Progress and Future Prospect of CFD in Aerospace

- Observation from 30 years research -

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JAXA: Japan Aerospace Exploration Agency

Three aerospace organizations before October 2003

* National Space Development Agency (NASDA)
* National Aerospace Laboratory (NAL)
* Institute of Space and Astronautical Science (ISAS)

JAXA was established on October 1, 2003 with about $ 1.7 billion/year budget and 1700 personnel

OUTLINE

- Glance back 30 years CFD research in Aerospace
- Discuss Current Status of CFD in Aerospace
  - What have we done in the past?
  - Have we done it in the right direction?
- Find clues for Future Prospect of CFD
  - Evolutional and Revolutionary Efforts toward the better use of CFD technology

Computer Speed and Memory for CFD

Supercomputer
1 GFLOPS performance, 256MB memory

It took 2 hours computer time in 1985

Now, takes 10 to 30 min. even on PC

3-D Navier-Stokes with 200,000 grid points

Current Pentium PC 2GB memory

→ 1,600,000? grid points

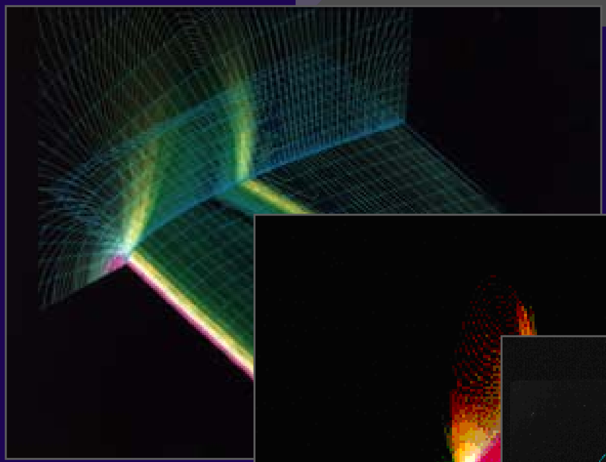
64 bits PC (Itanium II, …) with 8GB memory

→ 6,400,000? grid points

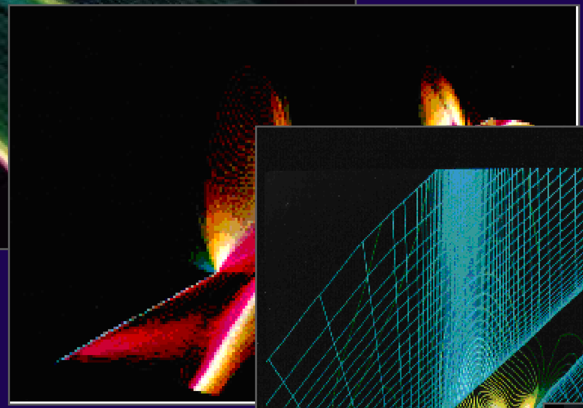
20-30 years CFD research

Does CFD replace Wind tunnel?

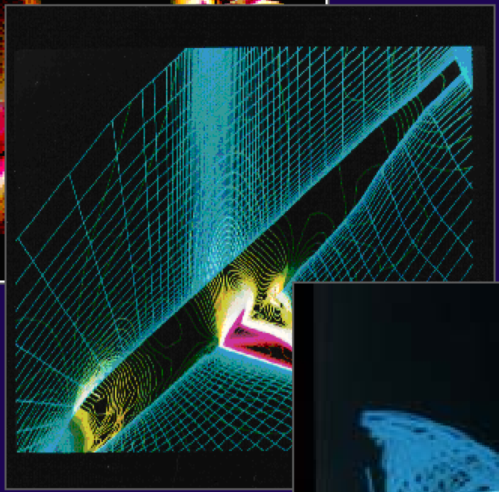
Does Wind tunnel replace CFD?



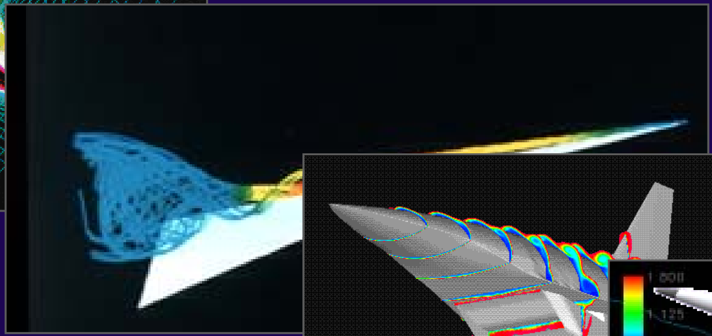
1984



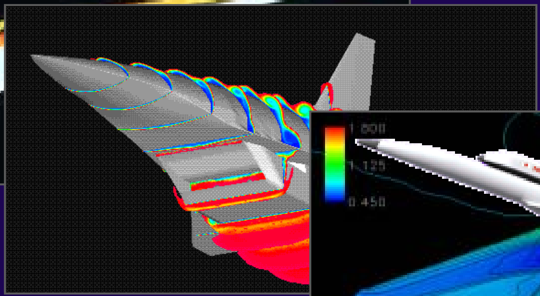
1985



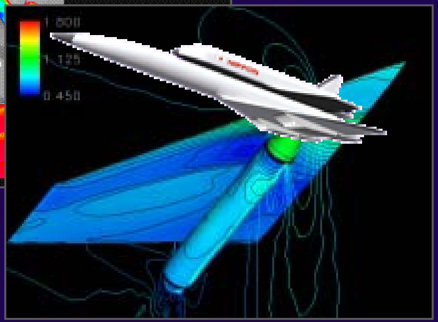
1986



1987



1991

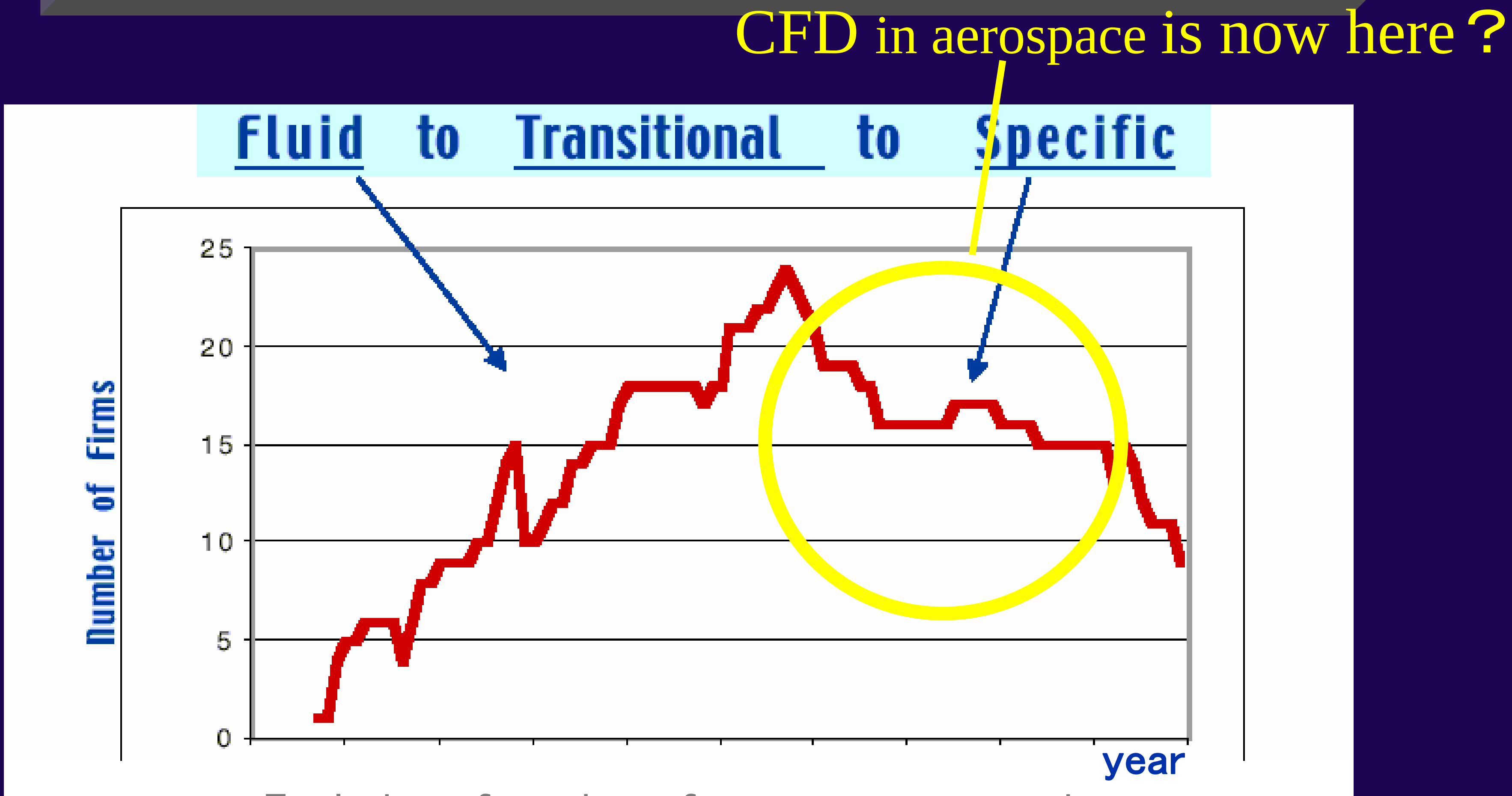


2003

More complex configurations

Where are we now?

Product Evolution -Utterback 's Theory



Evolution of number of aerospace companies

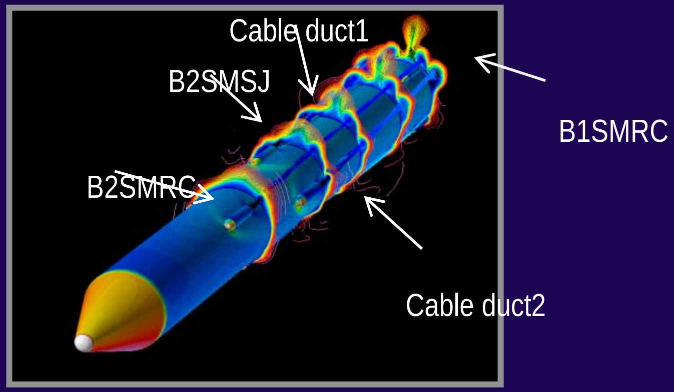
- Product Innovation dominates fluid phase
- Process Innovation dominates later phases

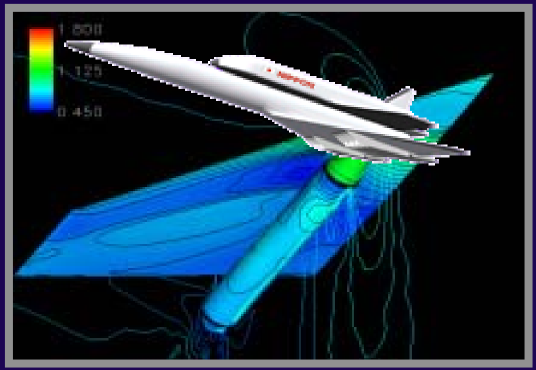
Viewgraph taken from the general lecture by Prof. Murman in ICAS2000

Status of Current CFD

- Simulations with order of million grid points are now feasible on PC's.

- Good software products are available for grid generation, flow simulation and flow visualization.

