Realization of Prof. Kuwahara's Messages
- after almost 30 years' Effort in CFD -

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Outline

- **Background of CFD in aerospace**
  - Chapman's message in 1977
  - HPC development and CFD effort since then
- **Main issues raised by Prof. Kunio Kuwahara**
- **Status of recent CFD**
  - Supersonic base flow
  - Flow Mechanism of DBD plasma actuator
  - Acoustics from rocket /supersonic jets
- **Future possibilities**
  - Toward Capturing scale effects
  - Real-time and Super real-time simulations
- **Summary**

Dean Chapman's Message in 1977

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

Prof. Dean Chapman at Stanford Univ. said,

" There are two major motivations behind CFD .

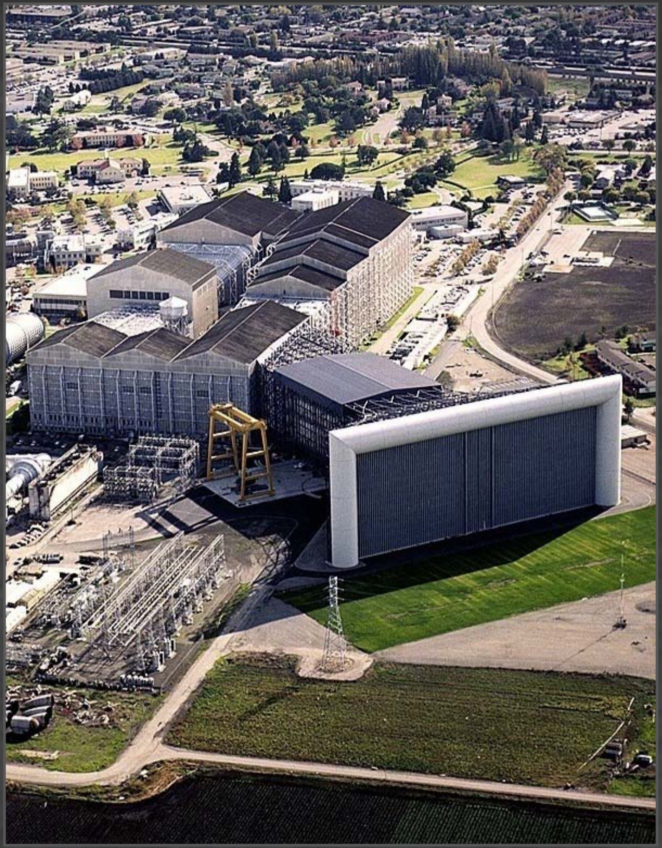
(1) providing an important new technology capability
(2) economics

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.

Supercomputers vs. Large-scale WT

JAXA Supercomputer System (JSS)
135TFLOPS with 100 TB memory



Huge wind tunnel at NASA Ames R. C.

Capturing "SCALE EFFECT" was one of the most important motivations of CFD in aerospace.

Computer Performance

昭和60年(1985年)1月8日 (火曜日) (日刊)

日本経済新聞

スーパーコンピューター
富士通が世界最高速

一秒に十億回
演算実現、近く発売

航空機設計などに威力

謹賀新年
西日本銀行
コミュニケーションバンク

World fastest supercomputer in 1985

same performance

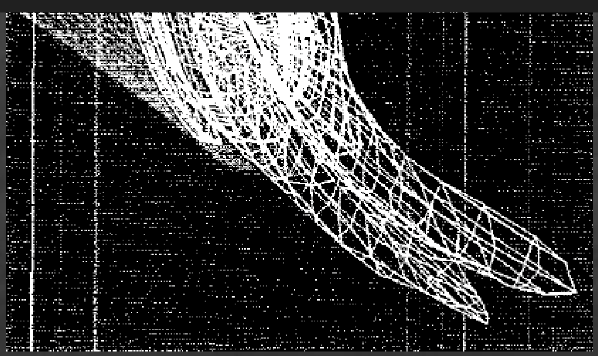
2008

1985	FUJITSU/VP400	6.7—9 μsec
2007	Intel PC (3.2GHz)	4.1 μsec

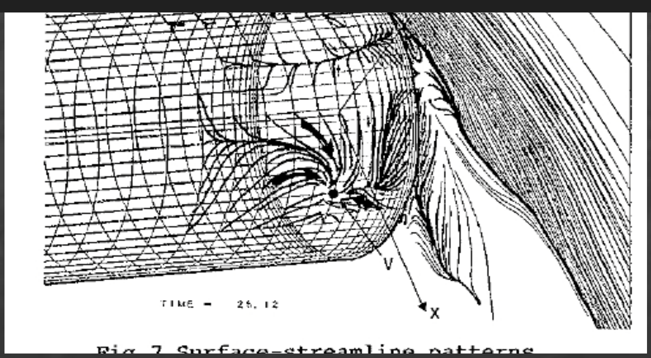
Prof. Kuwahara's Messages

- **Flow is essentially three dimensional and unsteady. 2D computation even with high grid resolutions would not reproduce flow physics.**
- **Use of turbulence model would contaminate simulation results. Direct simulations with insufficient grid resolution would be better than simulations with turbulence models.**

He did not say unresolved direct (or LES) simulations are good enough. He did such simulations with knowing shortcomings of them. He was trying to find practical (not theoretical) boundary of the grid resolution for acceptable accuracy.

