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Investigation of Flow Control with Fluidic injection for Jet Noise Reduction

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Outline

I. Introduction
   1. Concepts: jet noise, fluidic injection
   2. 60 years of fluidic injection for jet noise reduction
II. Current status of fluidic injection at CAE
   1. Tests of jet noise reduction with fluidic injection
   2. Simulations of flow control with air injection for jet noise reduction
III. Concluding remarks

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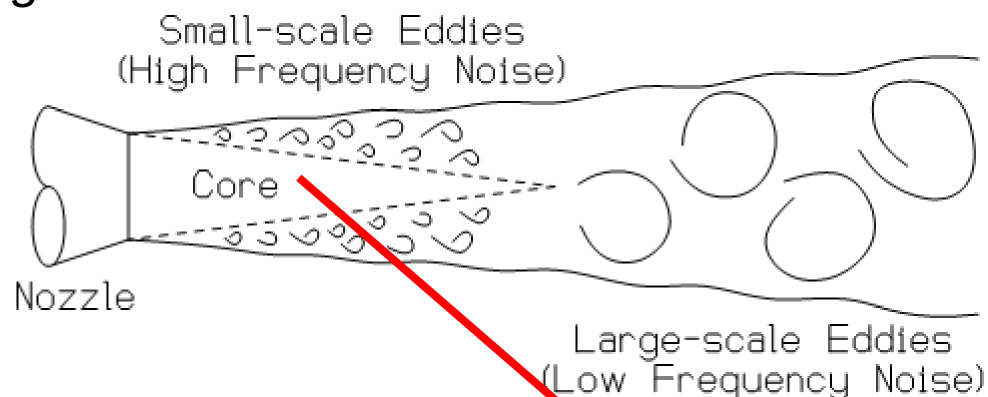
III. *Concluding remarks*

Jet noise

Jet noise

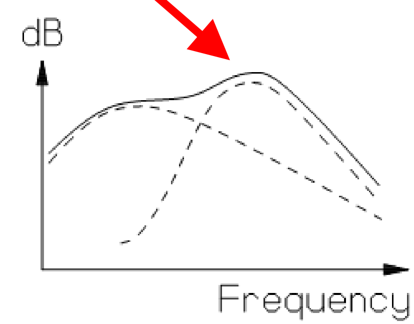
The noise generation caused by high-velocity jets and the turbulent eddies generated by shearing flow



Noise sources

Subsonic Jets

- ✓ *Fine scale turbulence*
  - *dominates the acoustic spectra in the upstream direction*
- ✓ *Large scale structures*
  - *dominates the acoustic spectra in the downstream direction*



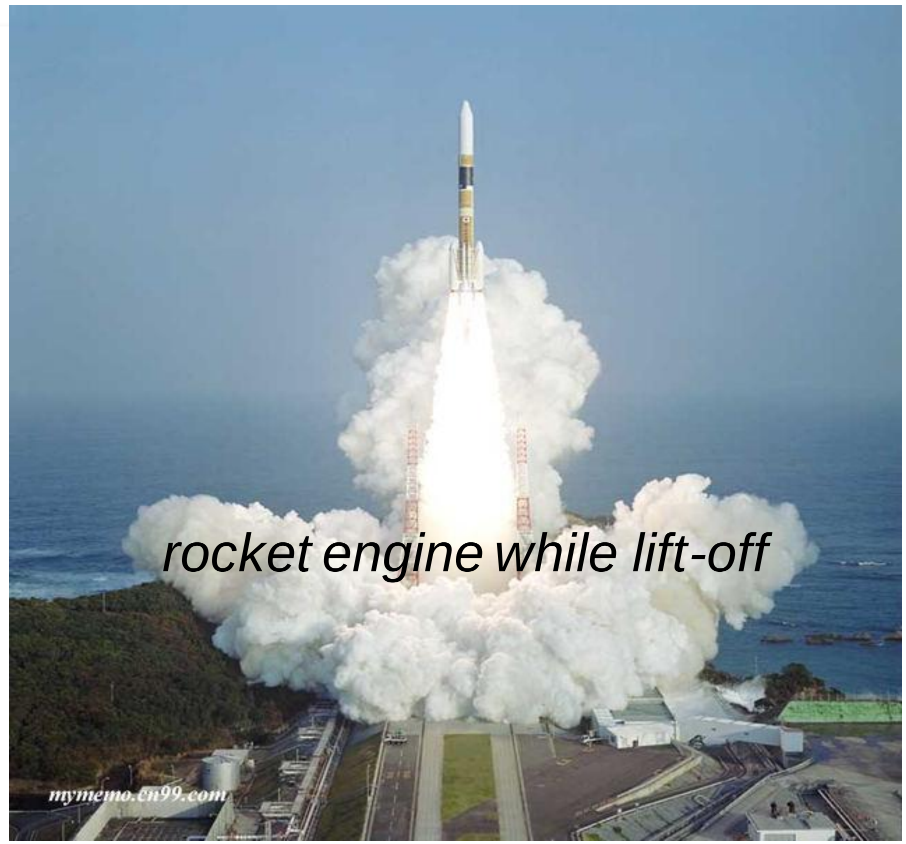
Supersonic Jets

- ✓ *Screech tones*
- ✓ *Broadband shock noise*
- ✓ *Mach wave emission*

Additional noise from shock waves

Jet noise

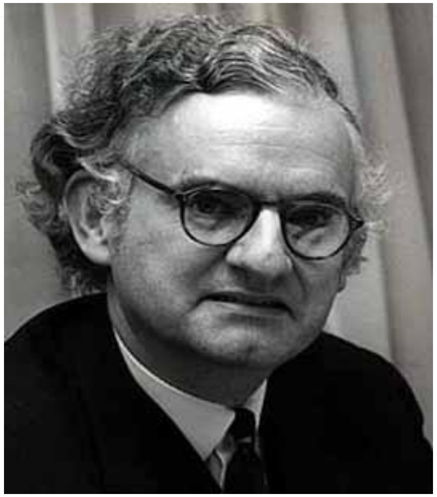
◆ *Problems of jet noise in aeronautics and astronautics*