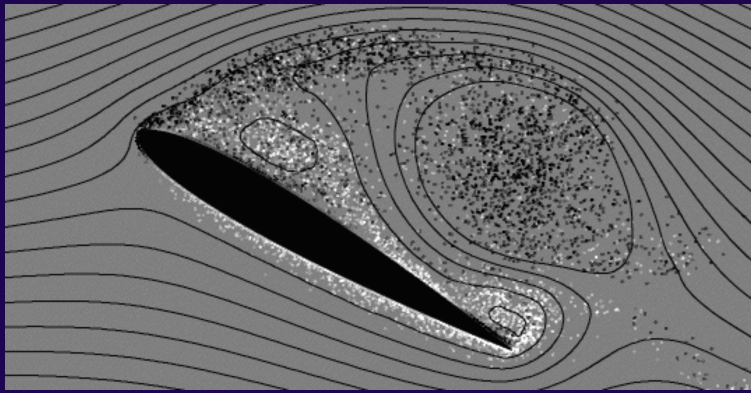




- There remain problems that are geometrically simple but are difficult to simulate.

Thin-Airfoil Stall Characteristics

Simulation of the flow near stall is an interesting but challenging problem.

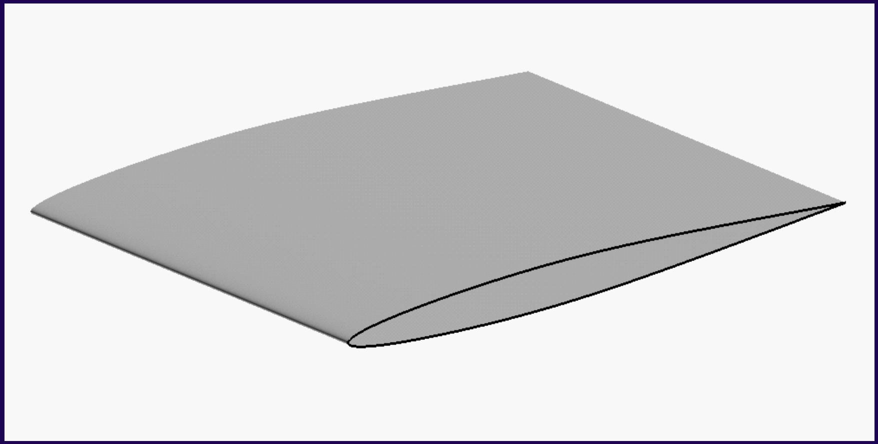


<u>CFD Workshop held at NAL Japan on 2000</u>

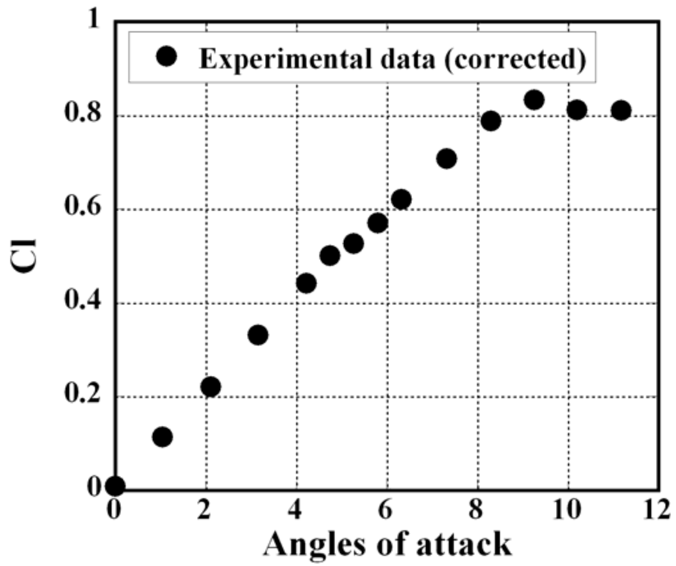
NACA63012: Leading-edge stall

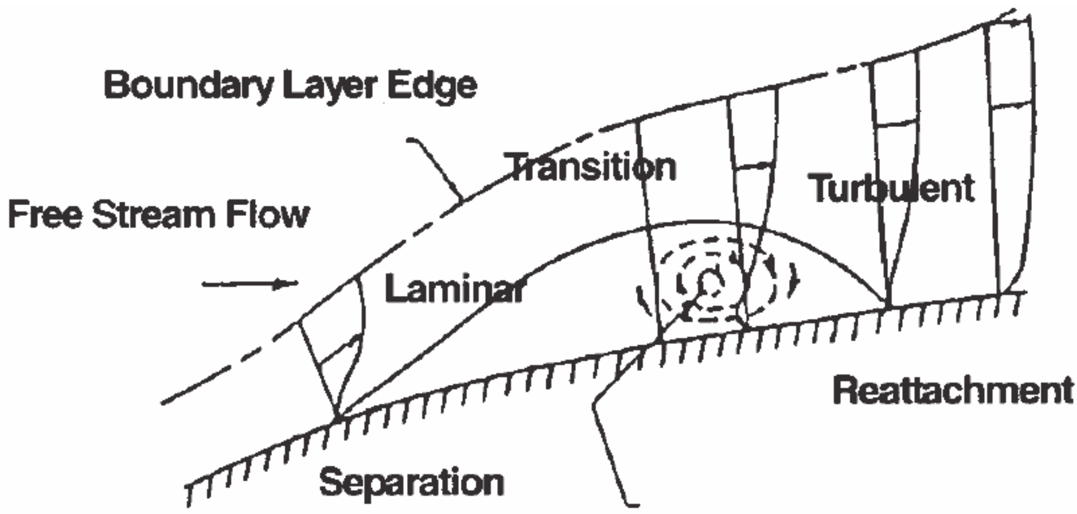
NACA63018: Trailing-edge stall

NACA64A006: Thin-airfoil stall



NACA64A006 Stall Characteristics

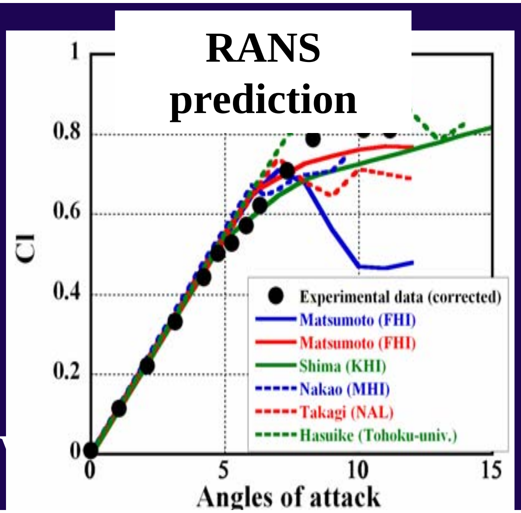




Attached flow

Laminar bubble flow

Fully separated flow



Taken from former NAL website

LES (Large Eddy Simulation) may be a good choice, but …

- To resolve the boundary layer at practical Re, more than 100 million grid points and order of 10,000 hours computer time on a single processor of leading-edge computers are required.

- Accurate prediction methods within acceptable computational cost are required until "Real LES" becomes feasible.

↓

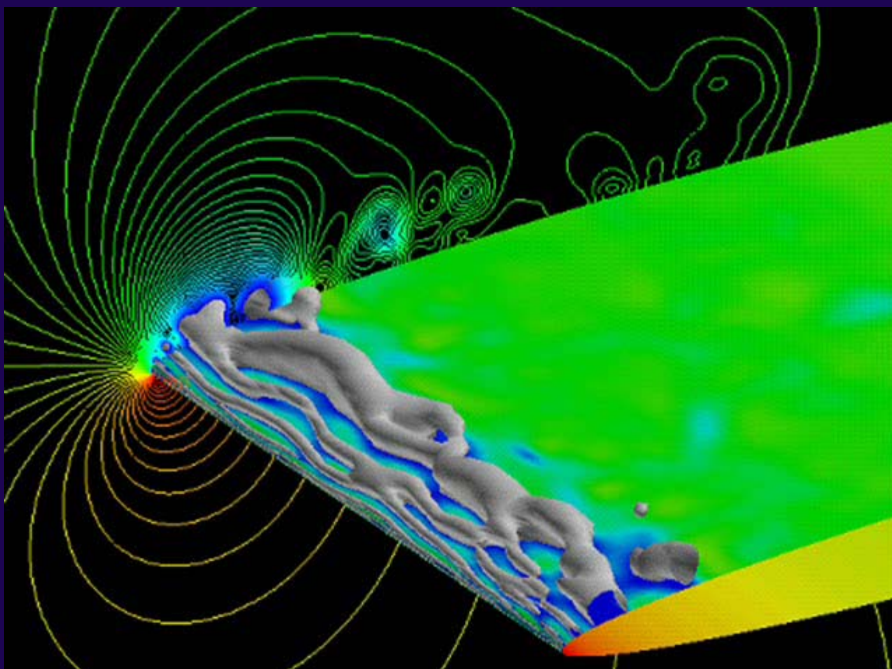
LES/RANS Hybrid Method

DES (Detached Eddy Simulation), LES/RANS hybrid method

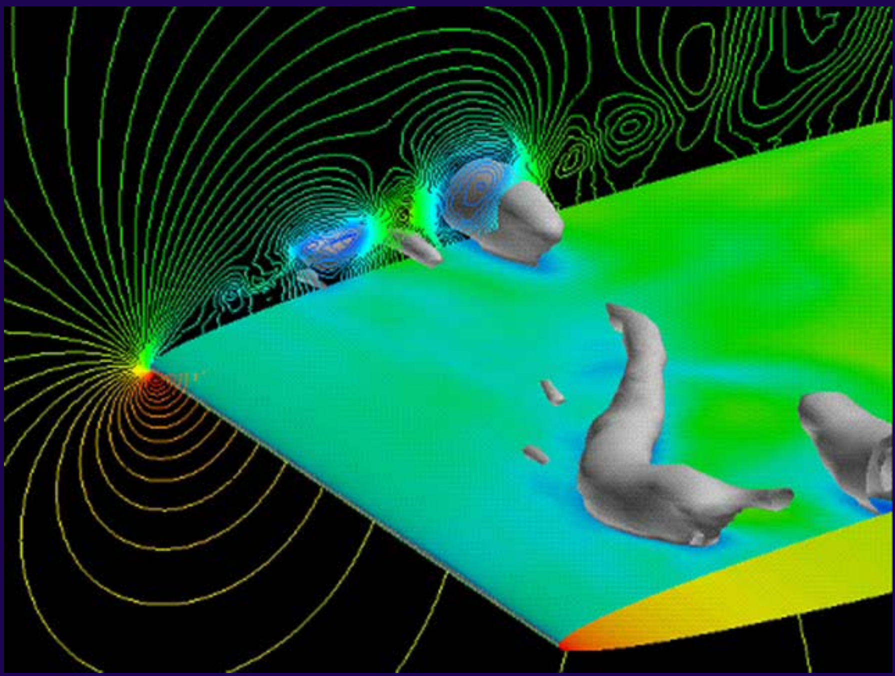
Computed total pressure isosurfaces

–LES/RANS hybrid-

NACA64A006 (Exp.: NACA TN1923)