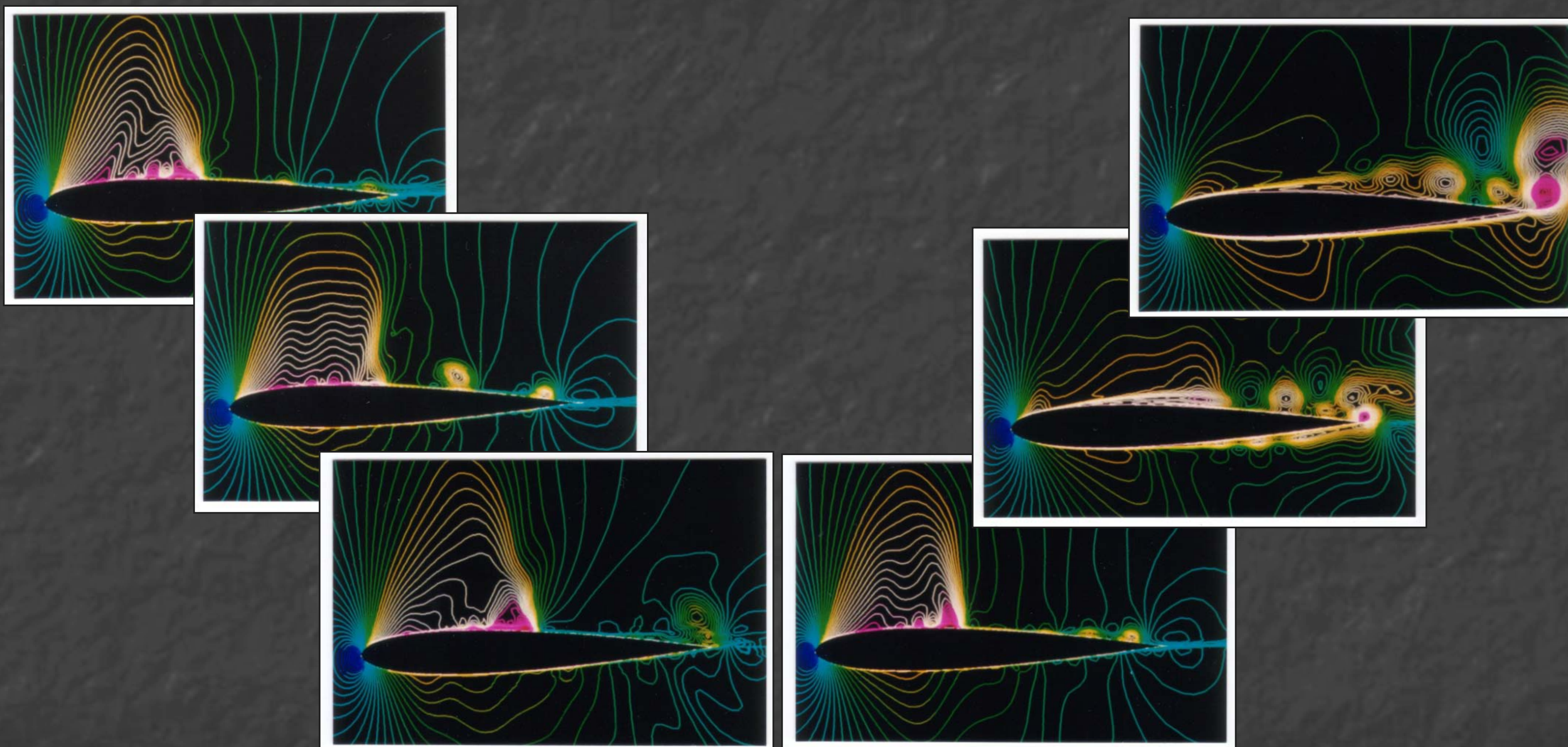


Himeno, Shirayama, Kamo, Kuwahara
AIAA Paper 85-1617



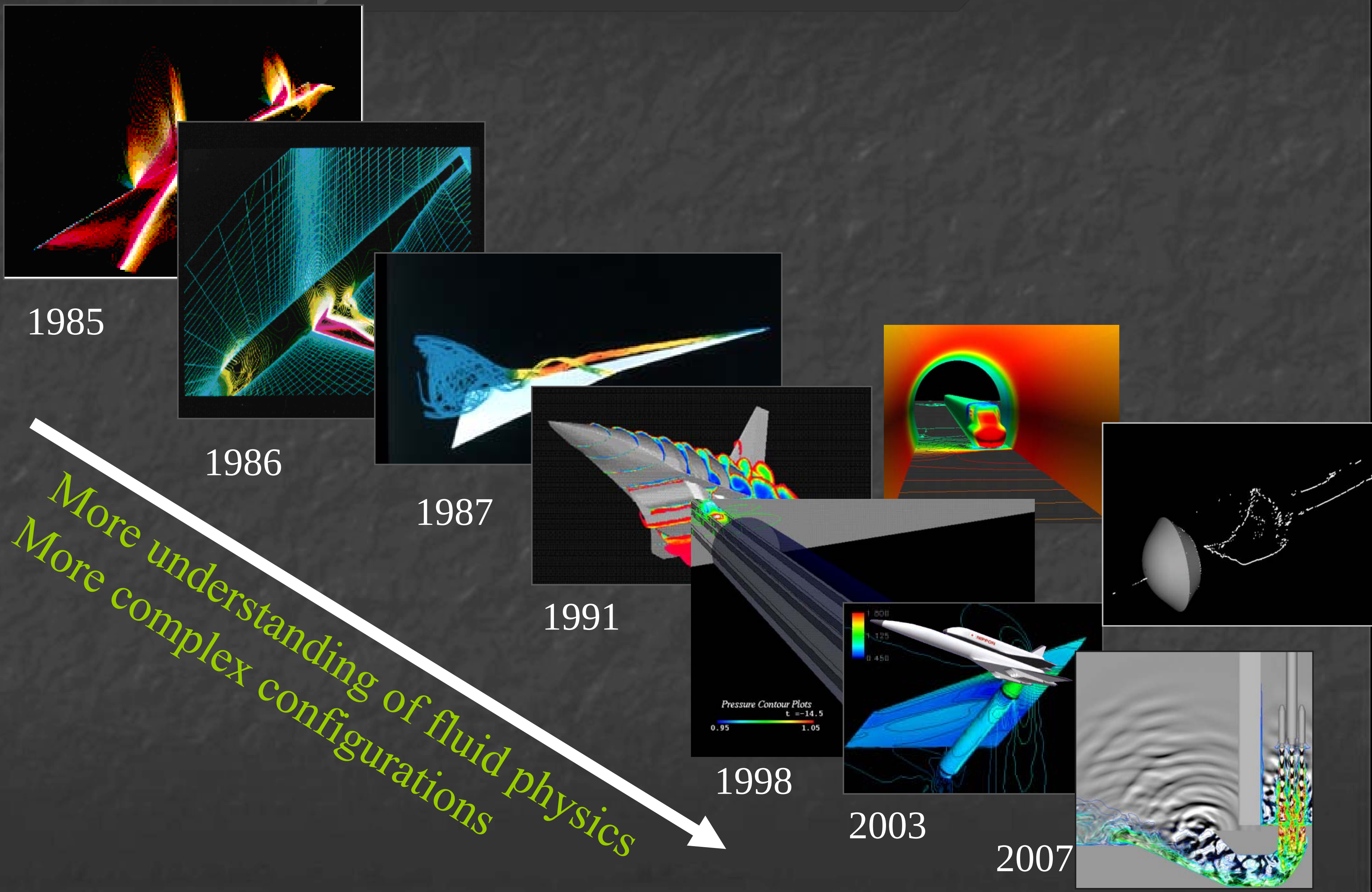
Sirayama, Ohta, Kuwahara
AIAA Paper 87-0605

Direct simulation of transonic flows



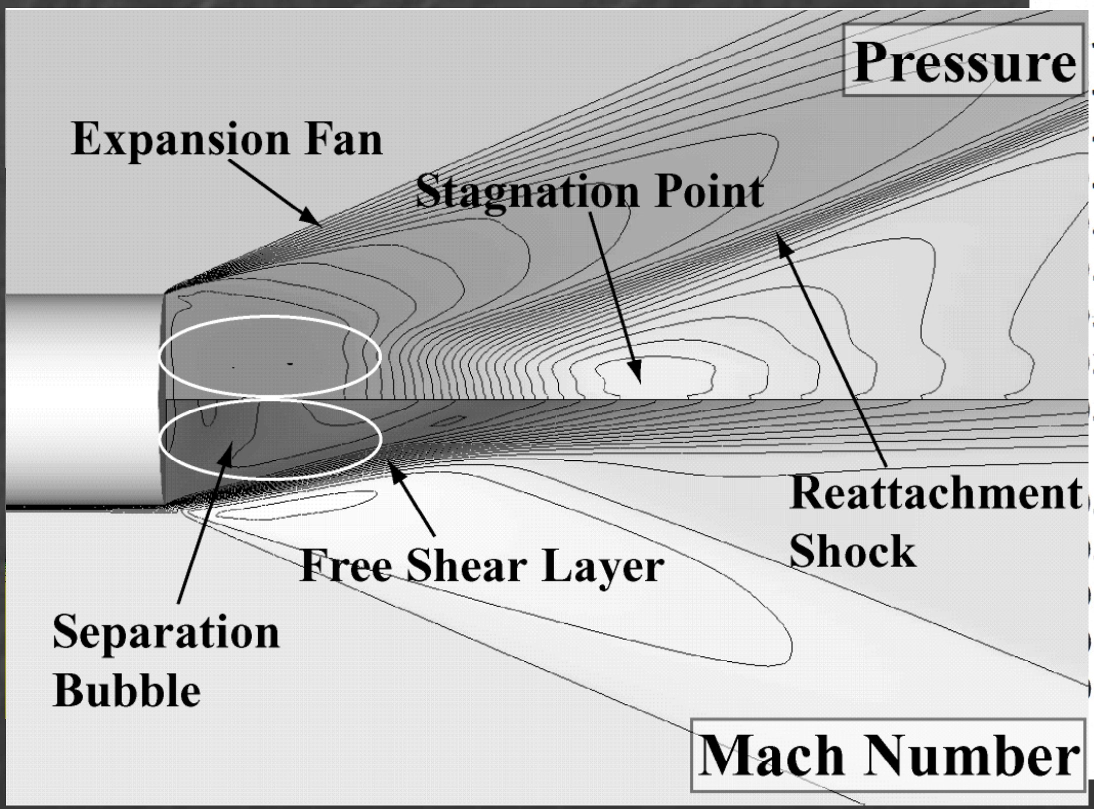
Obayashi's trial for flow with embedded shock waves