◆ *How to reduce jet noise*

✈ *Reduce velocity of jet flow*

(According to *Lighthill's eighth power law*)



Michael James Lighthill

Acoustic Power$= K\rho_0 a_0^{-5} L^2 V^8$

✈ *Control the turbulence*

Increasing the mixing between the jet and its surroundings

⇩

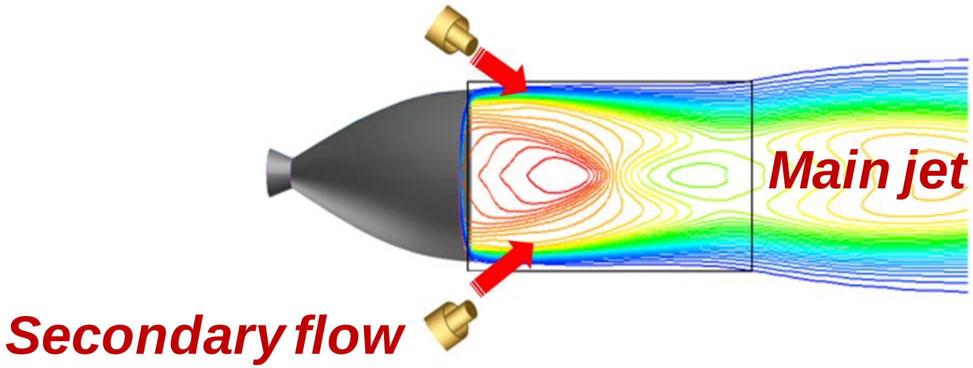
Splitting large-scale eddies into fine scale eddies

⇩

Reducing the low frequency noise

*Lighthill, M. J. (1952). "On sound generated aerodynamically," Proc. Roy. Soc. A. 211, 564–587.

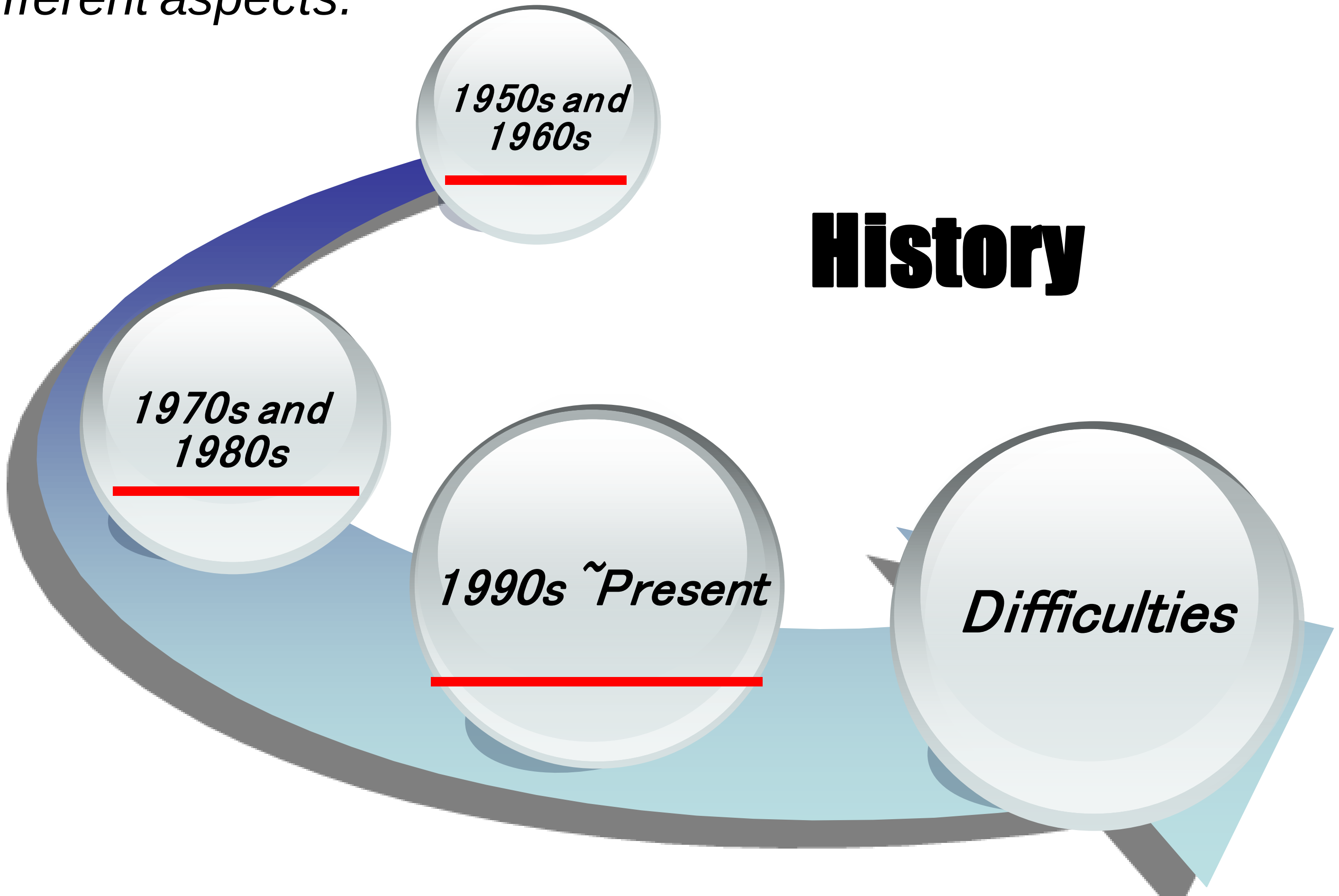
- *Fluidic injection(for jet noise reduction)*