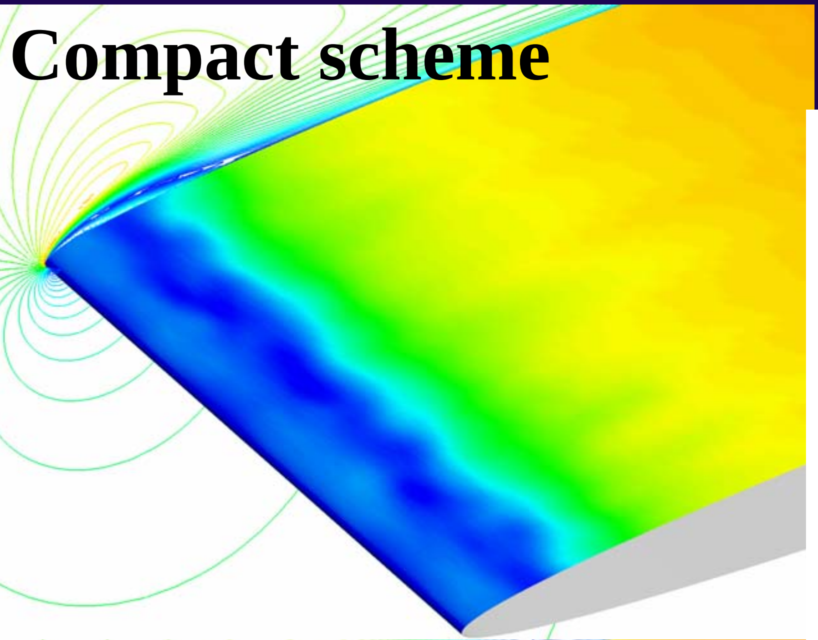
Compact scheme

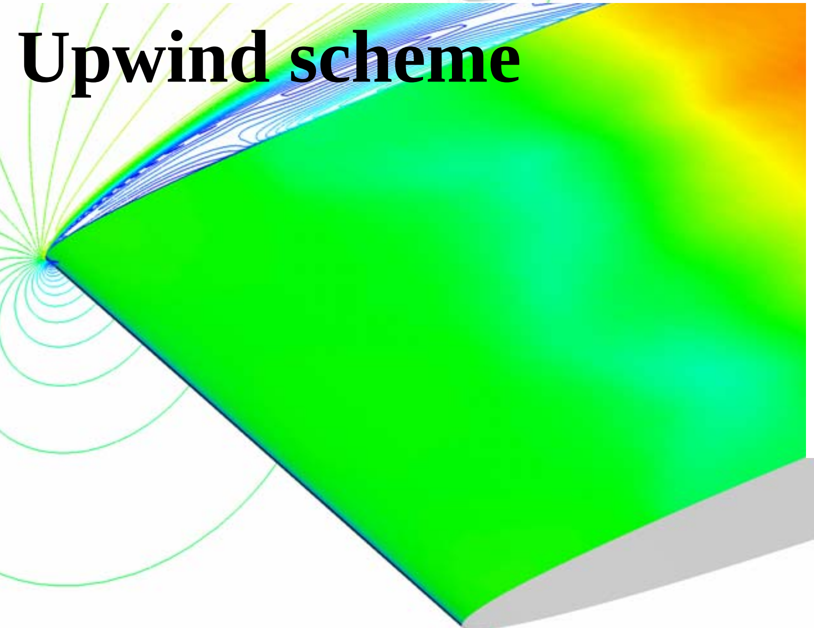


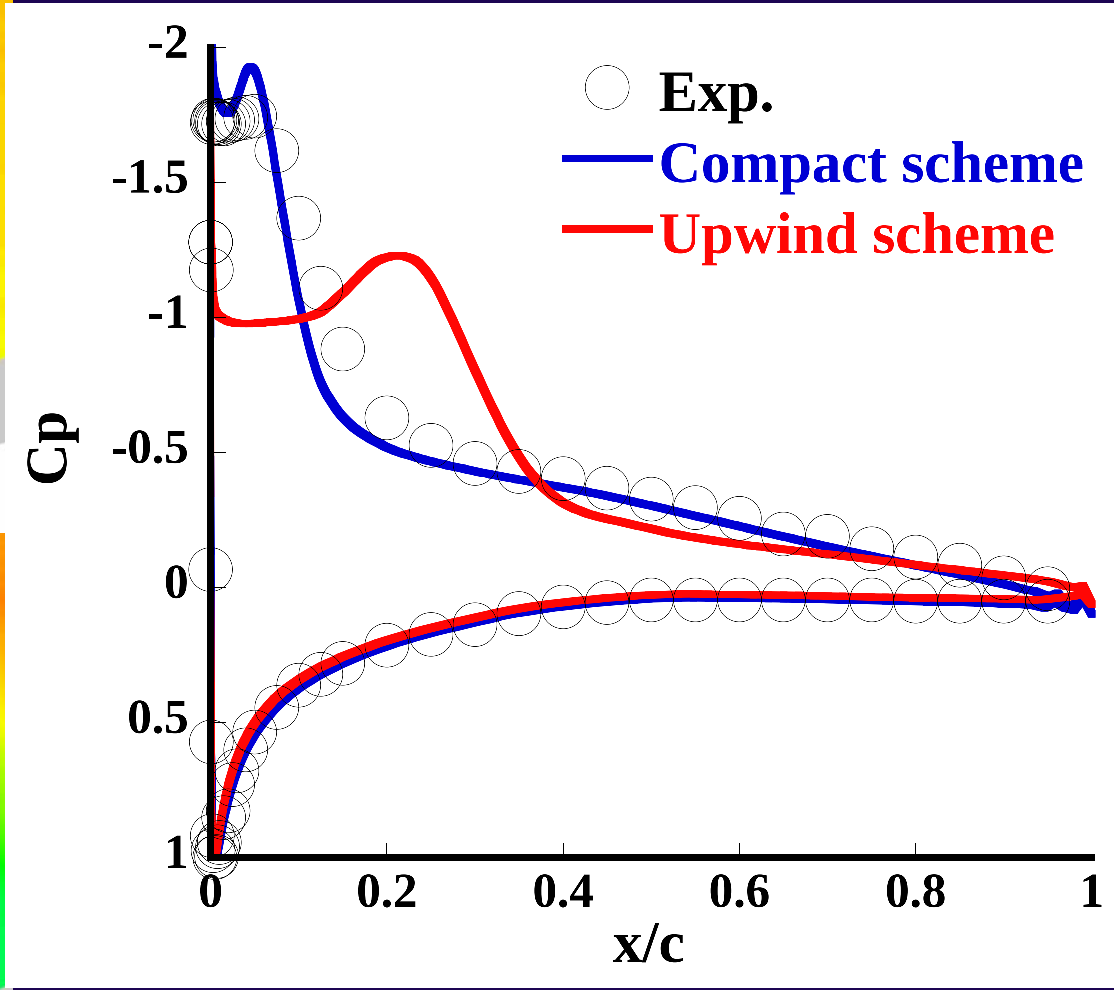
Upwind scheme

Mach number: 0.17, Reynolds number: 5.8×10^{6}

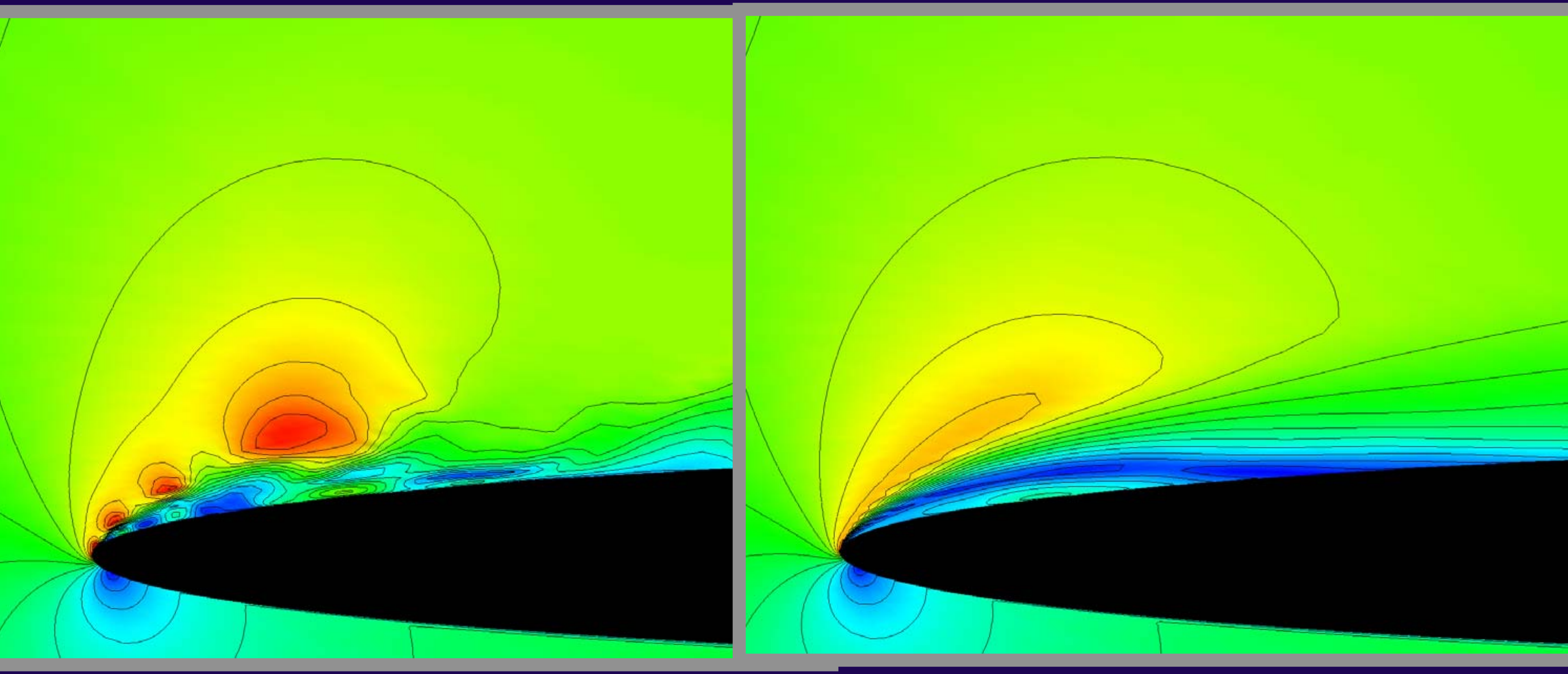
Time-Averaged Cp Distributions : α =5.5







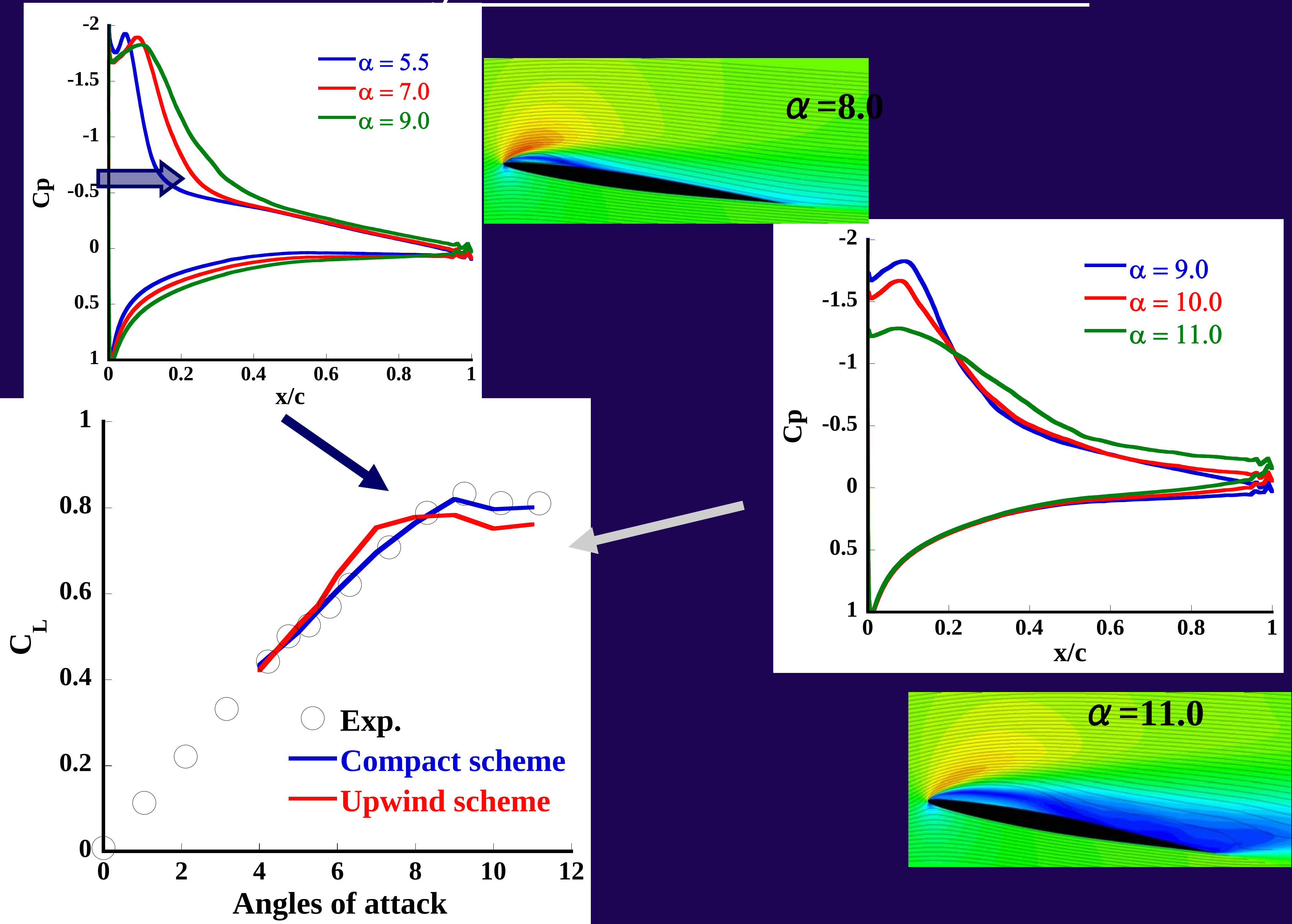
Formation of Short Bubble : α =5.5



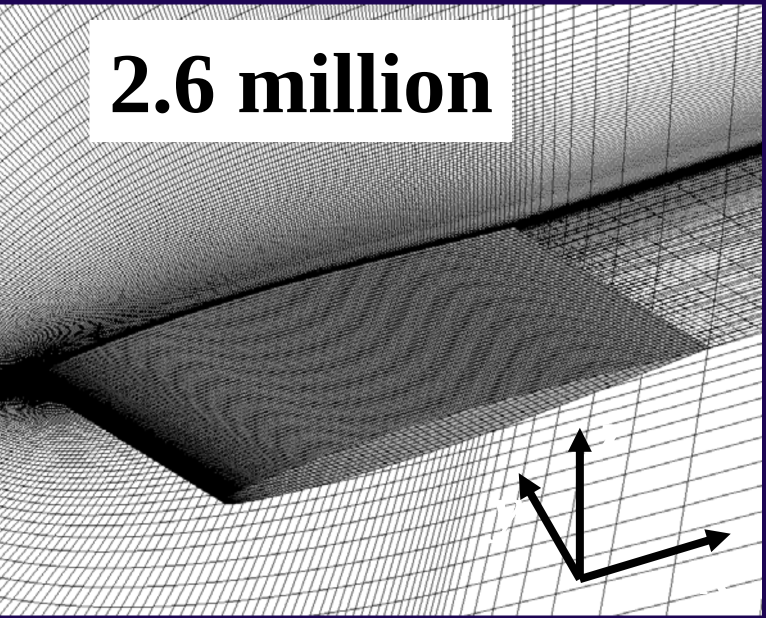
Instantaneous

Time-averaged

Aerodynamic Characteristics



Computational Grids and Cost



Present grid

