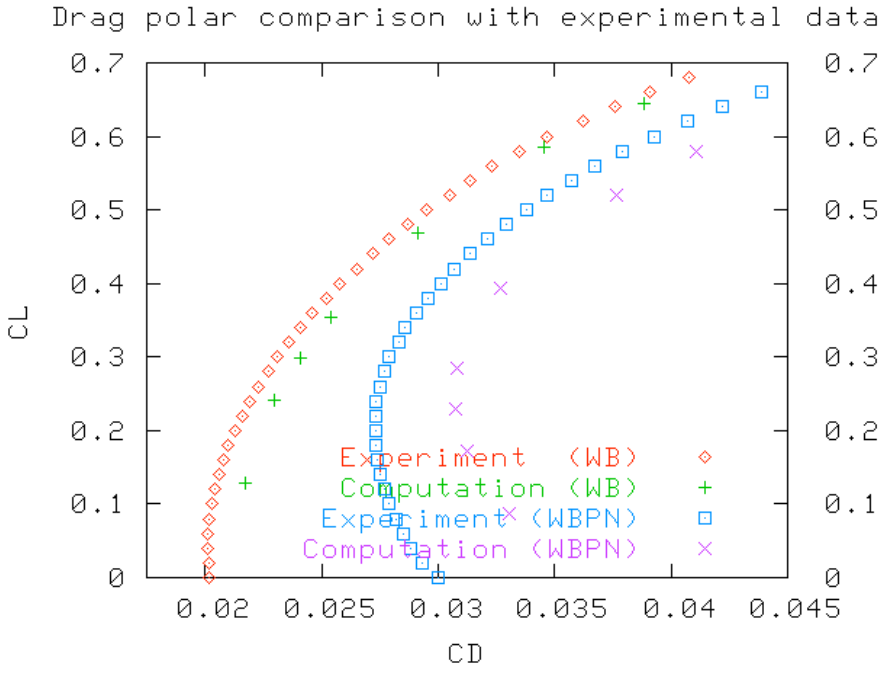
Alpha	CL_TOT	CD_TOT	CD_PR	CD_SF	CD-CL2/PA	CM_TOT
-3	0.128	0.02170	0.00891	0.01279	0.02115	-0.1483
-2	0.242	0.02299	0.01022	0.01278	0.02103	-0.1423
-1.5	0.298	0.02408	0.01131	0.01278	0.02110	-0.1394
-1	0.354	0.02543	0.01269	0.01274	0.02123	-0.1364
0	0.469	0.02916	0.01643	0.01273	0.02179	-0.1305
1	0.585	0.03458	0.02212	0.01246	0.02311	-0.1222
1.5	0.645	0.03887	0.02655	0.01232	0.02493	-0.1184

Test case 2: Wing/body/nacelle/pylon Configuration

Alpha	CL_TOT	CD_TOT	CD_PR	CD_SF	CD-CL2/PA	CM_TOT
-3	0.088	0.03303	0.01742	0.01561	0.03277	-0.1495
-2	0.172	0.03128	0.01558	0.01570	0.03029	-0.1428
-1.5	0.230	0.03078	0.01512	0.01566	0.02900	-0.1352
-1	0.285	0.03080	0.01518	0.01562	0.02808	-0.1340
0	0.394	0.03268	0.01707	0.01561	0.02748	-0.1274
1	0.520	0.03767	0.02154	0.01612	0.02861	-0.1206
1.5	0.580	0.04110	0.02507	0.01602	0.02983	-0.1134

Test case 2: Fully turbulent flow





Conclusions

- FEFLO was able to predict basic drag levels for DLR-F6 configuration on relatively coarse meshes in a timely fashion.
- Good agreements have been found between computational and experimental pressure data, especially at the inboard wing sections.
- Over-predicted drags for wing/body/pylon/nacelle configuration may be due to (1) lack of mesh resolution and (2) fully turbulent assumption, nevertheless require further investigation.
- Slow convergence for WBNP configuration at lower angle of attack requires a further study.