Liquid injection (Water)	● *Momentum transfer process between droplets and main jet* ● *Reduces jet velocity*
Gas injection (Air)	● *Introduction of streamwise vortex that evolve with axial distance* ● *impact large scale structures and fine scale turbulence in the shear layer*

60 years of fluidic injection for jet noise reduction

- Considerable work has been performed on fluidic injection for the reduction of jet noise.
- The history can be divided into these three timeframes that focus on different aspects.



- *1950s -1960s, Very early stages*
  - *Understanding sound generation in jets and development of noise reduction technology*
  - *Many "Firsts" of fluidic injection for jet noise reduction*

    A. *First experiment*

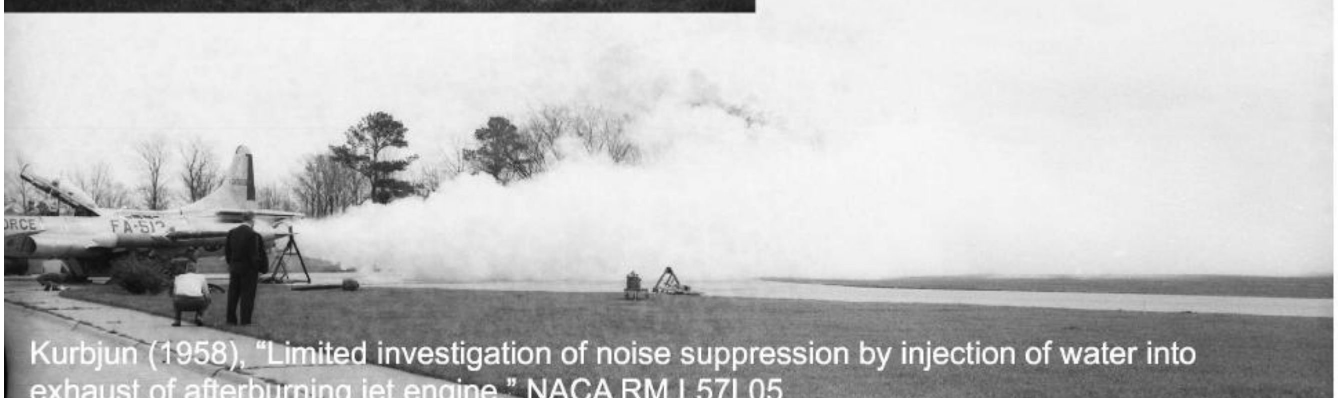
    B. *First patent*

    C. *First Commercial application*

    D. *……*

A. The first experiment

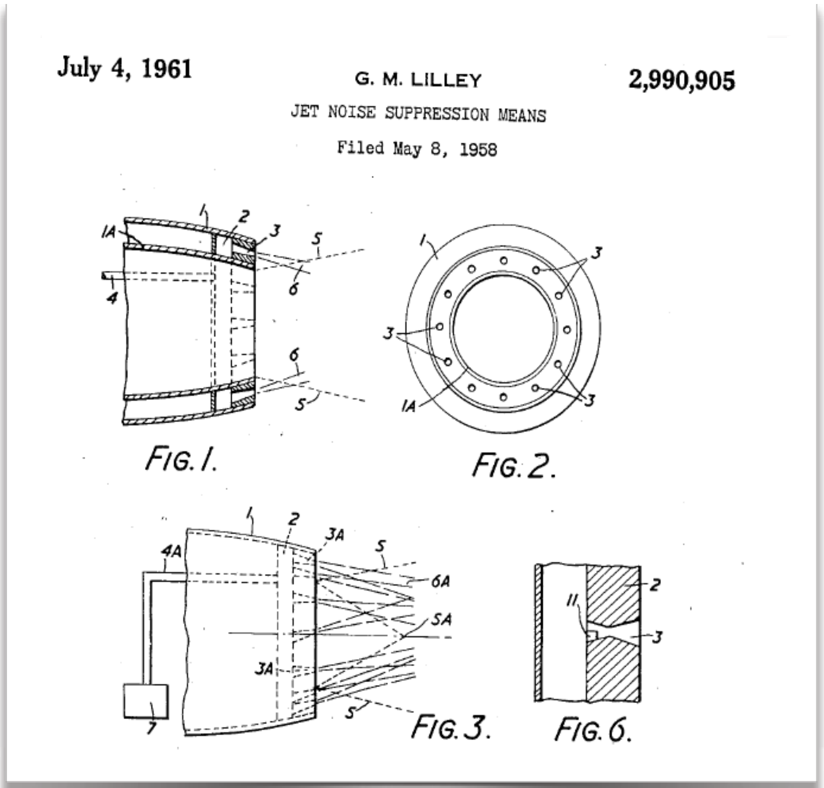
- *Using fluidic injection involved a water injection ring placed behind the exhaust of an afterburning jet engine.*
- *880 gallons of water/minute at 100 psig*
- *The water ring was effective at reducing low frequency noise(Roughly 6 dB OASPL in peak noise direction, reductions at other angles much smaller)*