Average mesh resolution on the suction surface

$$(\Delta x^+, \Delta y^+, \Delta z^+) = (537, 1469, 1.8)$$

LES in LESFOIL project

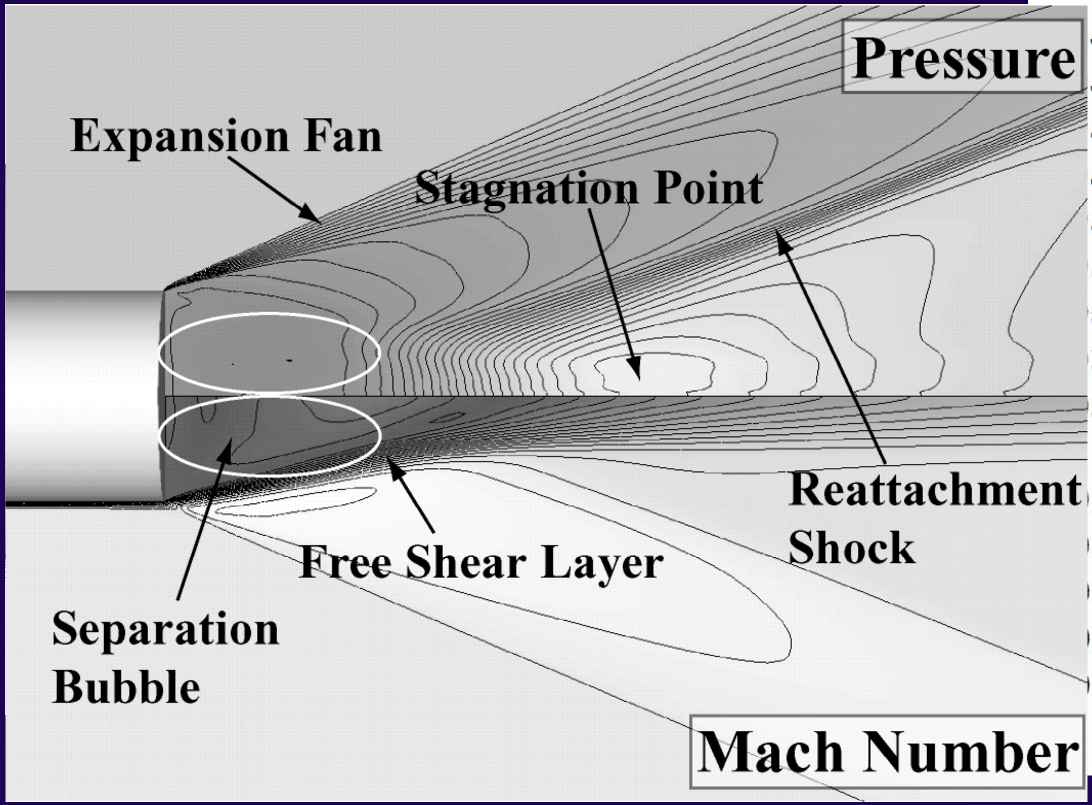
ONERA: Mary, I., and Sagaut, P.

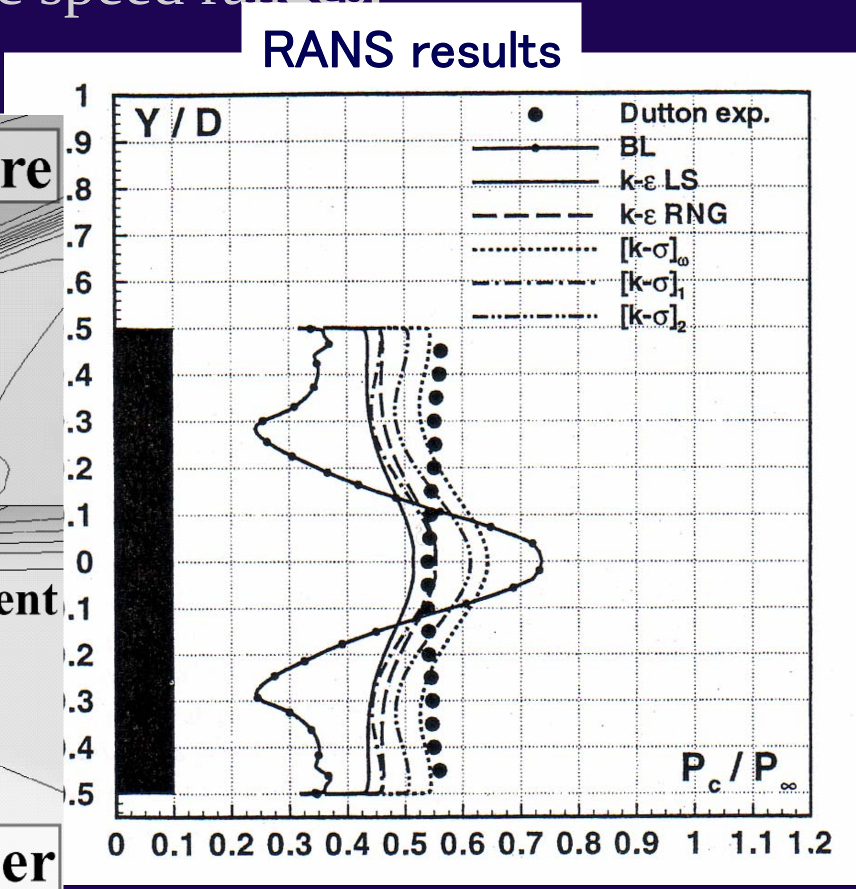
$$(\Delta x^+, \Delta y^+, \Delta z^+) = (60, 25, 2)$$

Computational cost is reduced to 1/500.

Supersonic Base Flows

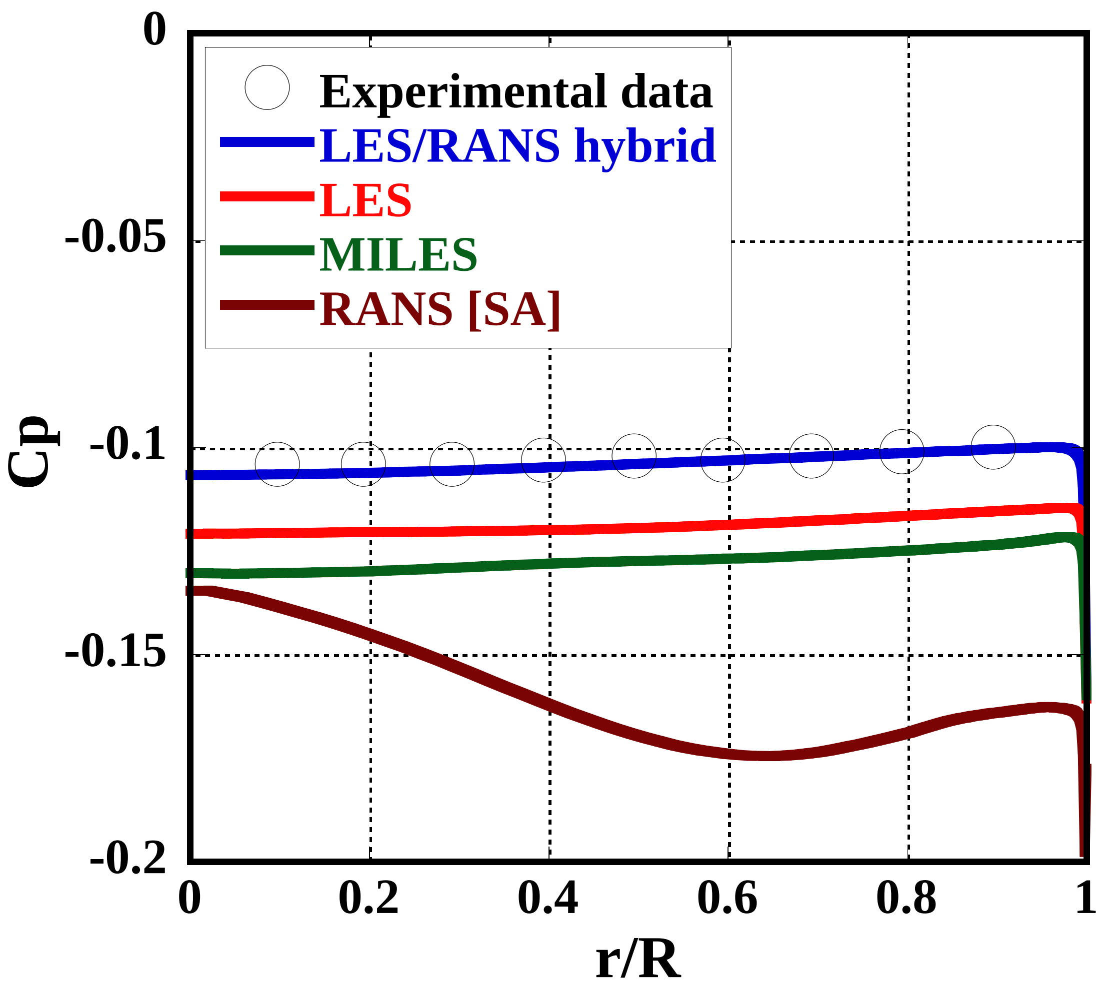
Base pressure prediction is important for the drag estimation from high subsonic to low supersonic speed ranges.