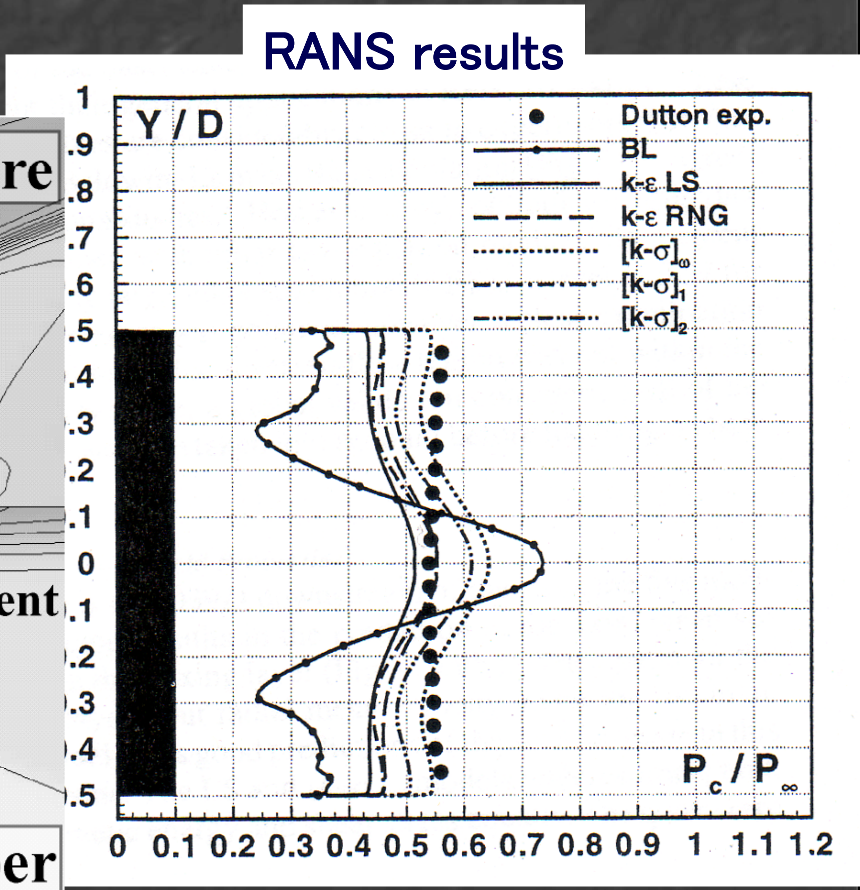
20-30 years CFD research



Status of recent CFD -1

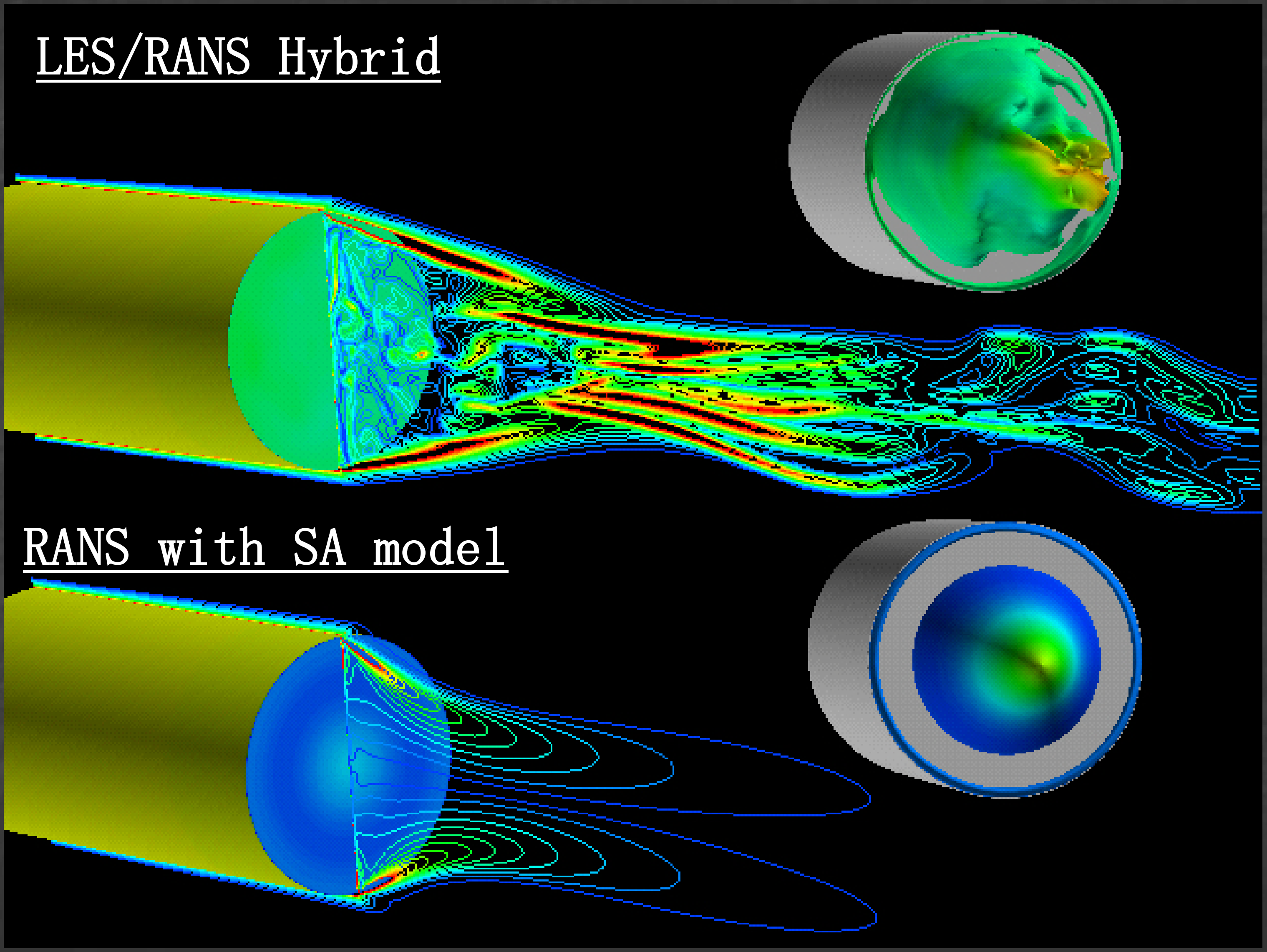
Ex. 1 Supersonic base flows



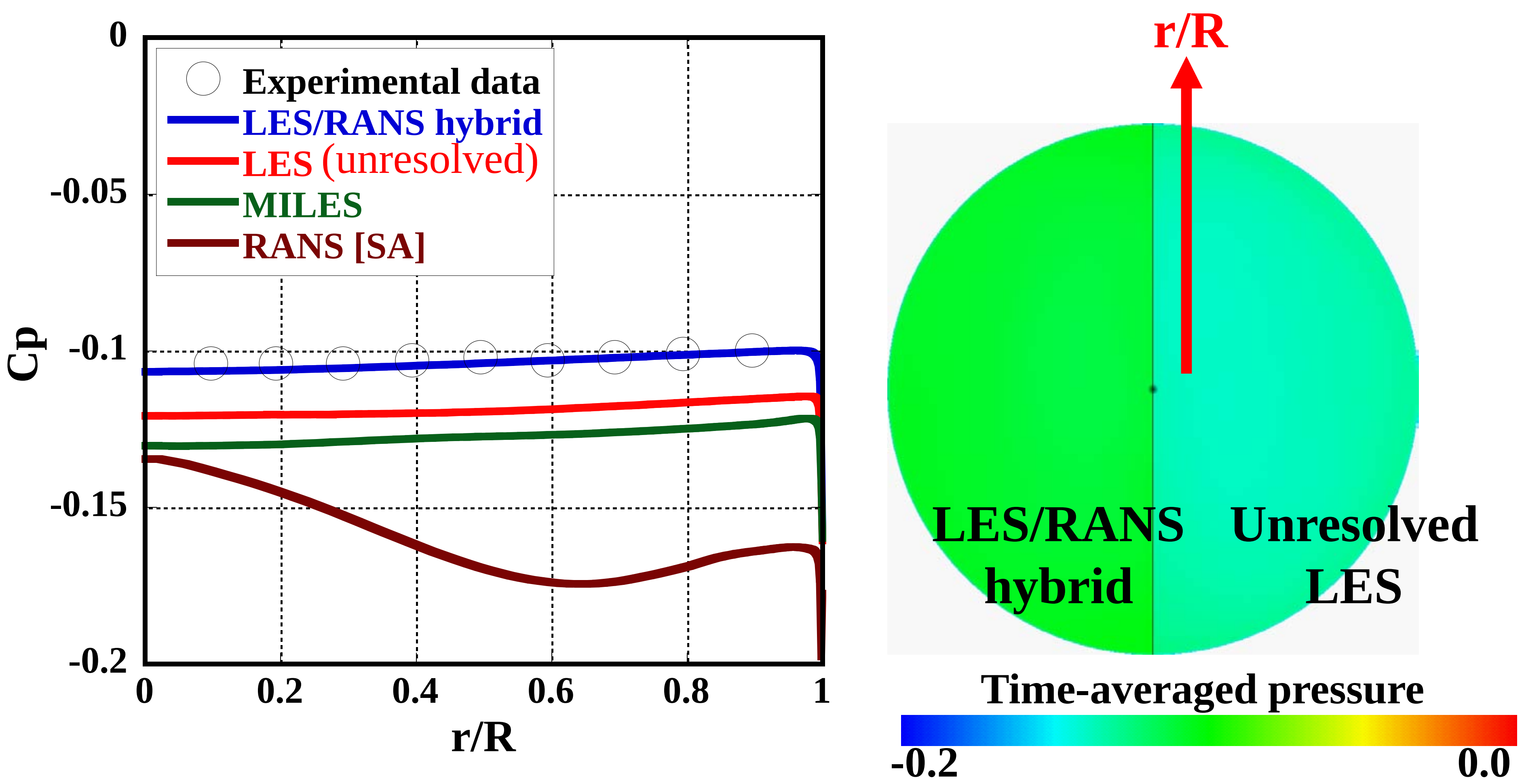


AIAA J., 2001

LES/RANS hybrid vs. Unsteady RANS

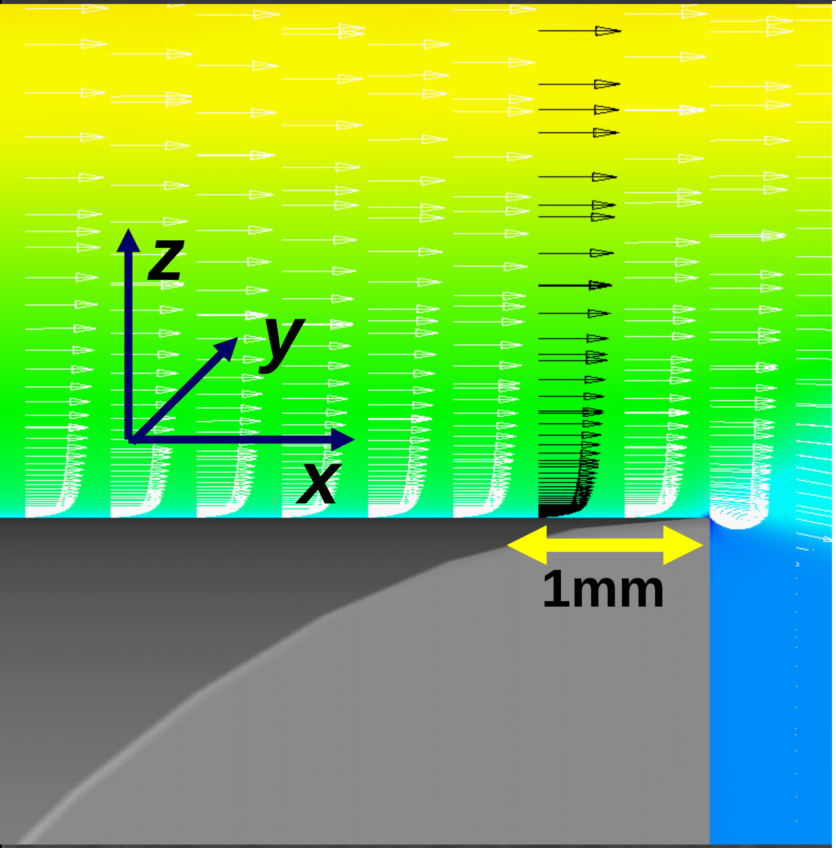


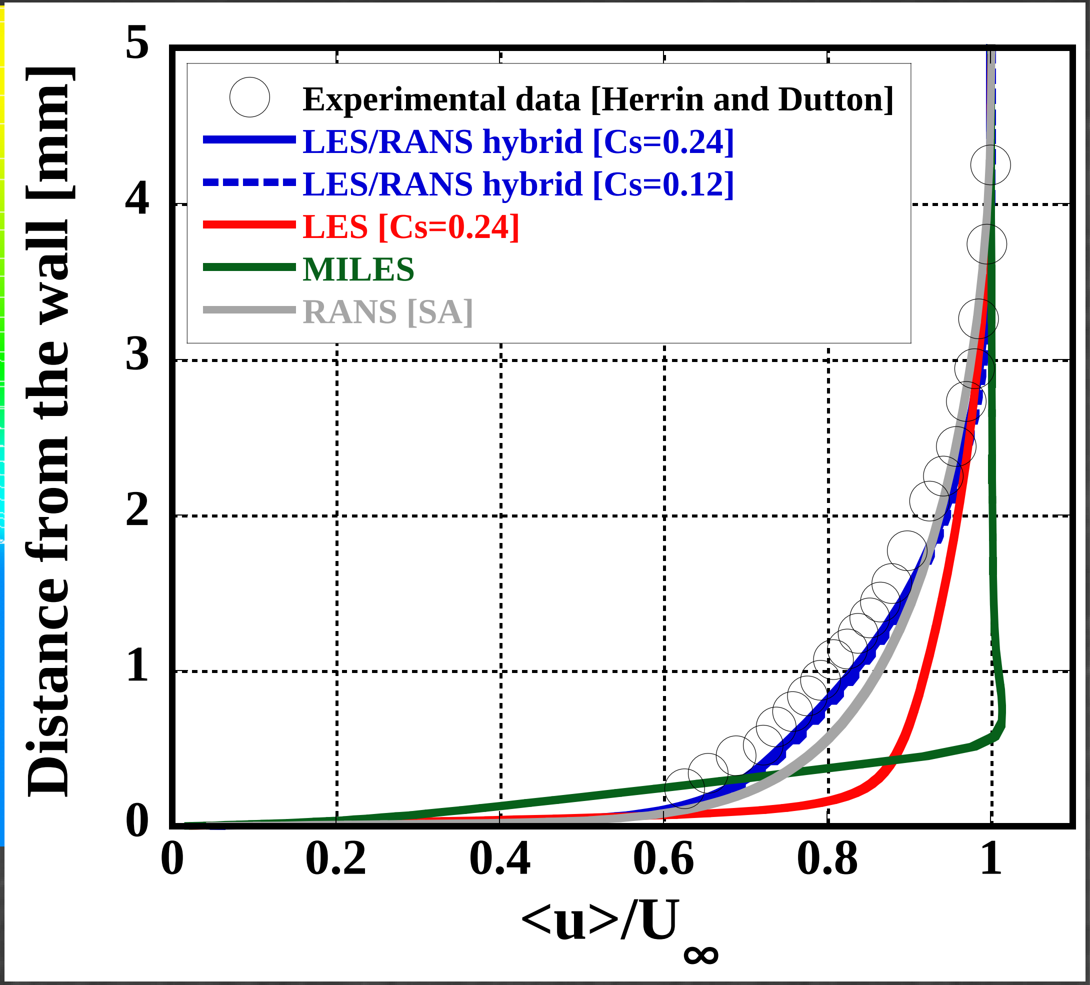
Base Pressure Distributions



Kawai and Fujii, AIAA J., Vol. 43, pp. 1265-1275, 2005