Engine produced 8000 lb thrust with afterburning

B. The first patent

- *The patent to turbo-jet engines was recognized in 1958 by Lilley*.*
- *A jet noise suppression concept by fluidic injection*
- *Reduction of jet noise through*
  - ✓ *Enhanced mixing*
  - ✓ *Restricted formation of large eddies*



**Lilley, G. M. (1961). "Jet Noise Suppression Means," U. S. Patent # 2,990,905.*

- *1970s-1980s, focused on high speed jets*

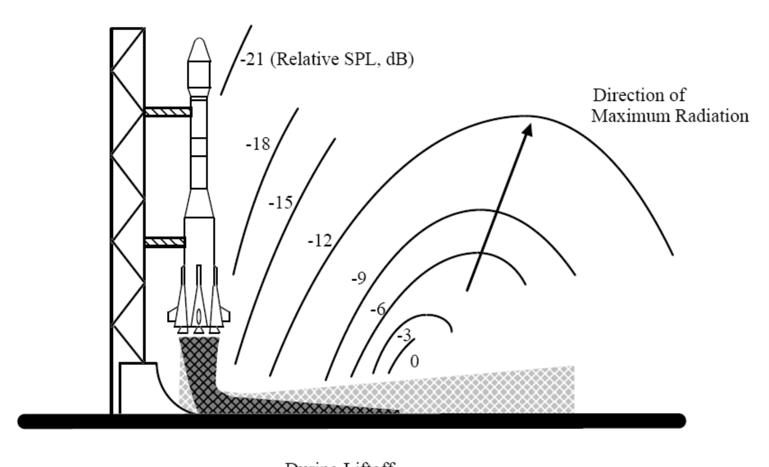
  A. *Water injection for the reduction of excess overpressures encountered during the Space Shuttle lift-off*

  B. *Fluidic noise suppression approaches for in-flight use(STP)*

**STP: Supersonic Transport Program*

A. Suppressing overpressure from lift-off of Space Shuttle by water injection

- ✓ *achieving An OASPL reduction of about 10dB with about 10 times mass flow water than engine jet plume(MFR>990%)*

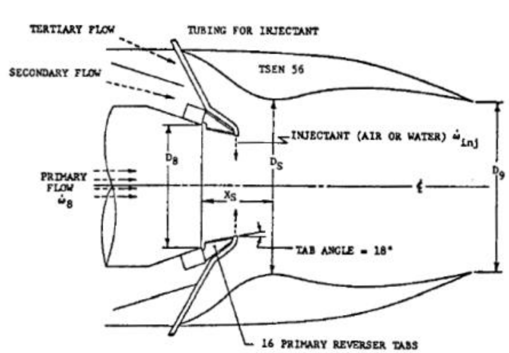


Contour of equal overall SPL

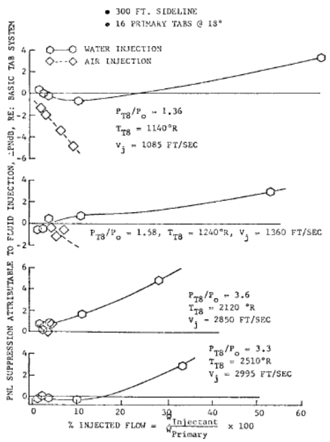
**Guest, S. H.(1976). Space Shuttle noise suppression concepts for the Eastern Test Range, 13th JANNAF Congress, Technology for the New Horizon, 4-59 to 4-78.*

A. Fluidic noise suppression method for in-flight use(STP)

- *Air and water injection acted on the core stream of a dual stream jet*
  - ✓ *Additional noise reduction of roughly 2 dB was achieved with water injection at a mass flow ratio of 15%*
  - ✓ *Air injection did not enhance acoustic performance and the effect of air injection on noise reduction was not obvious.*
- *Large quantities of water were required to obtain additional noise reduction beyond that achieved with the mechanical suppressor systems alone*



Primary tab/fluid injection suppressor system



Effect of air and water injection

◆ *Beginning in the late 1990s, developing a physical understanding of the injection process and noise*

A. *Fundamental understanding was enhanced by CFD analysis and advanced measuring tools(PIV, Phased arrays)*

- ✓ *Experimental and Simulating studies have investigated the impact of some key factors on the radiated jet noise*

● Injector shape	● Pressure
● Size	● Momentum flux
● Injection angle	● Mass flow rate
● Yaw angle	● Etc.