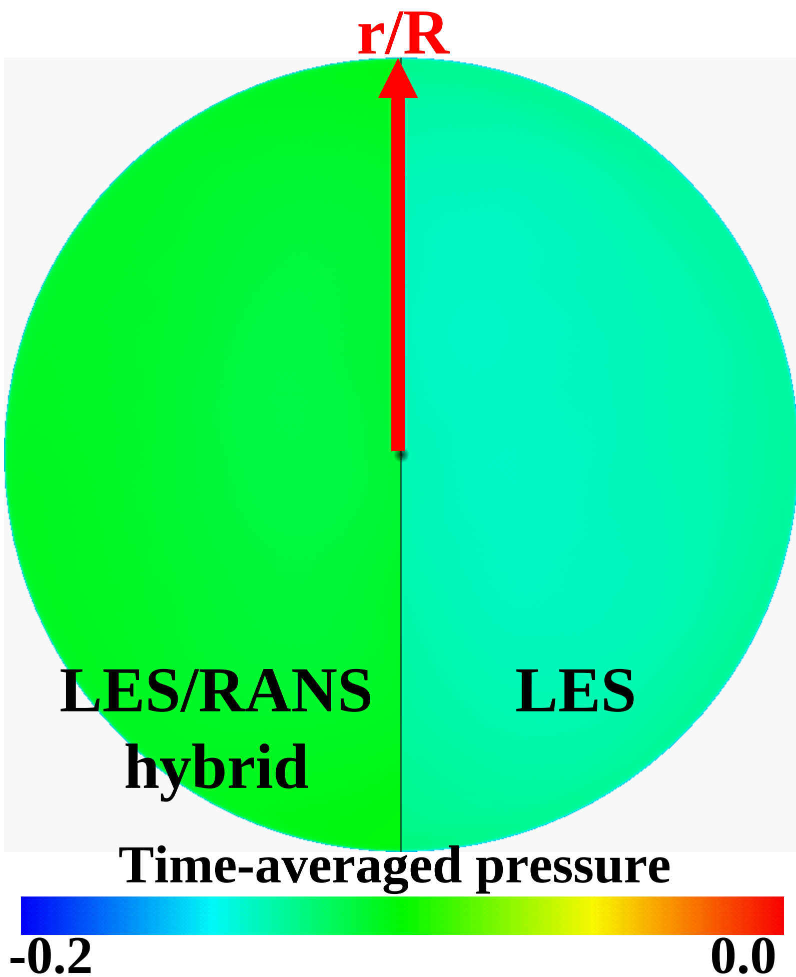




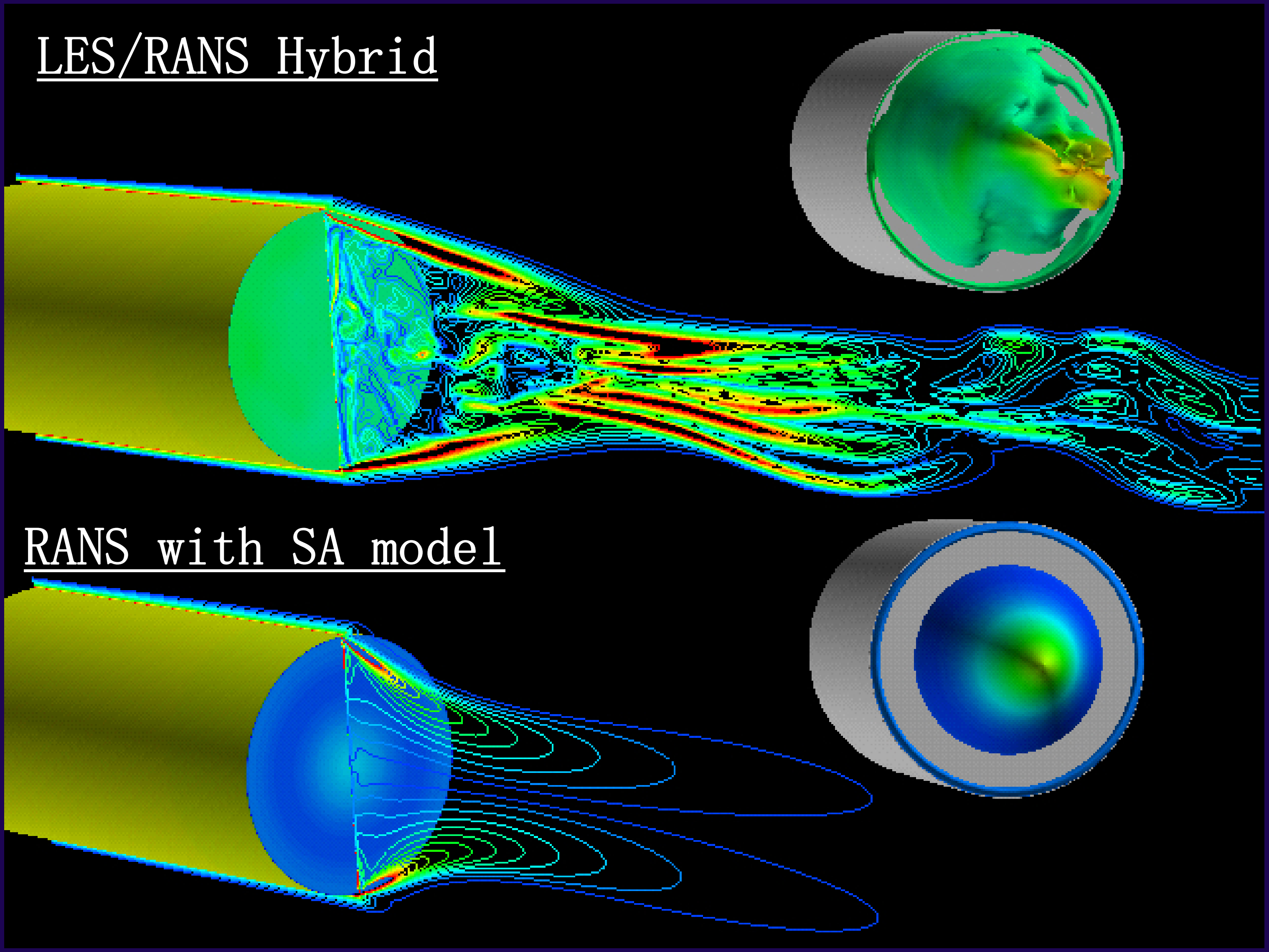
AIAA J., 2001

Base Pressure Distributions

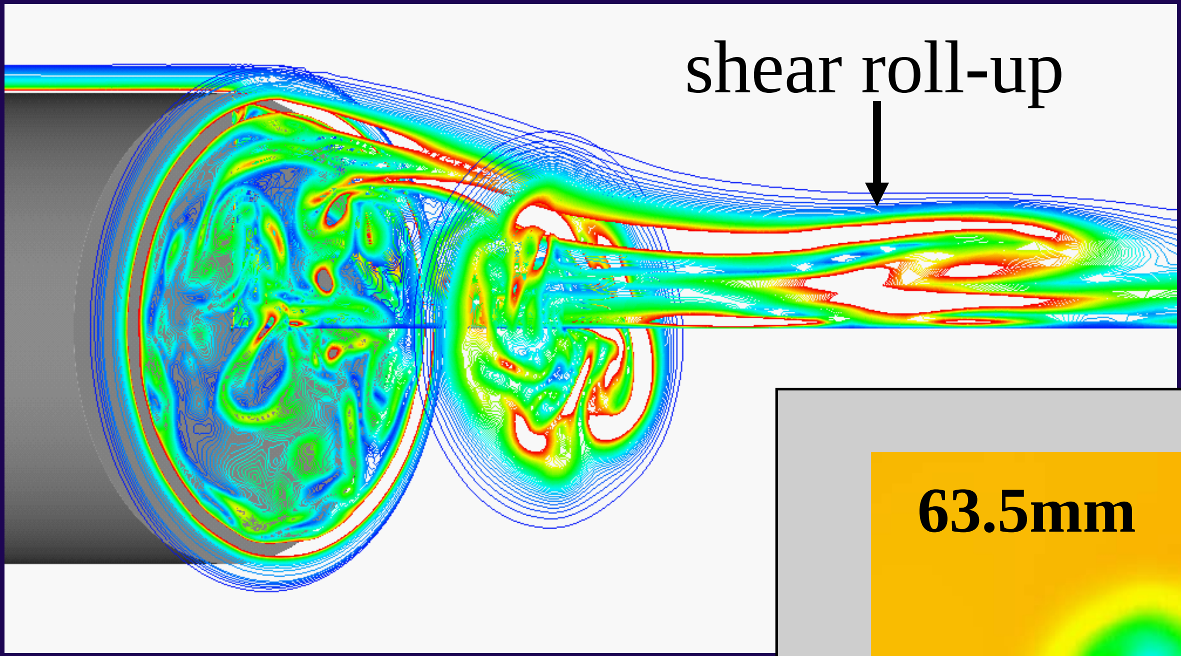




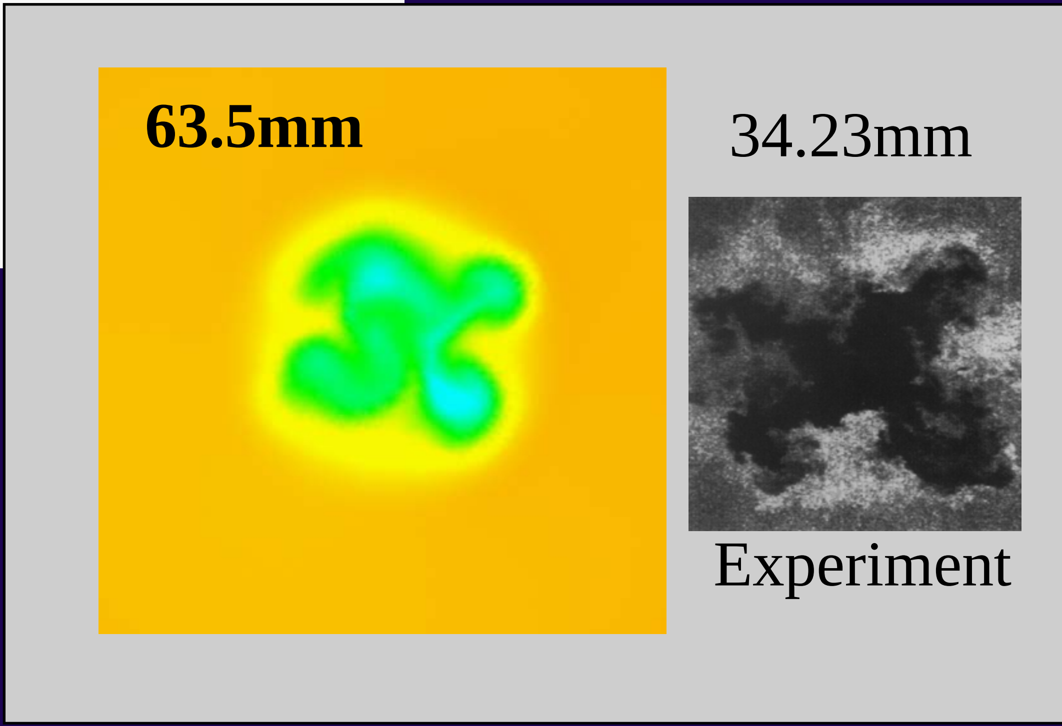
LES/RANS hybrid vs. Unsteady RANS



Unsteady Flow Structure



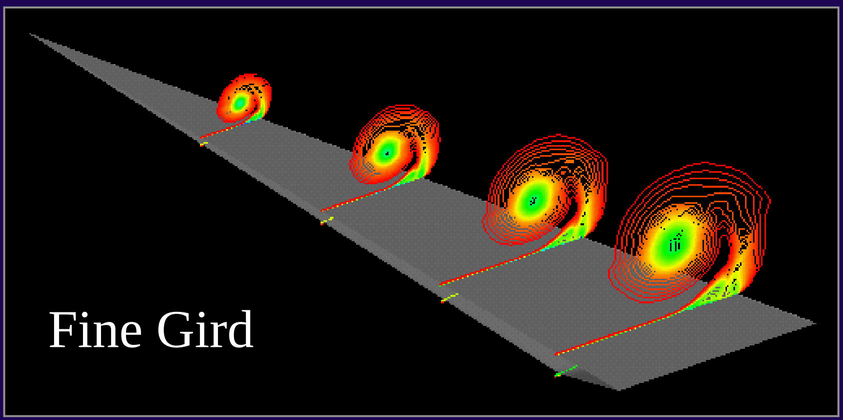
Mushroom-shaped turbulence structure behind the stagnation point: endview