Kawai and Fujii, AIAA J., Vol. 45, pp. 289-301, 2007

Boundary Layer Profile



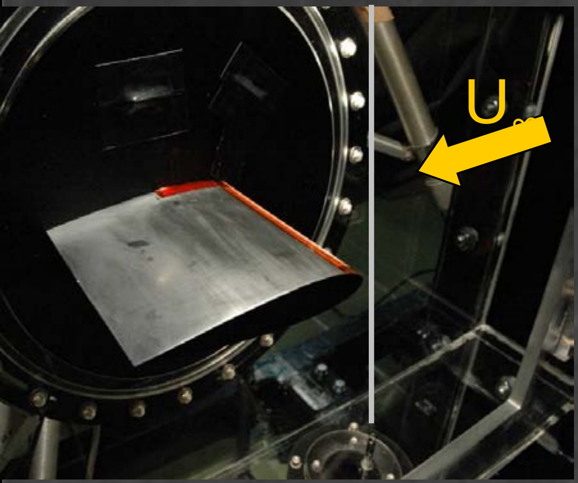


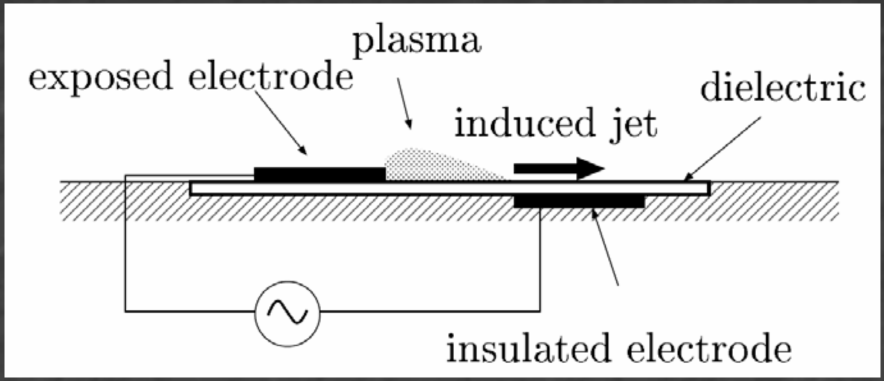
Average mesh resolution on the lateral surface

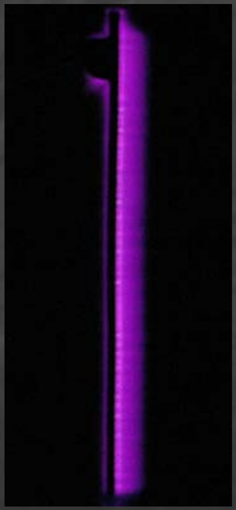
$$(\Delta x^+, \Delta y^+, \Delta z^+) = (1727, 1404, 0.8)$$

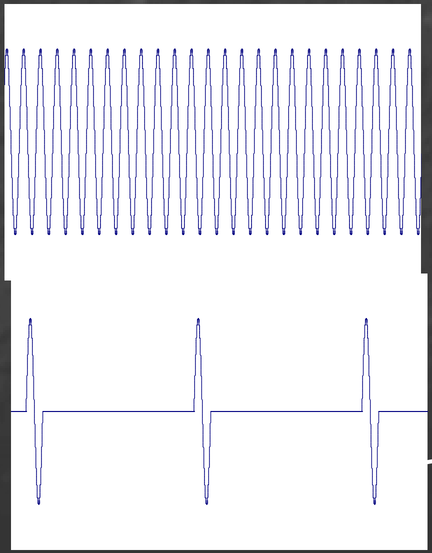
Status of recent CFD -2

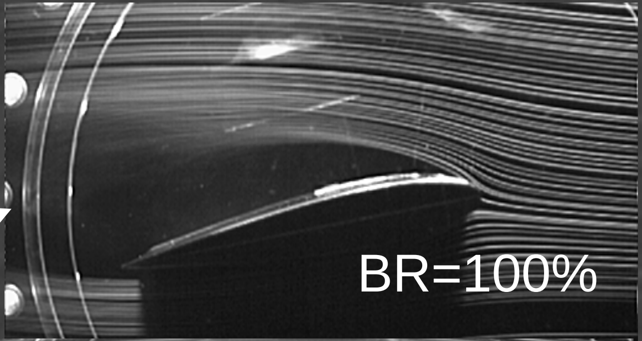
Ex. 2 DBD plasma actuator for flow separation