B. *Far more research has been performed for gas injection, Why?*

- ✓ *Compressor bleed air as the injection medium on an aircraft*
- ✓ *Injection mass flow rates are much lower for air than water*

The difficulties

- *Developing a general physical understanding of the injection process and the resulting acoustic radiation*
  - *Vast differences in the injection configurations and operating conditions used in researches.*
  - *Only a few studies have combined flow-field and acoustic measurements*

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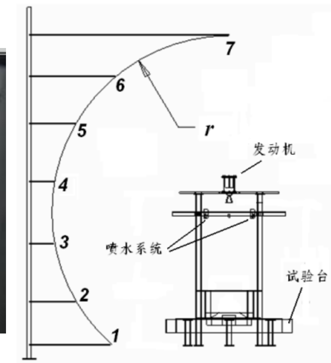
Tests of jet noise reduction with fluidic injection

- *Supersonic heated jet noise reduction by Water*

Single flow stream nozzle
Mach number=3.9
Total temperature=3800K



- *Supersonic cold jet noise reduction by Water*

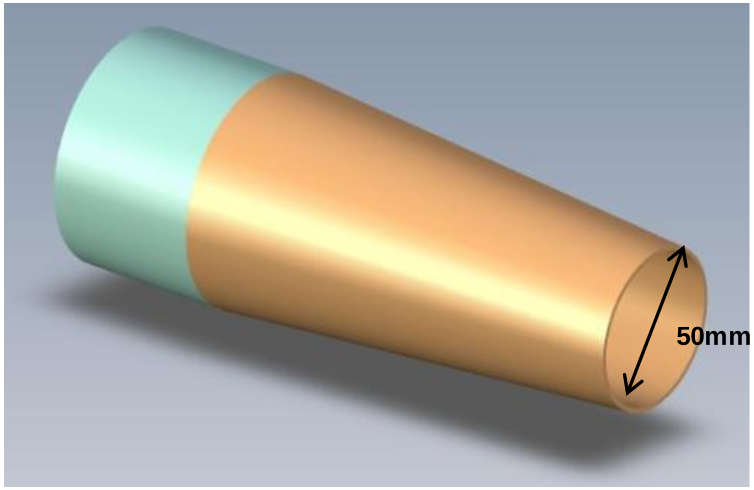
Single flow stream nozzle
Mach number=1.5
Total temperature=300K

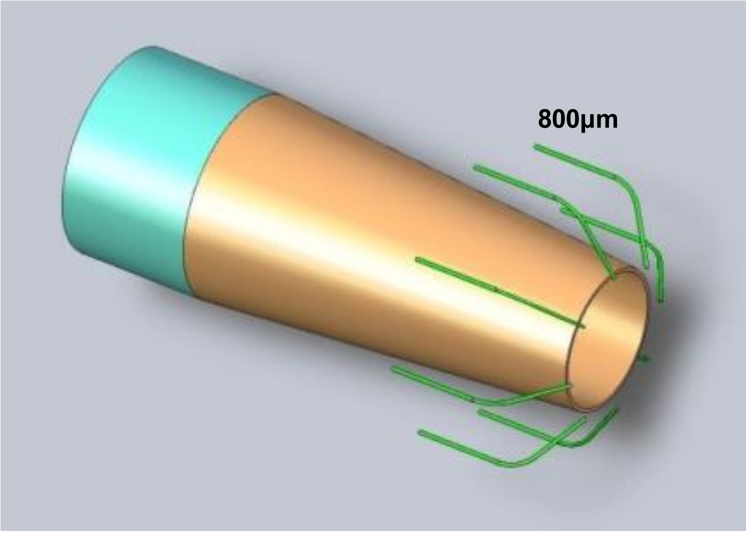
- *High subsonic cold jet noise reduction by Air injection*

Single flow stream nozzle
Mach number=0.9
Nozzle exit diameter De=50 mm

Jet noise prediction with air injection based on Hybrid method

- *To learn the effect of air injection on jet flow and acoustic characteristics*
  - *3 Cases*
    - a. *Base nozzle(Without air injection)*
    - b. *Air injection with MFR = 1%*
    - c. *Air injection with MFR = 2%*
  - *Model*
    - *Single flow stream convergent nozzle*
    - *Number of air injection nozzle = 12*
  - *Main Parameters*
    - *Nozzle exit Mach number =0.9*
    - *Nozzle exit diameter D=50 mm*
    - *Injection angle α=60°*
    - *Microjet diameter dμ=Φ800μm*





MFR: air-to-main jet mass flow ratios

Jet noise prediction methods

- *Three methods for jet noise prediction in use*

  - *Semi-empirical model method*

    Empirical method combining a large number of experimental data with similarity theory