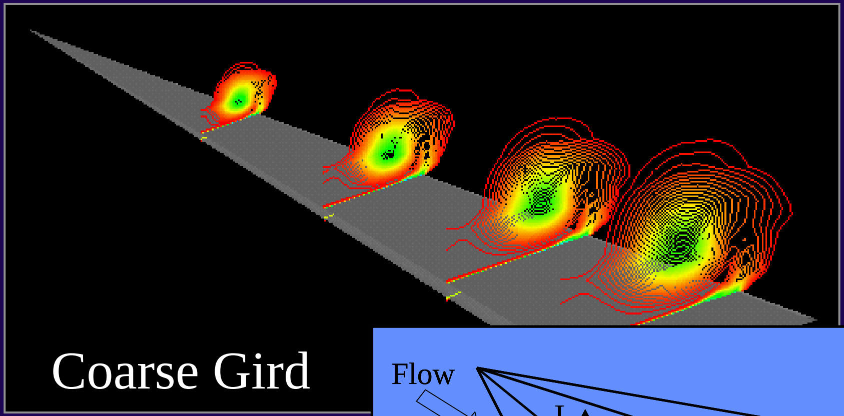


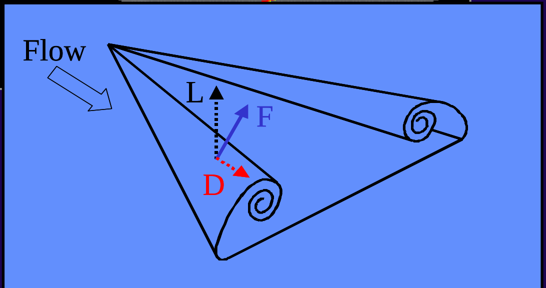
LES/RANS hybrid method captures unsteady flow features.

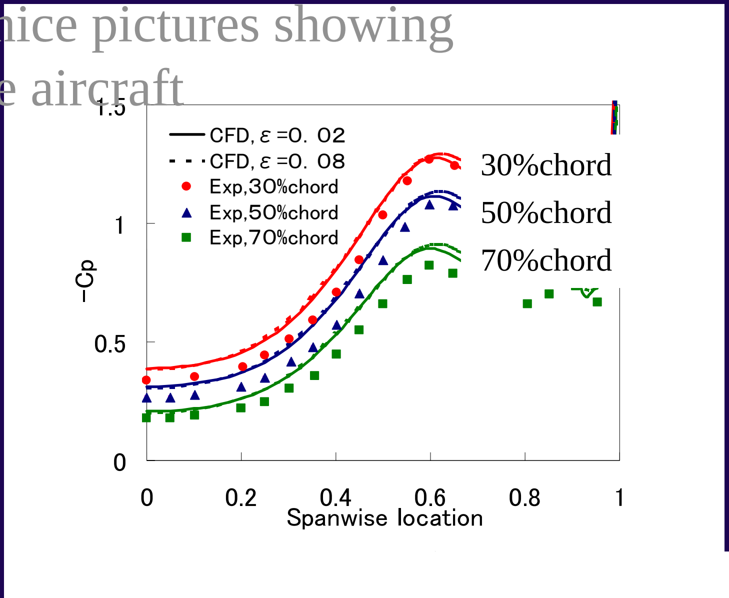
LESV Flow Field over a Simple Delta Wing

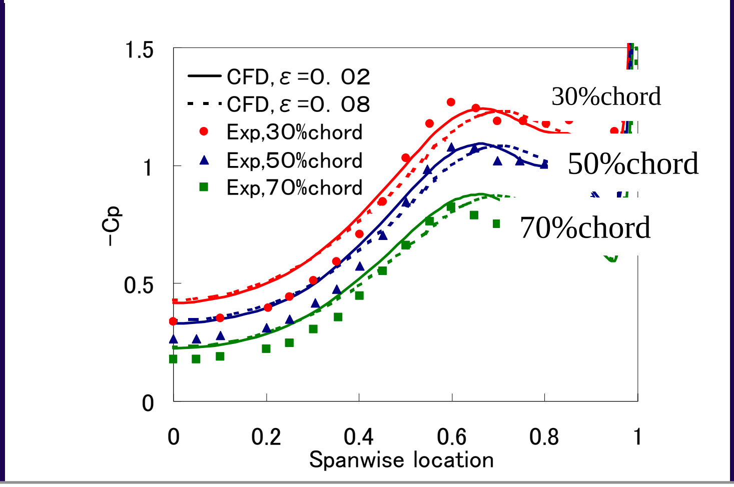
These days, we have a chance to see a lot of nice pictures showing LESV particle traces for complex fighter-type aircraft