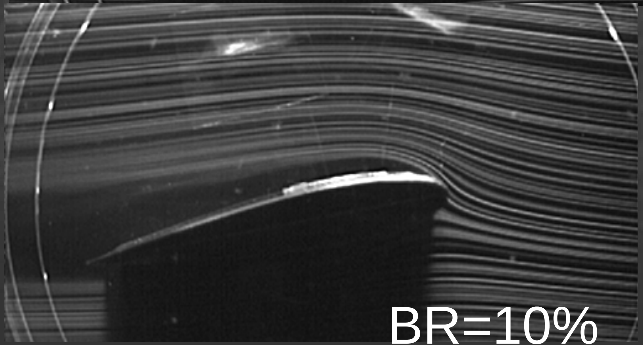




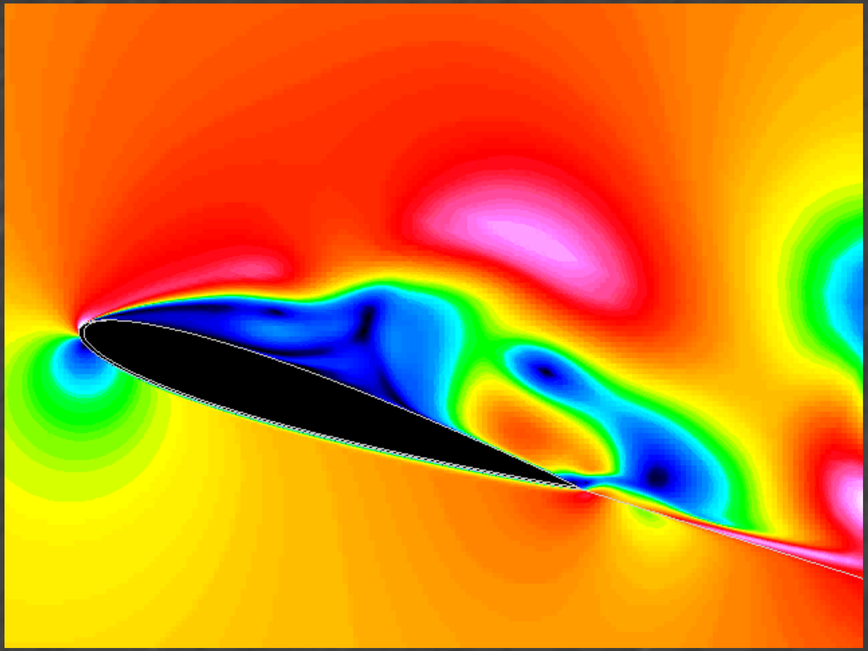


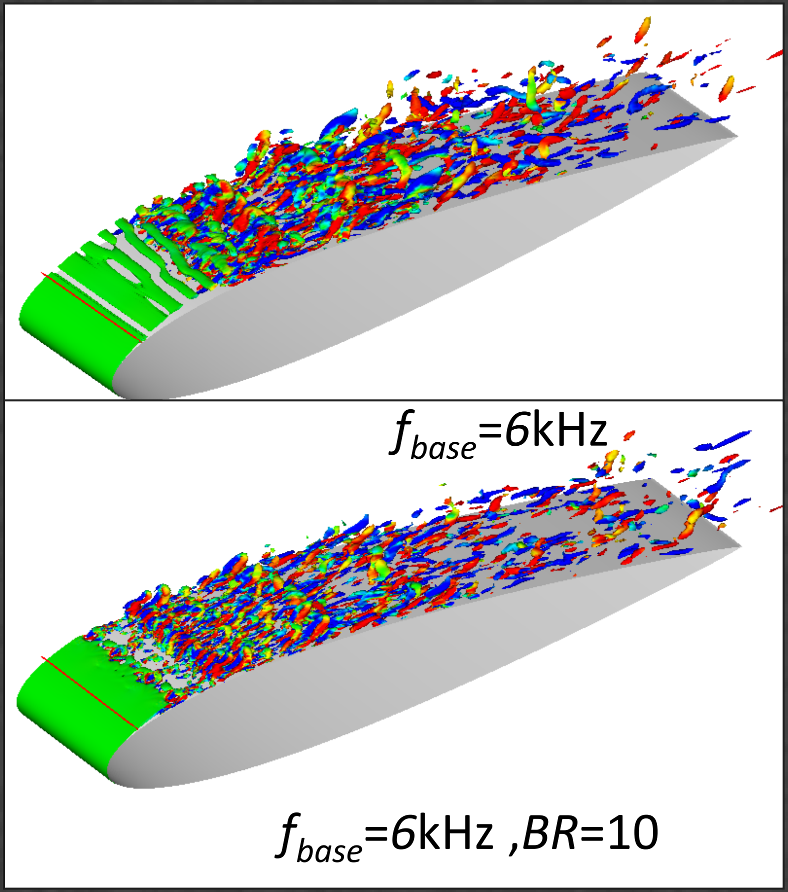






RANS vs. LES simulations

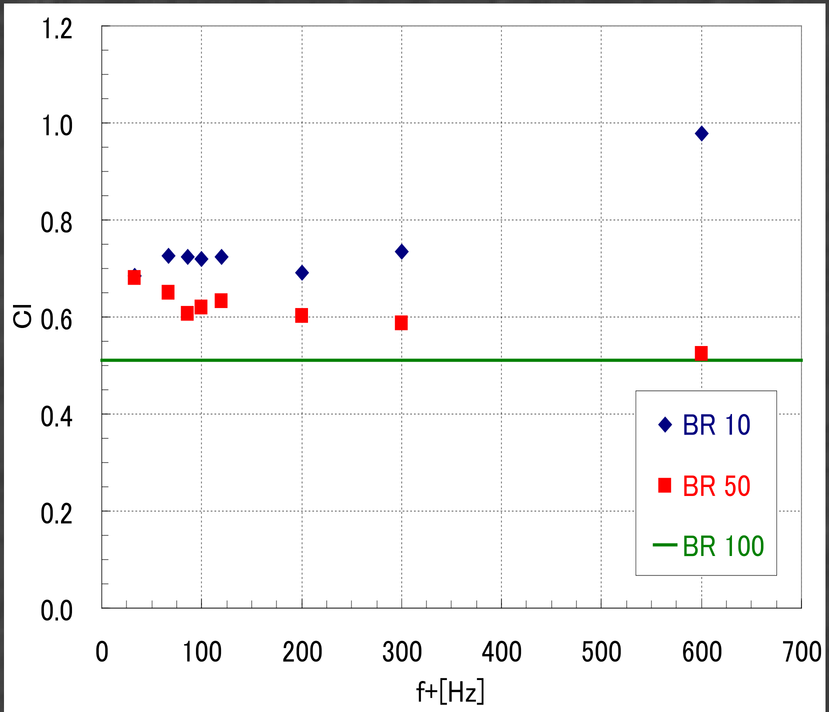




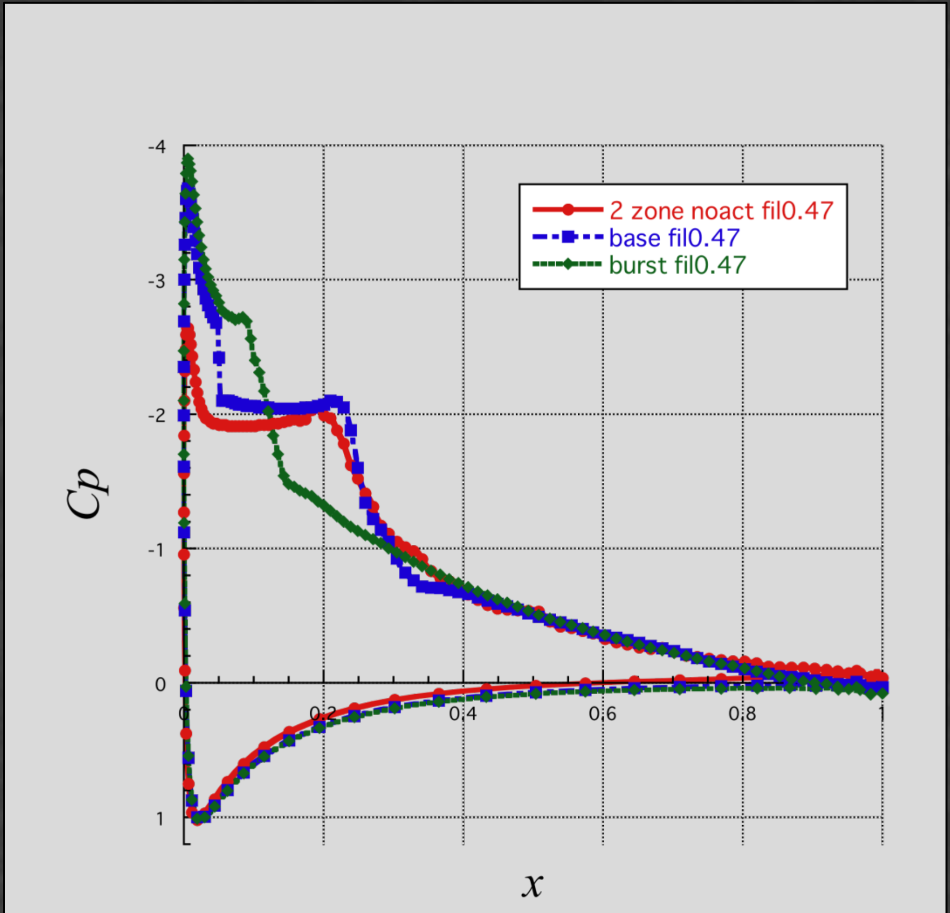
RANS simulation

LES simulation

Burst effect to the CL



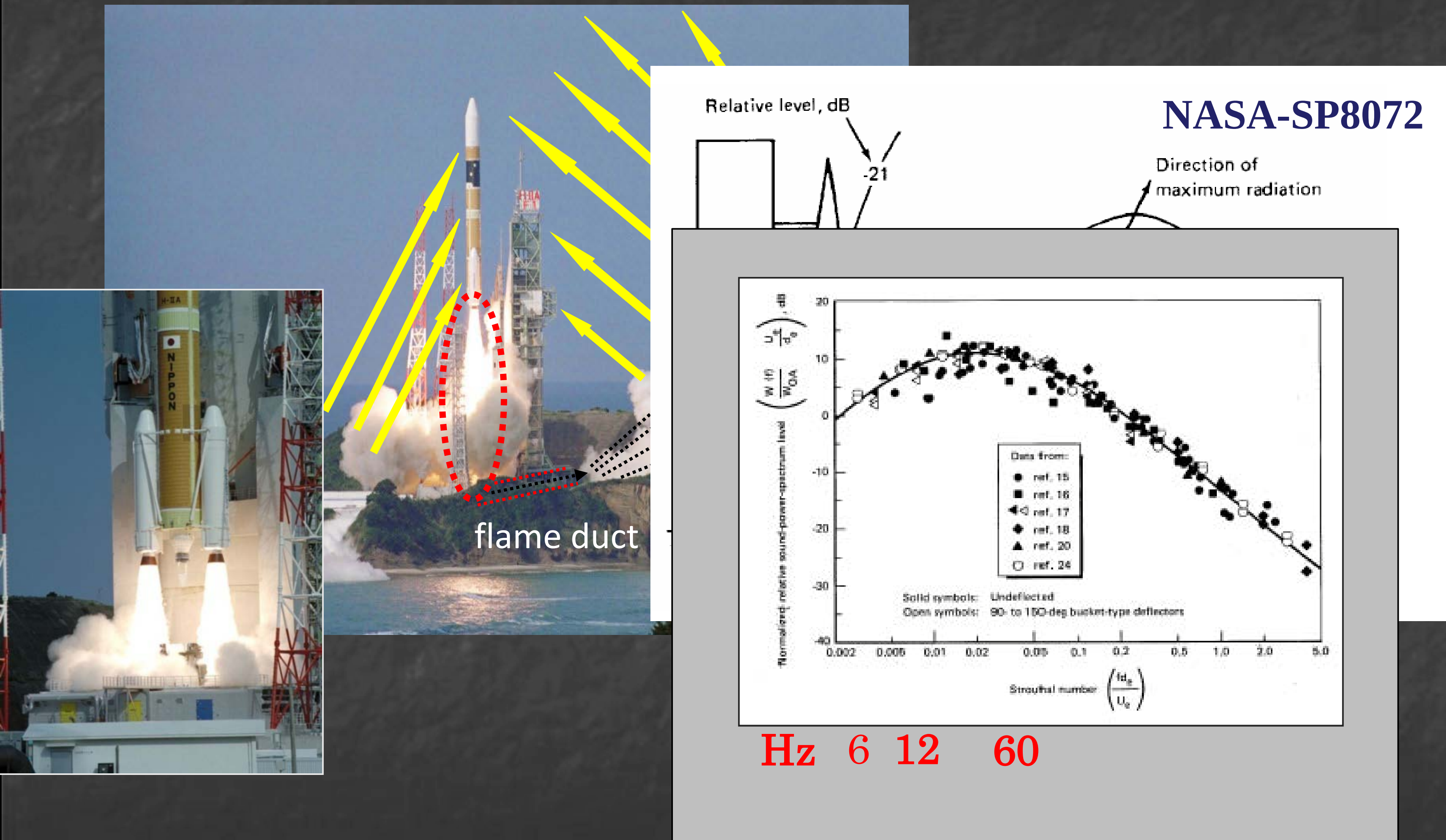
CL vs. frequency



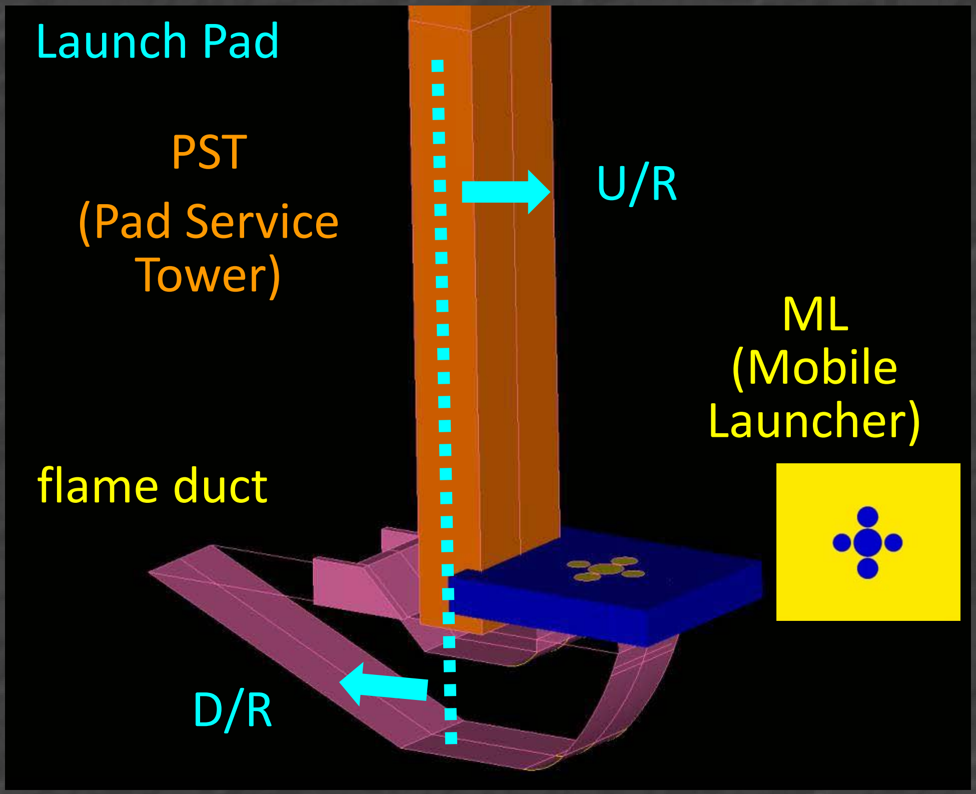
Cp distributions over an airfoil