  - *Computational Aero-Acoustics(CAA)*

    To analyze the generation of noise by turbulent flows through numerical methods

    a) Direct numerical simulation (DNS) Approach

    b) Hybrid Approach

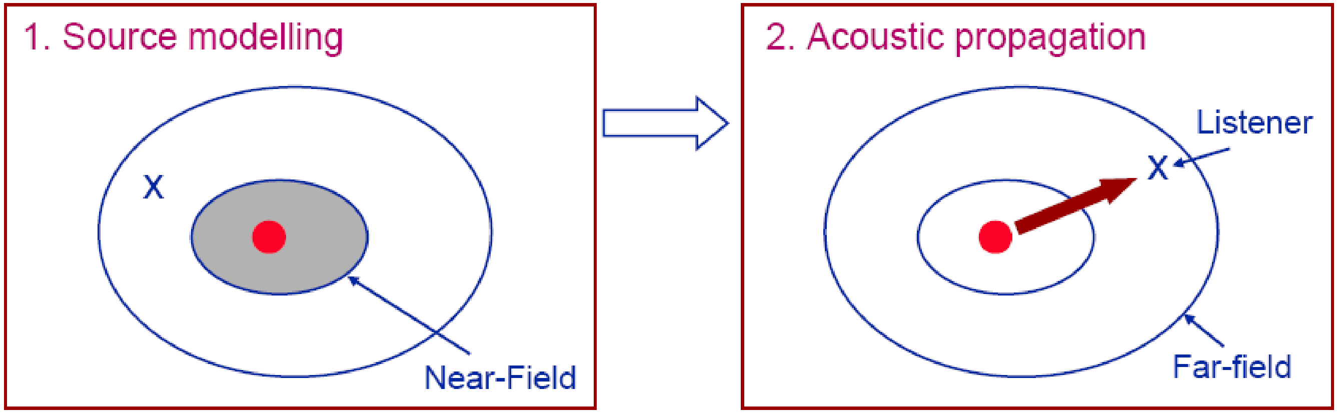
Jet noise prediction methods

◆ *Semi-empirical model method*

- ✈ *Aircraft Noise Prediction Program(ANOPP) form NASA*
  - ✓ *For evaluation of aircraft noise airworthiness*
  - ✓ *Fully using semi-empirical model including jet noise, fan noise, etc.*
- ✈ *Distributed Source Method(DSM) from NASA Langley Research Center*
  - ✓ *For rocket jet noise prediction of Saturn 5, Crew Launch Vehicle (CLV)*
  - ✓ *One of NASA Space Veicle Design Criteria(NASASP-8072) in 1971*
  - ✓ *Still in use and continuous improvement based on CFD Technology*

Disadvantage: rely on test data heavily!

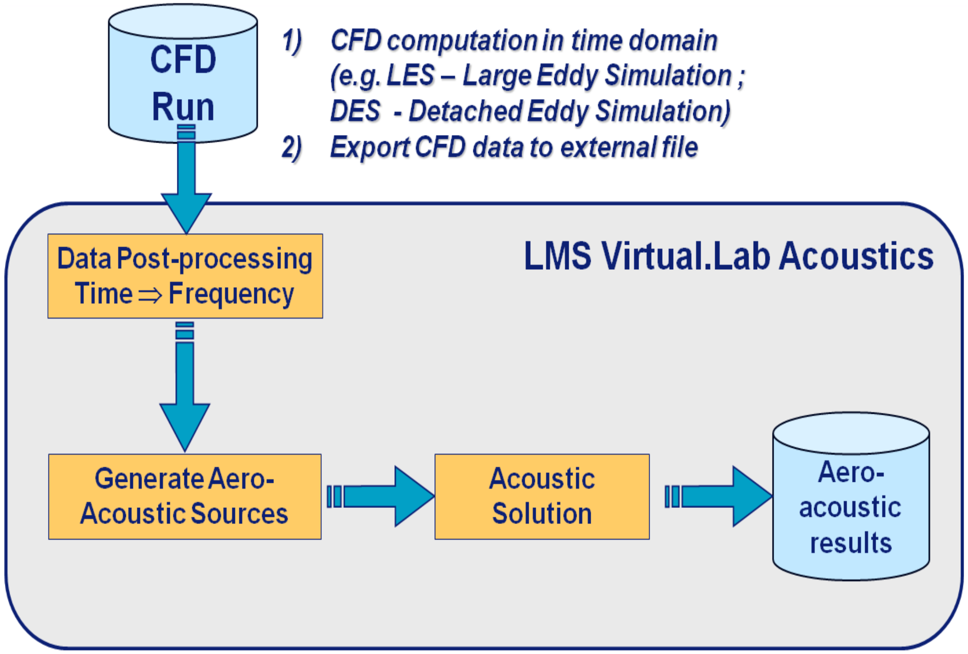
- *Hybrid method*
  - ✓ *Computational domain is split into different regions*
  - ✓ *Governing acoustic or flow field can be solved with different equations and numerical techniques*



Simulation of jet noise based on hybrid method

- *Numerical methods*
  - *Solvers: ANSYS Fluent 14.1 and Virtual.lab acoustics module*
  - *DES model based on Realizable k-ε turbulence model*
    - *0.4<M<2*
    - *Suitable for round jet*

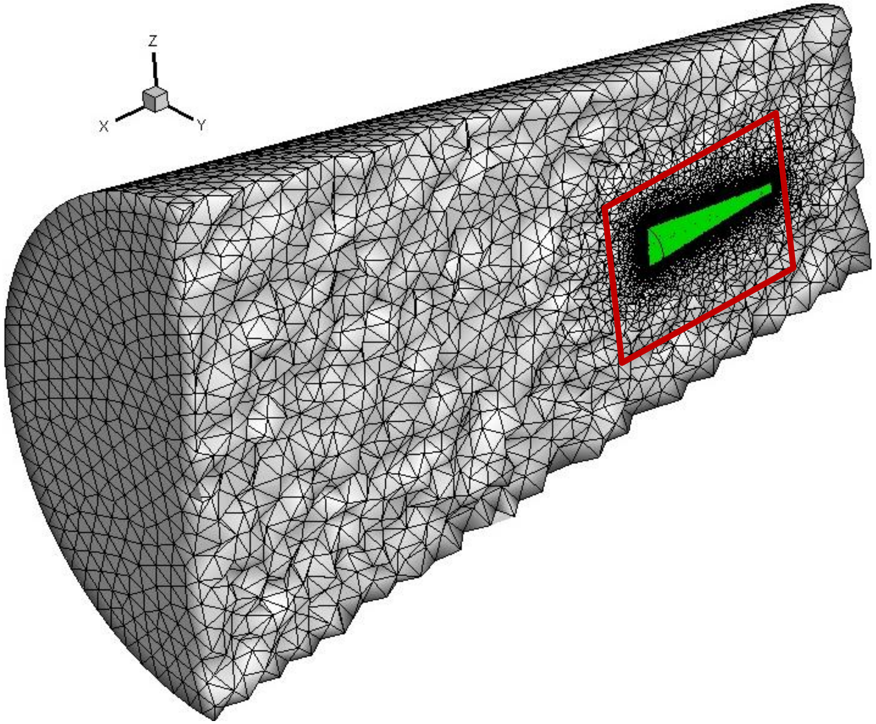
$C_{1\varepsilon}$	1.4
$C_{2\varepsilon}$	2.02
σ_k	0.324
σ_ε	0.377
Pr_T	0.422