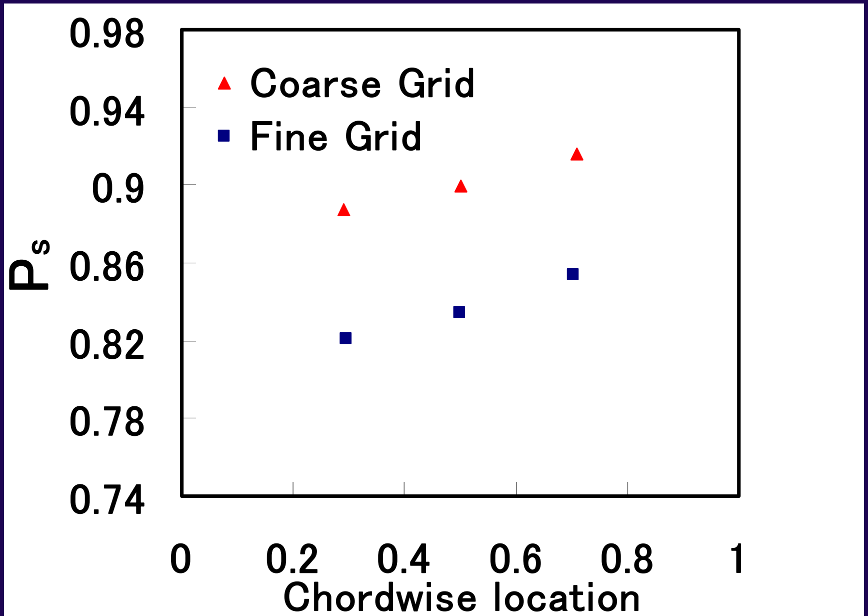


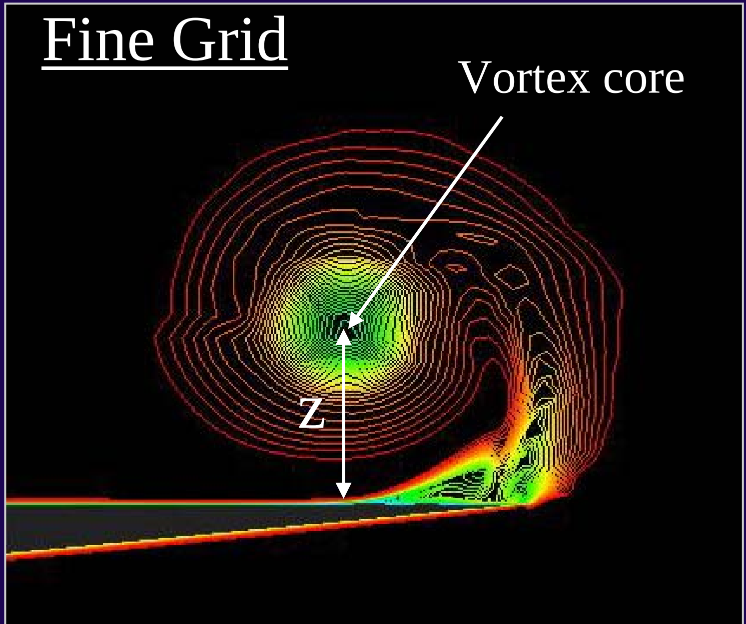


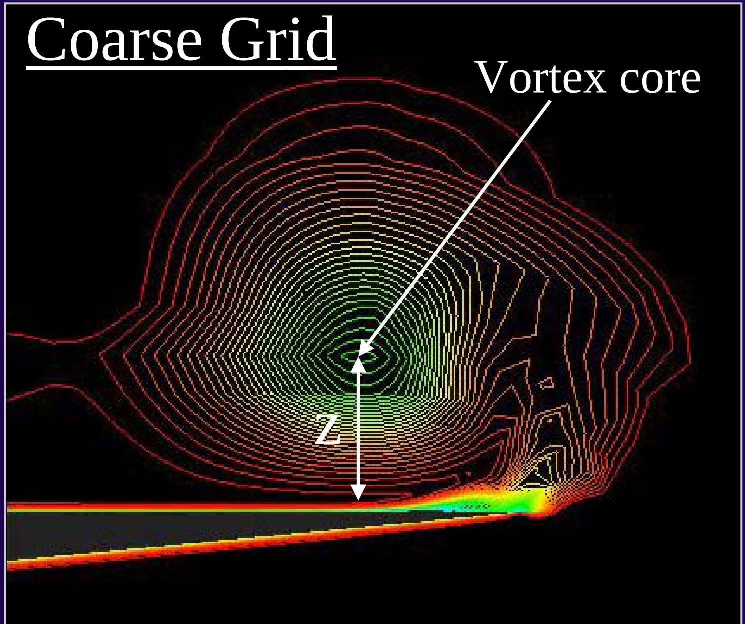


Pressure distributions over the upper surface

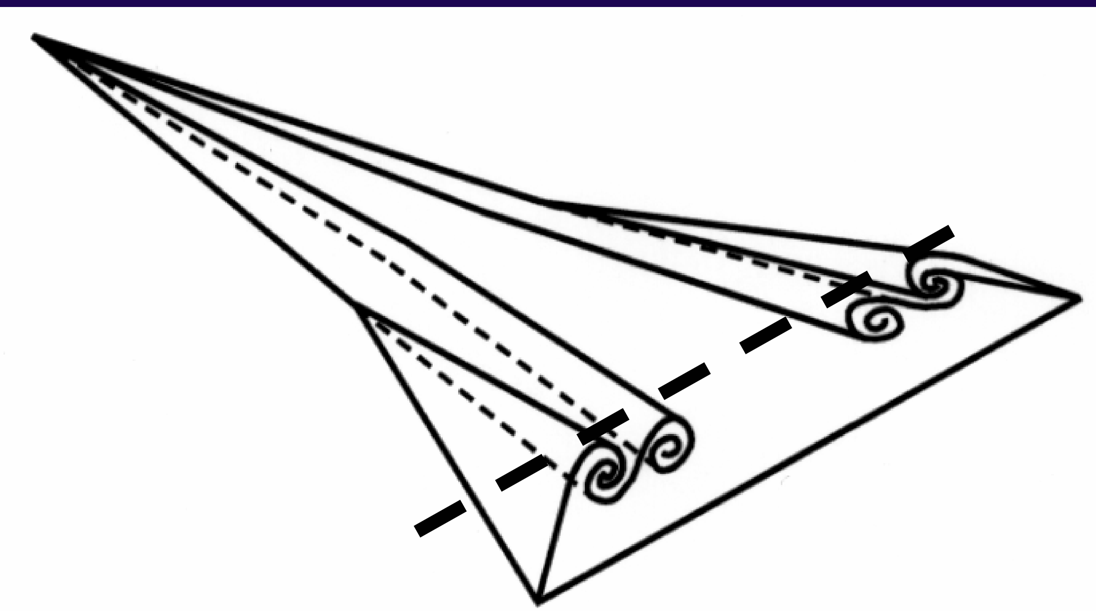
Minimum Pressure of the Vortex Core

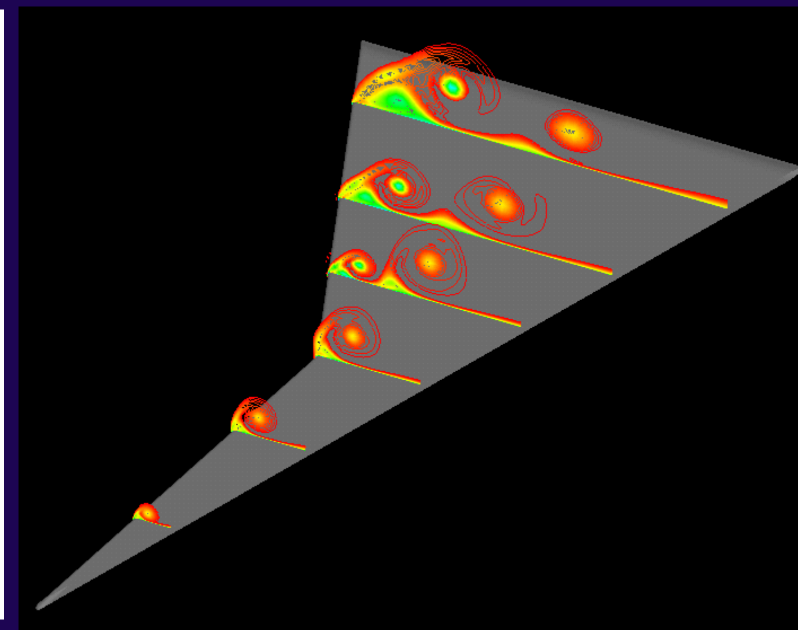






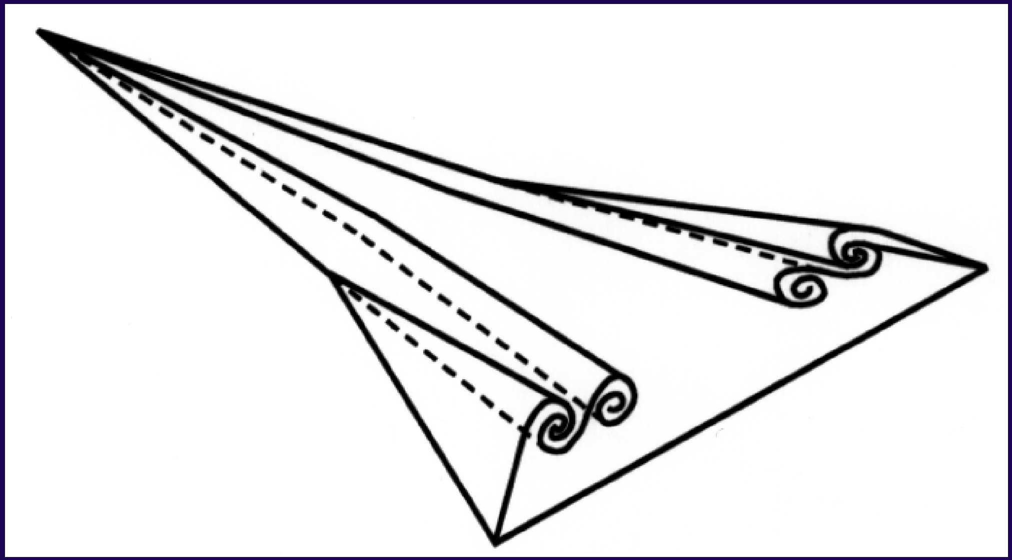
Strake-Delta Wing Flow Field





RANS/compact

- LES/RANS hybrid method successful for LESV?



- We do not even know which part of the flow field is critically important; leading edge, b. l. over the upper surface, roll-up shear layer,…
  - much more effort necessary for LESV!

Evolutional Effort with Its Background

- There remain problems that look simple but are difficult to simulate.
- Research interest is moving from steady flows to unsteady flows even in engineering problems.

- We will have to shift from RANS simulations to LES/RANS hybrid simulations.

Capturing localized strongly-unsteady flow structure is necessary even for the simulation of steady-state flows

Reconsideration of CFD Work

We have been trying to show the capability of CFD by attacking the simulations for more and more complex configurations.

When considering CFD from the engineering viewpoint,

- Sophisticated simulations are <u>not necessarily</u> useful in design process although they are useful as demonstrations.

- Single large-scale simulation does <u>not necessaril</u>y tell much.

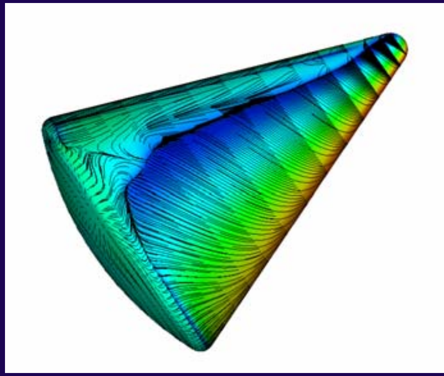
<u>Key for better use of CFD</u>

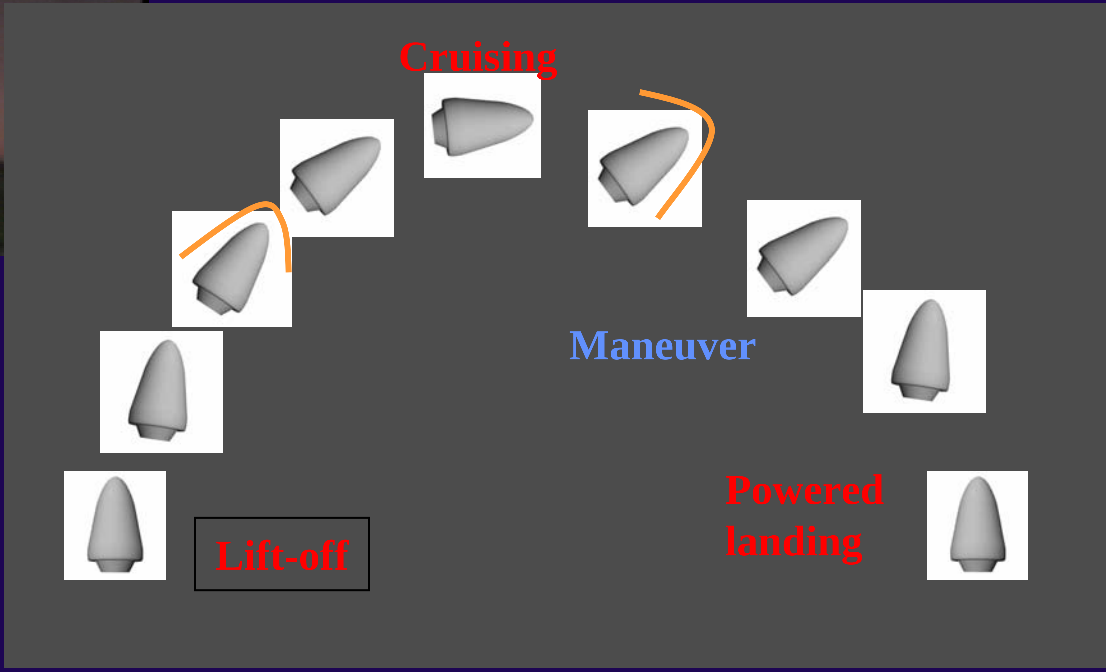
- Decision of right tool for the process of R & D.

It is true that we need to demonstrate an impressive results to extend the boundary. We have to continue it, but that is not everything. We need to spend more time for the analysis of the design process, find out the key bottlenecks and develop proper modeling in certain areas.

Aerodynamics of SSTO-Reusable Launch Vehicle

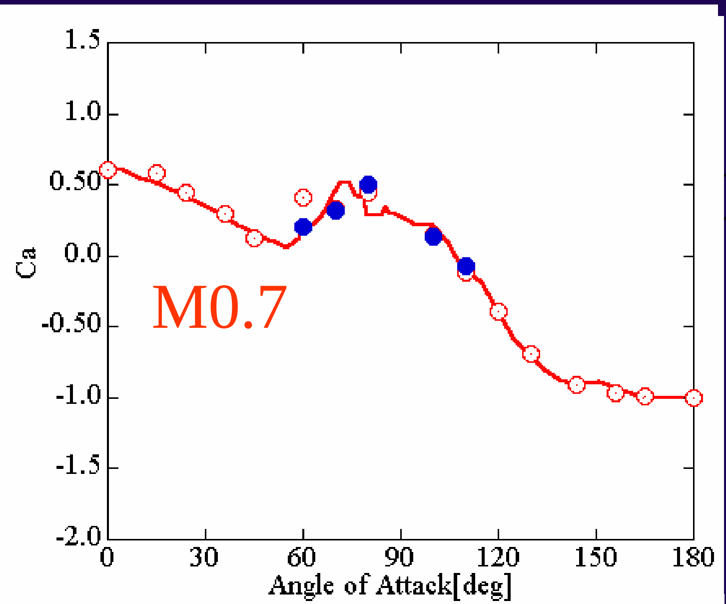
RLV(ISAS)



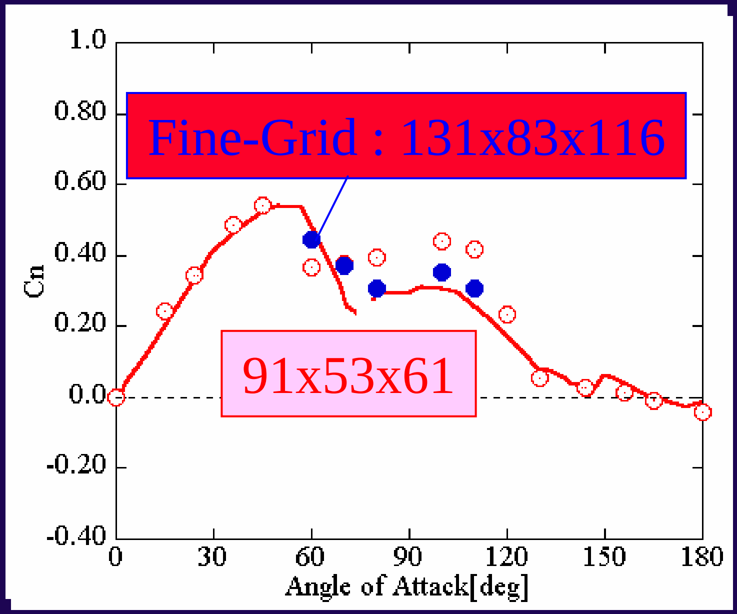


We cannot clearly tell how accurate RANS CFD method is?