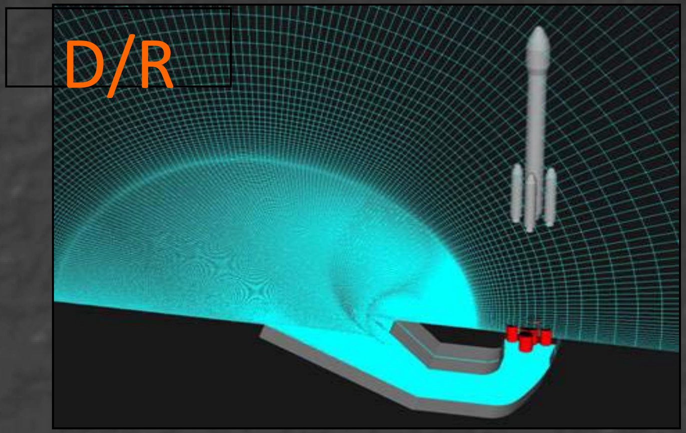
Status of recent CFD -3

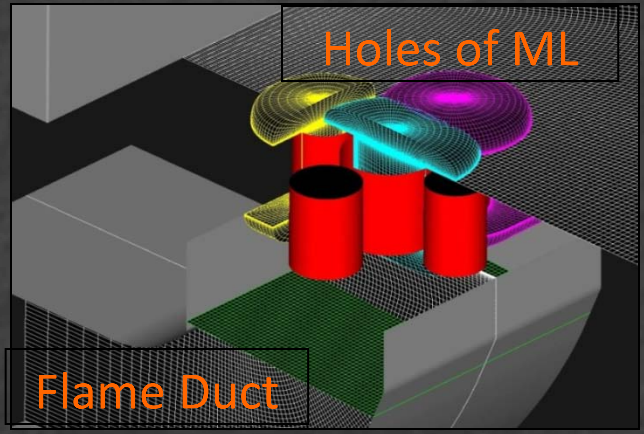
No. 3 Rocket plume acoustics



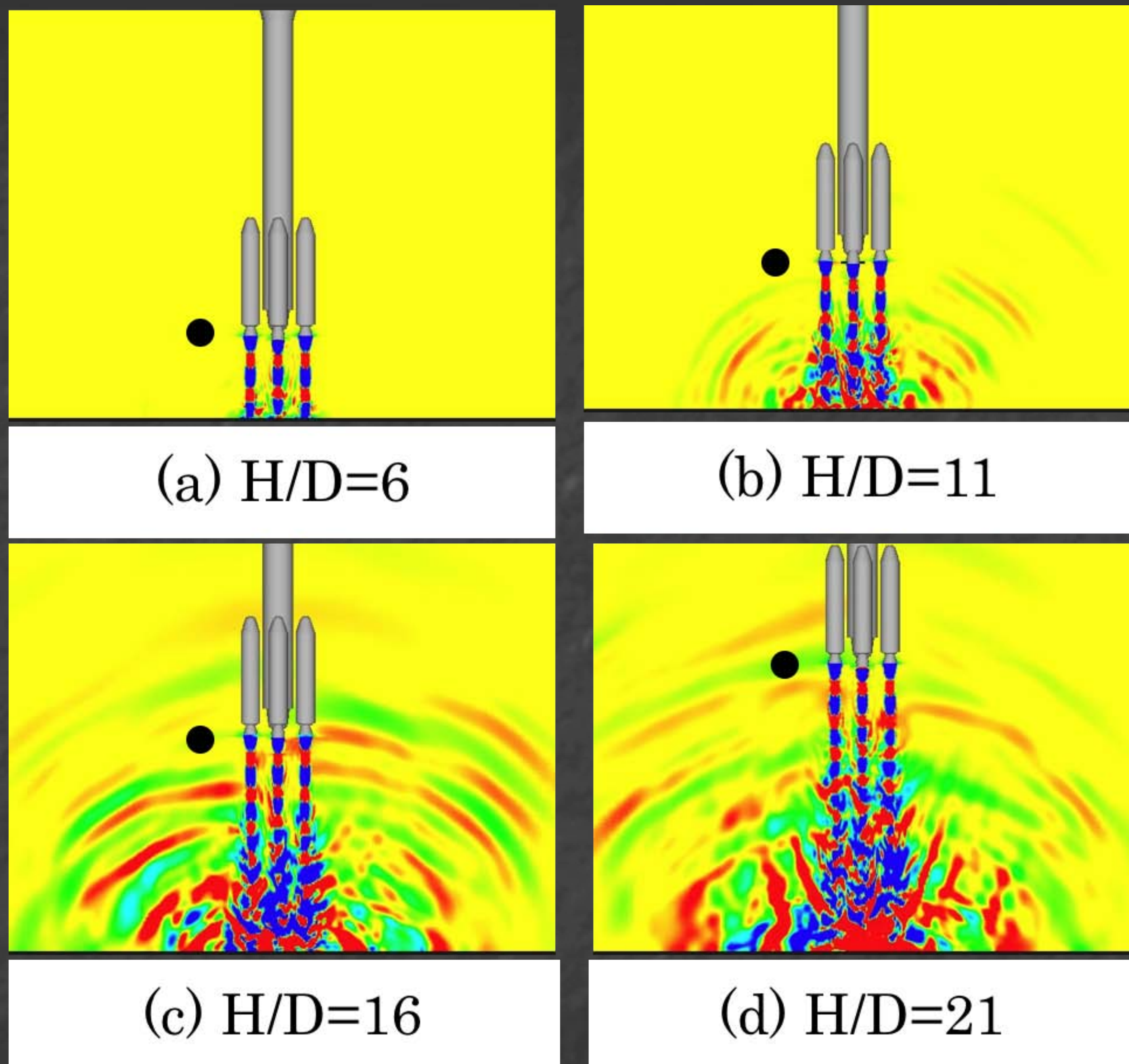
Simulations of Practical Configurations





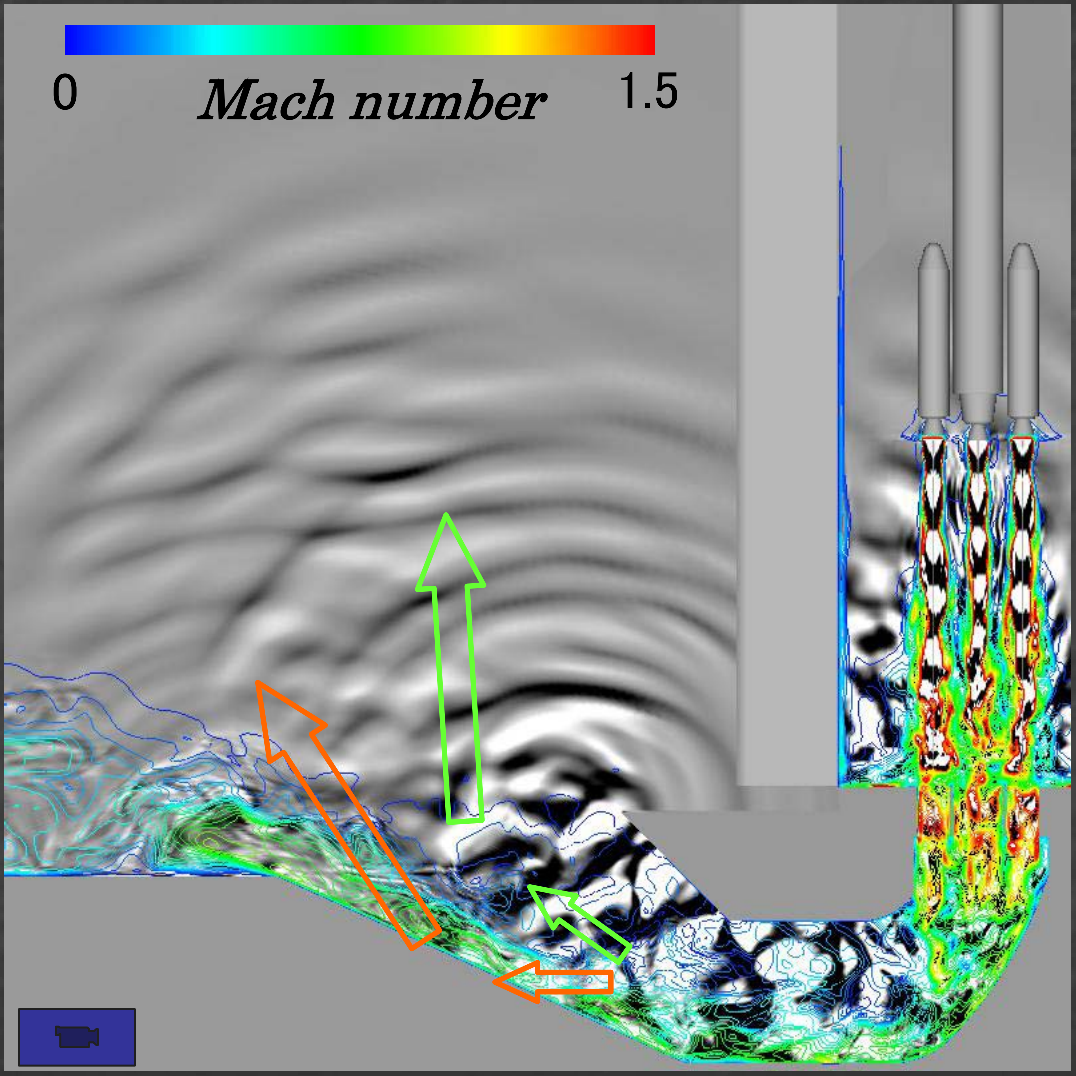


Example of simulations results



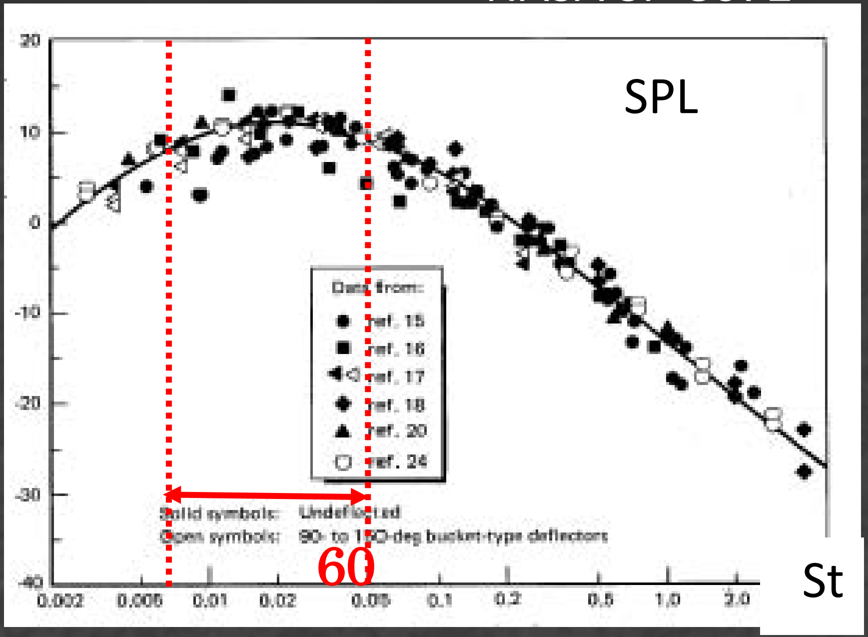
Pressure fields for different lift-off distance H/D

Result for the simulation of HIIA launching