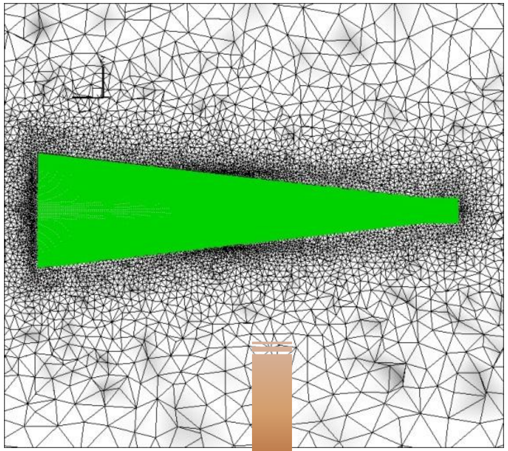


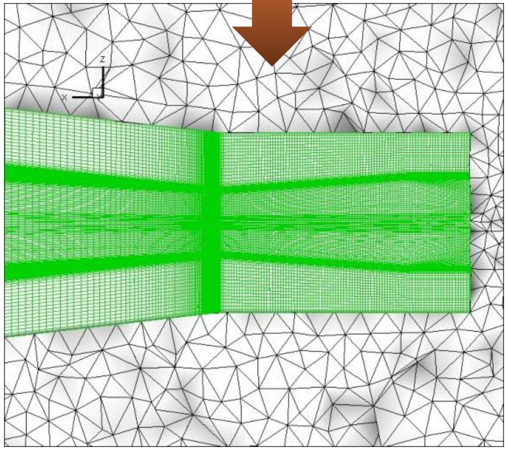
** Thies A, Tam C K W. Computation of turbulent axisymmetric and nonaxisymmetric jet flows using the k-ε model. AIAA Journal, 1996; 34(2):309-316*

Simulation of jet noise based on hybrid method

- *View of mesh used for simulations*



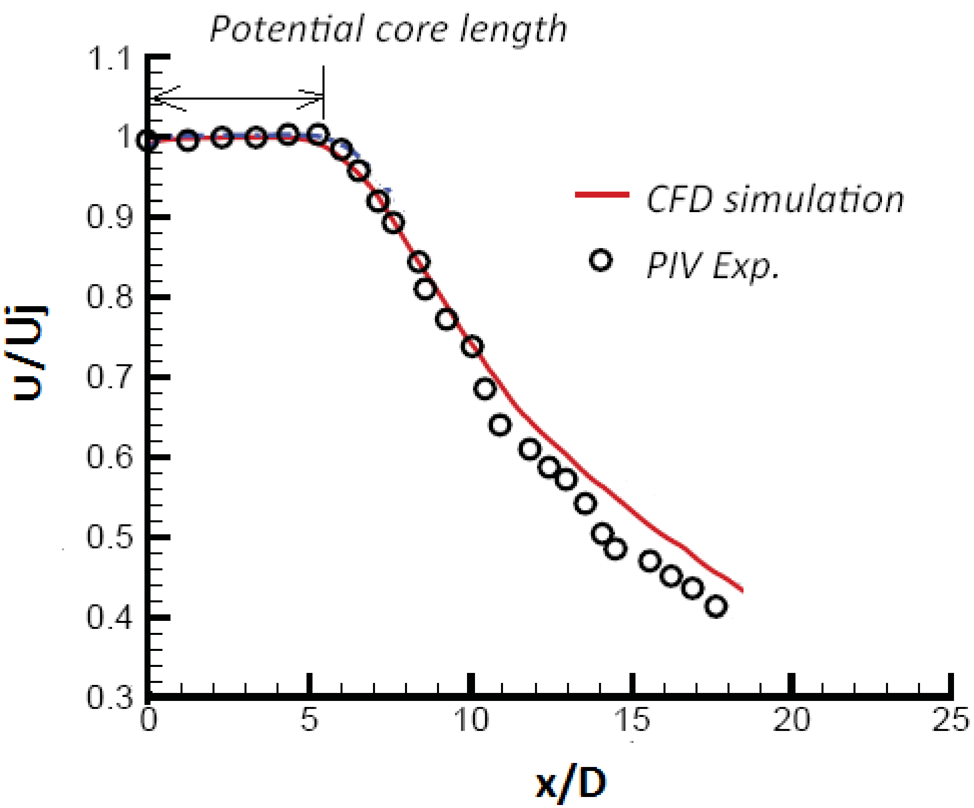




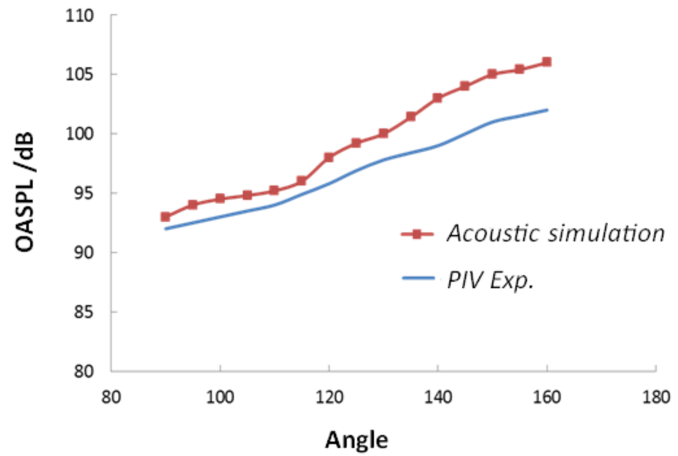
(*Number of Cells ≈ 8Million~10Million*)