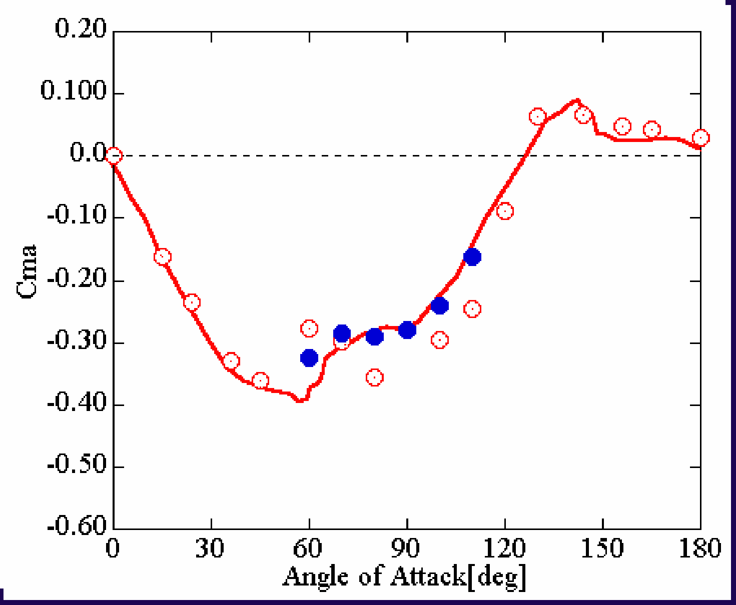
Conventional RANS analysis for Apollo



C_A

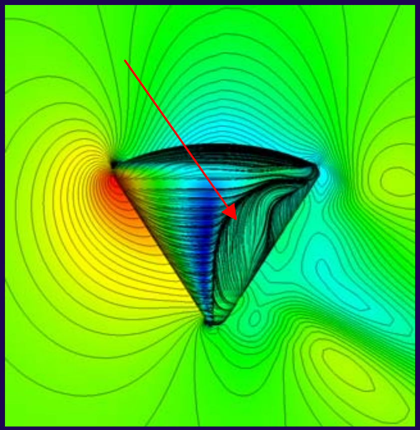


C_N



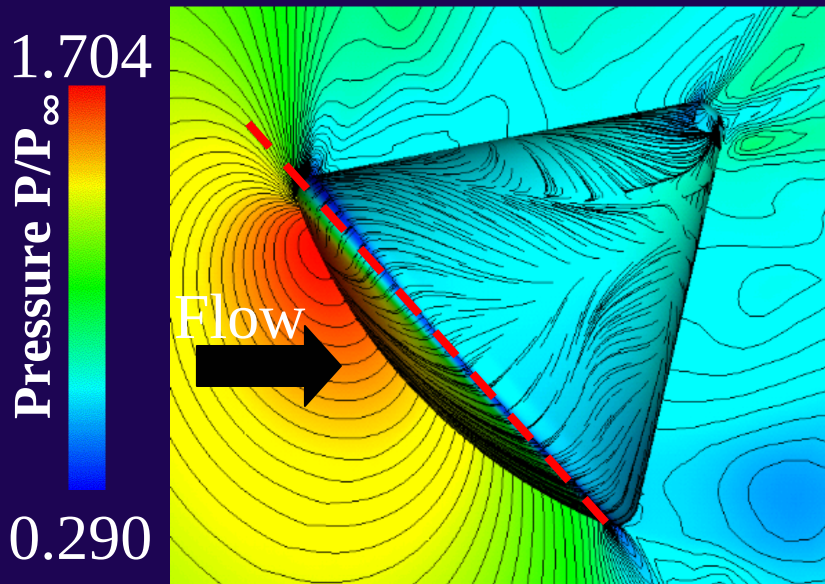
Cma

Separation line

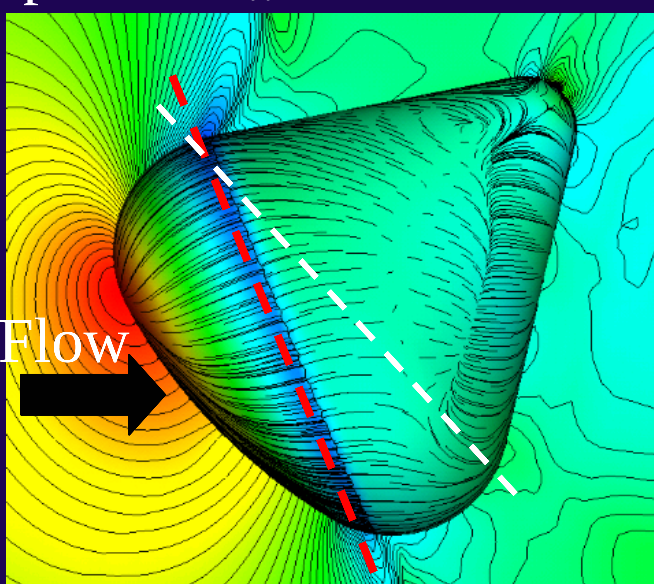


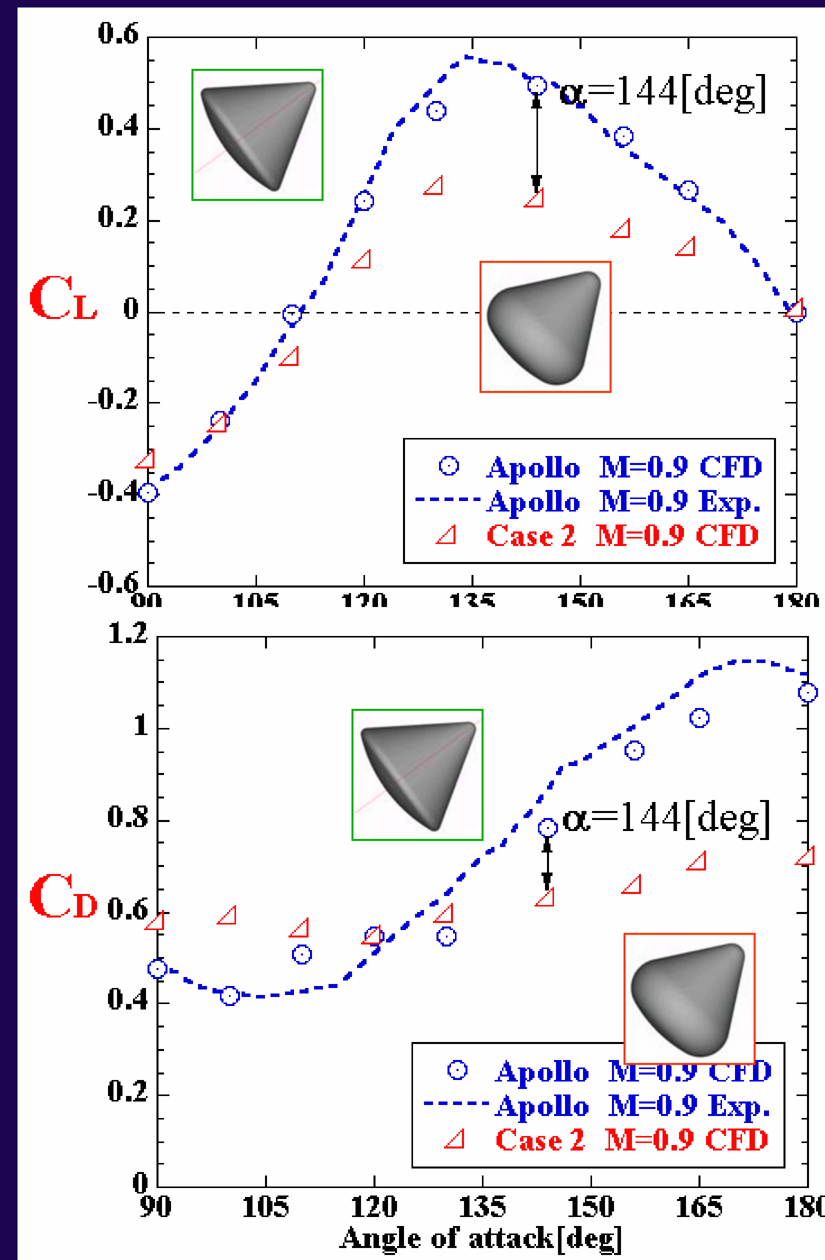
M=0.7 alp= 90[deg]

Effect of shoulder radius - Base-entry



Apollo $M_\infty = 0.9$ $\alpha = 144°$





Revolutionary Effort -1

- CFD researchers tend to look at CFD from CFD viewpoints, and they have been trying to show the CFD capability by the flow simulations over complex body configurations.
- However, there is something else that may be necessary from design and development viewpoint.
- Simulations for simple body configuration, or simulations with rather low accurate models may still be useful for design and development.
- Accumulated data should be summarized as a Database with additional aerodynamic information attached.

Now, move to another revolutionary effort

Message by Dean Chapman in 1977

Workshop "Computer Requirements for Computational Aerodynamics" was held at NASA Ames R. C. in 1977.

Prof. Dean Chapman said,

" There are two major motivations behind CFD .

(1) providing an important new technology capability

(2) economics

It would not change in coming decades."

There are many restrictions in the wind-tunnel experiment such as scale effects, wall and support interference, aerodynamic distortion, and else. The restriction of CFD comes from the speed and storage, but the technical trend shows that such limitations are rapidly decreasing.

CFD Research

- Use in design process - economics

  as a tool to evaluate aerodynamic characteristics

- Physical understanding - new technology tool

  as a tool to understand flow physics

Both can be understood as a replacement of WT experiment

- CFD should be able to do more than wind tunnel !

  First key issue : SCALE EFFECT

  Second key issue : CONCEPTUAL DESIGN”

Revolutionary Effort -2 and 3

SCALE EFFECT

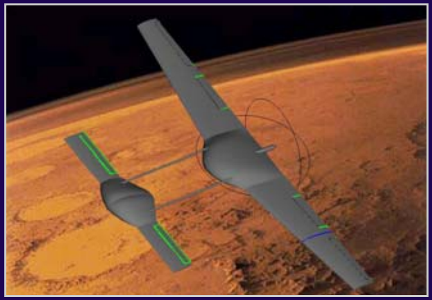
Dean Chapman's comments on CFD are not satisfied by the current CFD technology.

• We need to develop a CFD tool that can continuously evaluate aerodynamics from low to high Reynolds numbers.

CONCEPTUAL DESIGN

• CFD has been used for the configuration update when the basic concept has been determined and will not change, or used for the design of each element.

• CFD is a good and easy tool when working on a new concept.



possibility of new concepts even for current commercial or fighter aircraft

Concluding Remarks -1

We glanced back our 30 years' effort in CFD

• CFD researchers' effort has been mainly toward the simulations of flows over complex body configurations.

• There still remain problems that are geometrically simple but are not easy to simulate.

We need evolutional and revolutionary efforts

• There are something else that may be necessary from design and development viewpoint.

• Current CFD does not necessarily satisfy the key motivations given in 1977.

Concluding Remarks-2

Evolutional effort

• Capturing strongly-unsteady flow structure leads to a successful simulation (and flow control) of physically tough problems.

• LES/RANS hybrid method will help us in the next several years.

Revolutionary effort

• There are problems where "easy" simulations are useful. CFD database with additional detailed flow data may become useful.

• We have to develop CFD technique that handles Scale effect: continuous evaluation of aerodynamics from low to high Reynolds numbers

• Conceptual design with CFD may lead to a revolutionary concept of aircraft and spacecraft

Message for Future CFD

From a tool to replace wind tunnel

To a strong tool for creative design

Wind Tunnel and Beyond

Different flow domains by the scale effect should be evaluated with reasonable level of confidence under the key important physical background.

↑

We have to choose right modeling and use right equations based on our knowledge of fluid dynamics and aerospace engineering.