Grid resolution required

NASA SP-8072



- 20 grid points per a wave. ⇒ St_max=0.05
- For FFT analysis ⇒ St_min=0.007 (3w@NEC SX-6)

Capturing frequency range up to 150Hz to 200Hz and SPL for each frequency component is required.

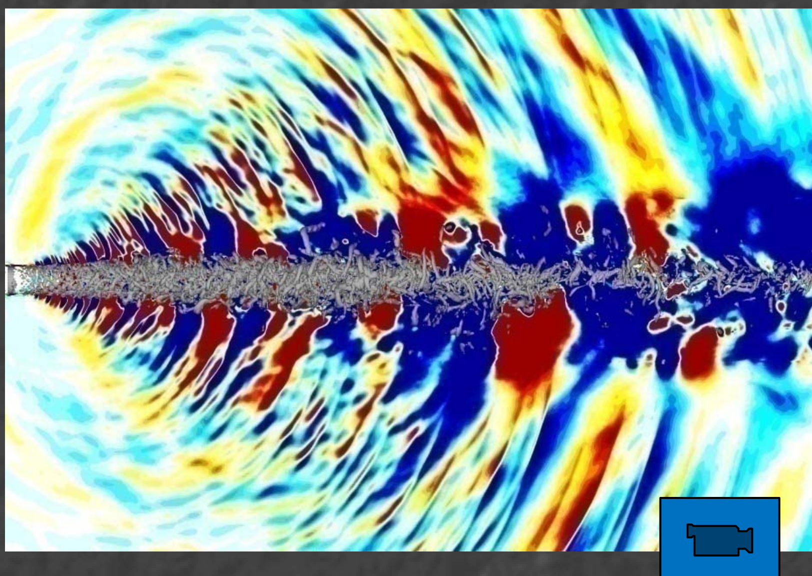
Improve space resolution →

WCNS (Weighted Compact Nonliear Scheme) by Deng et al.

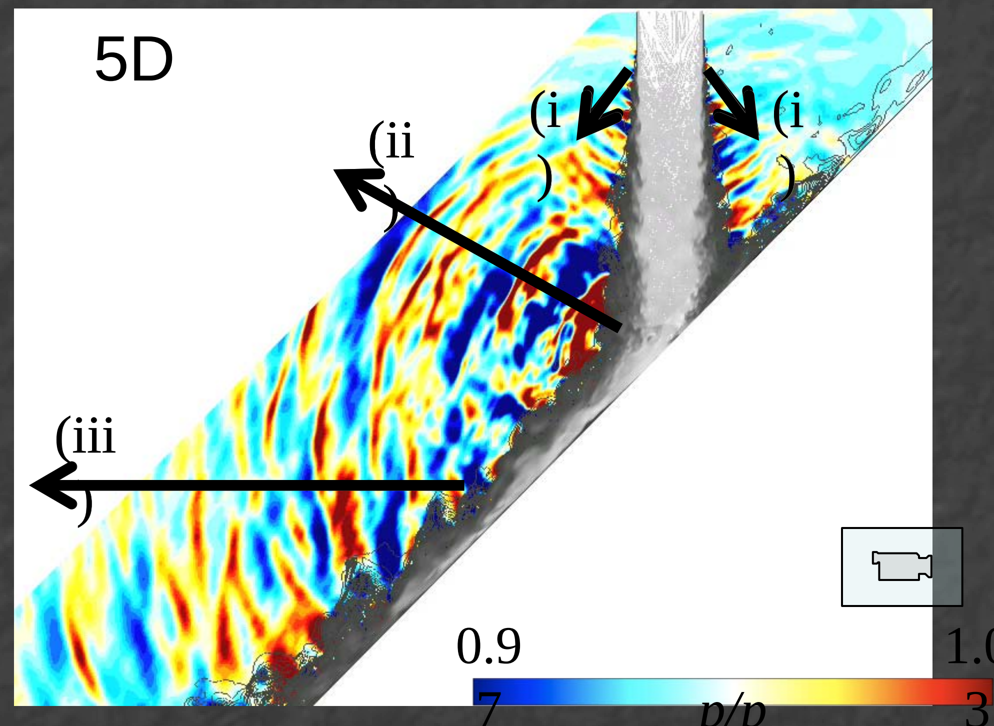
Localized Artificial Diffusivity (LAD) by Lele et al.