Results and analysis

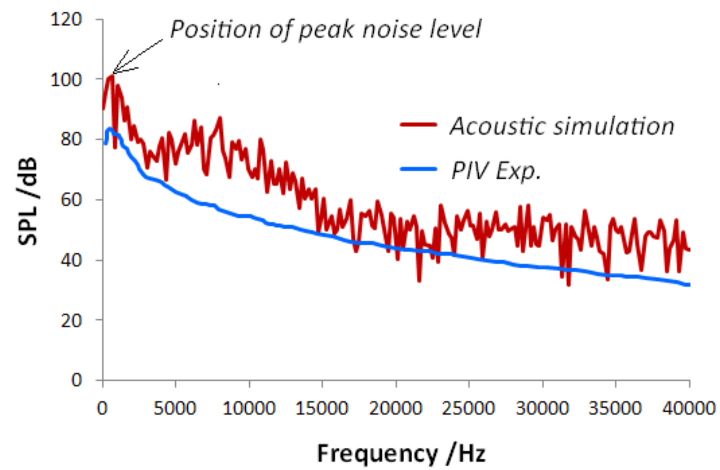
- *Comparison between CFD/Acoustic simulations and experimental data(base nozzle configuration)*



Centerline mean velocity



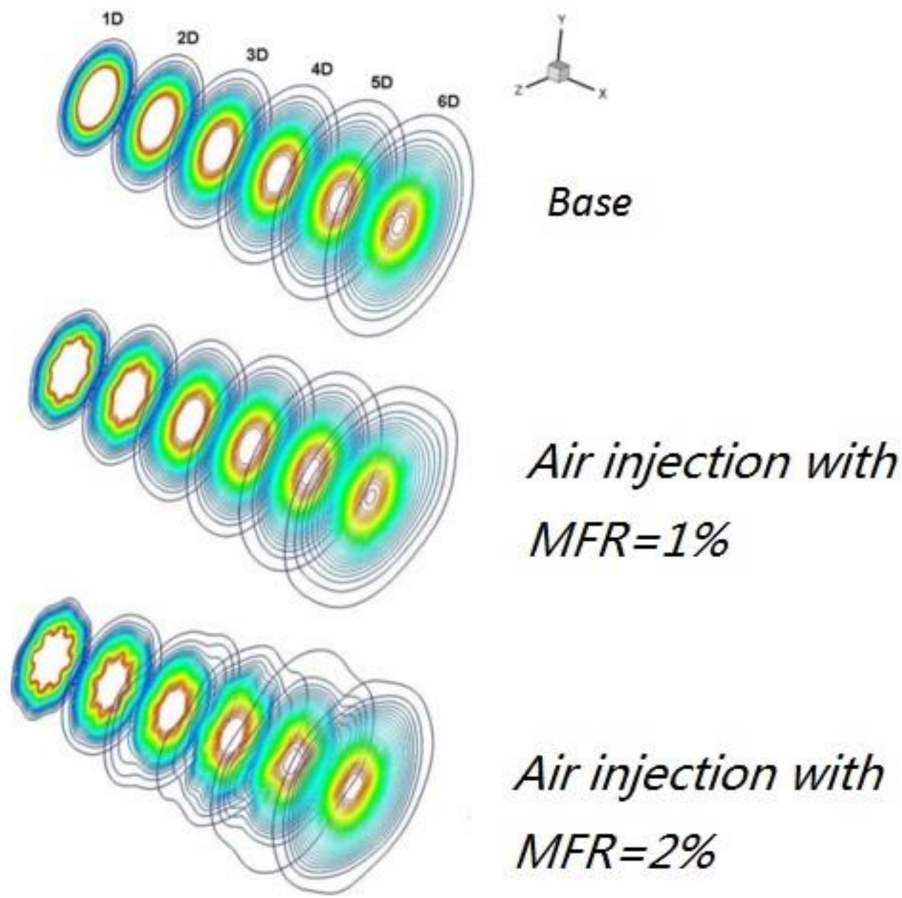
OASPL directivity



Sound Pressure Level spectra

Results and analysis

- *Time-averaged mean streamwise velocity (u/Uj) at different stations downstream of the jets (all 3 cases)*



Comparison at the plane cutting through the centers of two opposite injection nozzles and those of the base nozzle.

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Concluding remarks

- *The history of fluidic injection for jet noise reduction and current status of fluidic injection at CAE were reviewed.*
- *Water injection had been used for jet noise reduction during space shuttle liftoff but not for in-flight because large quantities of water were required. The application of gas injection for in-flight jet noise reduction is uncertain.*
- *Simulations of jet flow field and acoustic characteristics with air injection had shown that*
  - ✓ *The simulating results agreed well with experimental data.*
  - ✓ *Jet noise could be reduced by disturbing the jet flow structure under the computational conditions, but not in-flight conditions.*

Capability of gas injection for aircraft is waiting to be proved!

Thank you！