Simple Jet Acoustic Problem

- for better understanding flow physics -

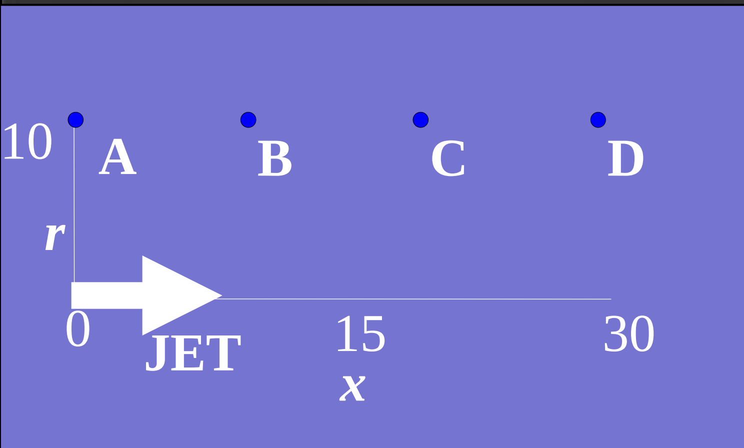


Simple free jet

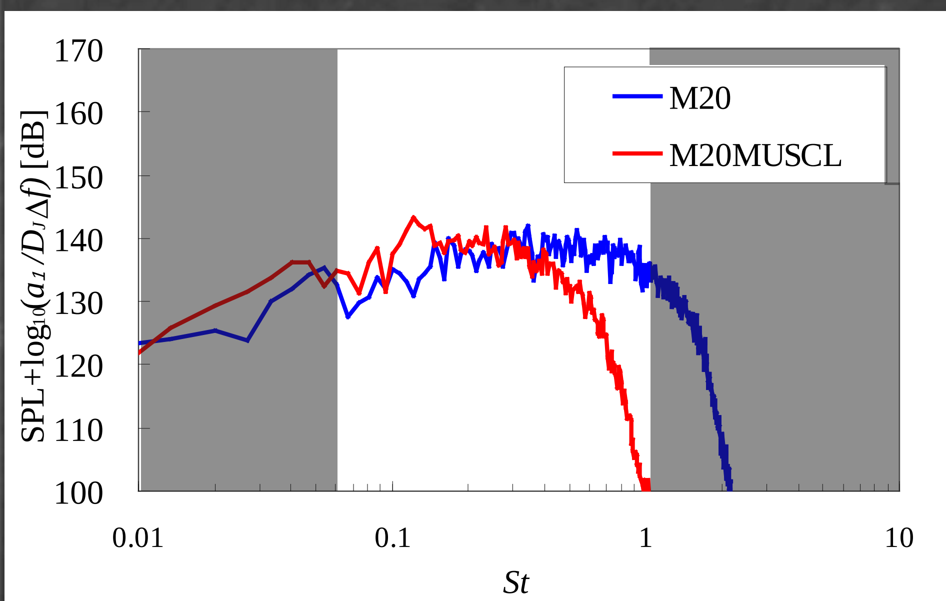


Free jet impingement

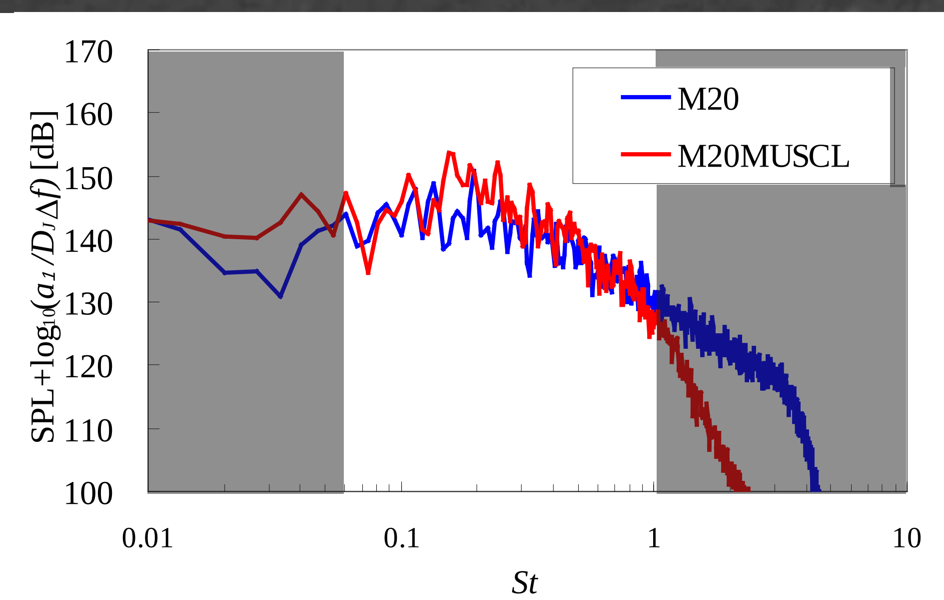
Sound Pressure Spectrum



Point B

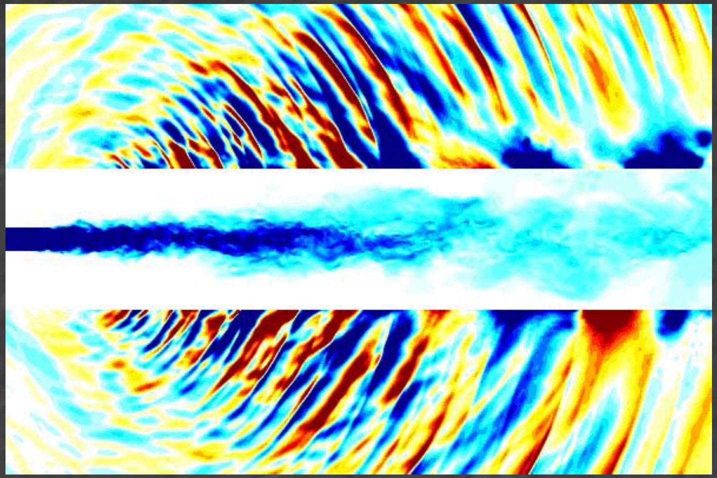


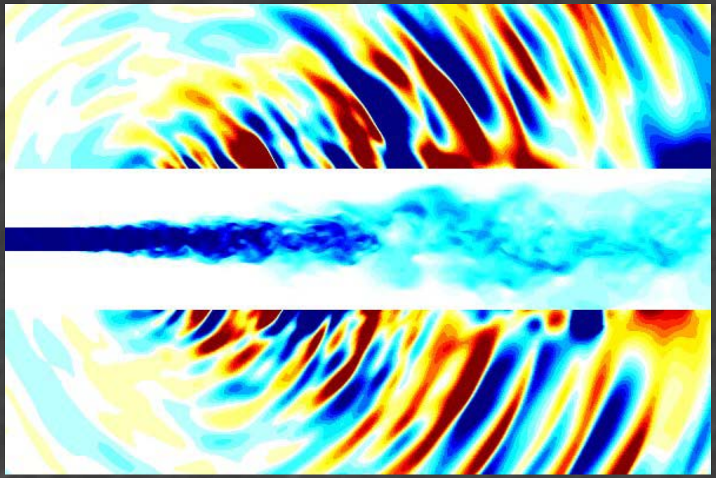
Point D



Comparison of WCNS with Conventional 2nd order TVD

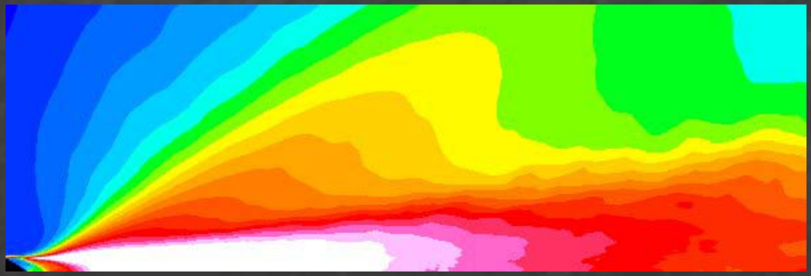
Jet acoustics

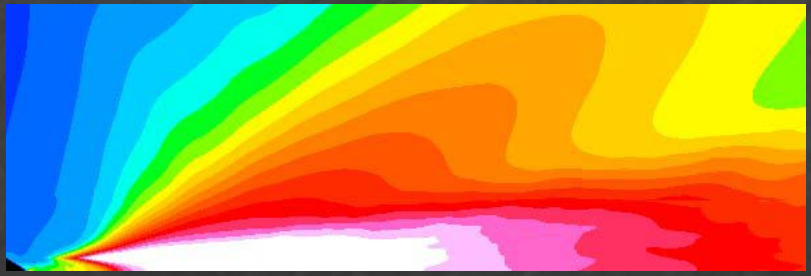




OASPL

JET





M20(WCNS) **M20(MUSCL)**

Back to the discussion of Scale effect

	Lower than $Re=10^5$ MAV, UAV, Mars Aircraft	$Re=10^6$ Wind tunnel level	Higher than $Re=10^7$ Civil transports
No. Grid points (required memory size)	1.25×10^9 (1 TB)	1.250×10^{11} (100 TB)	1.250×10^{13} (10 PB)
Computer time on SX-6 one node	120 hours (5 days)	12,000 hours (17 months)	1,200,000hours (137 years)
Computer time on **1 TFLOPS**	10-50 hours (1-2 days)	1,000-5000 hours (1-6 months)	100,000 -500,000 hours
Computer time on **1 PFLOPS**	0.1-0.5 hours	1-5 hours	100-500 hours (5-20 days)

Another Step to Real-time Simulations

Rough and optimistic estimation from the current data

（Ex. ）Plume acoustic simulations for rockets

1 TFLOPS machine

One time step: Computer 2.4×10^{-1} sec = Physical 6.1×10^{-6} sec

40 PFLOPS machine

One time step: Computer 6.0×10^{-6} sec = Physical 6.1×10^{-6} sec

Summary

- Prof. Kuwahara’ messages in 1980’s are now realized by many CFD researchers.
- That is happening due to grid resolution improvement and supporting computer performance progress.
- Prof. Kuwahara’s approach is very necessary for capturing “Scale Effect” of Chapman’s message in late 70’s.
- Real-time and super real-time simulations will open new use of CFD.

Prof. Kunio Kuwahara’s Third Message

- Do not discuss flow fields in technical papers, but only show the computed results. Authors’ interpretation would influence to the readers’ understanding of the results, and that should be avoided.