Lift Enhancement for Upper Surface Blowing (USB) Airplanes

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Outline

- **Introduction**
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- **Current Study**
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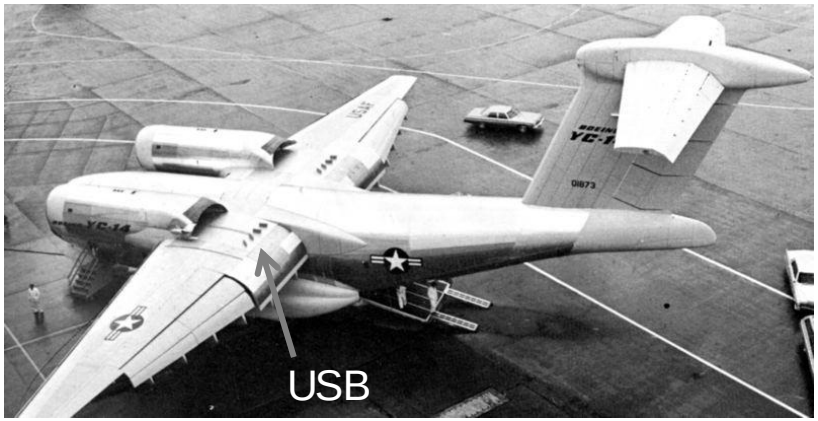
- **USB Enhancement Techniques**
  - **Geometrical modifications**
  - **Active Flow Control (AFC)**
    - **AFC concept**
    - **Actuation modes**
      - **Constant**
      - **Pulsed**
      - **Sprinkler**

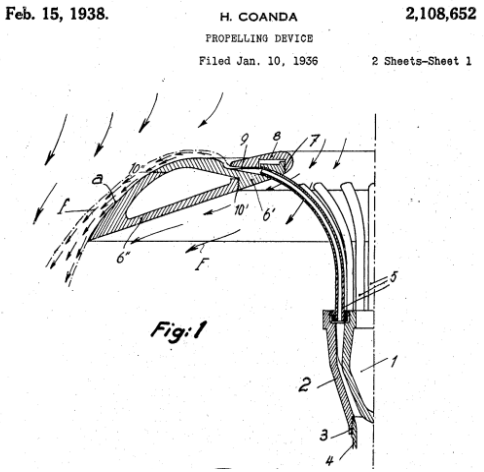
Powered lift concepts

- **Increase lift production by exploiting engine exhaust jet**
  - **Externally Blown Flaps (EBF)**
  - **Internally Blown Flaps (IBF)**
  - **Upper Surface Blowing (USB)**

- **Coanda Effect**

  "Deviation of a plain jet of a fluid that penetrates another fluid in the vicinity of a convex wall"




Feb. 15, 1938. H. COANDA 2,108,652

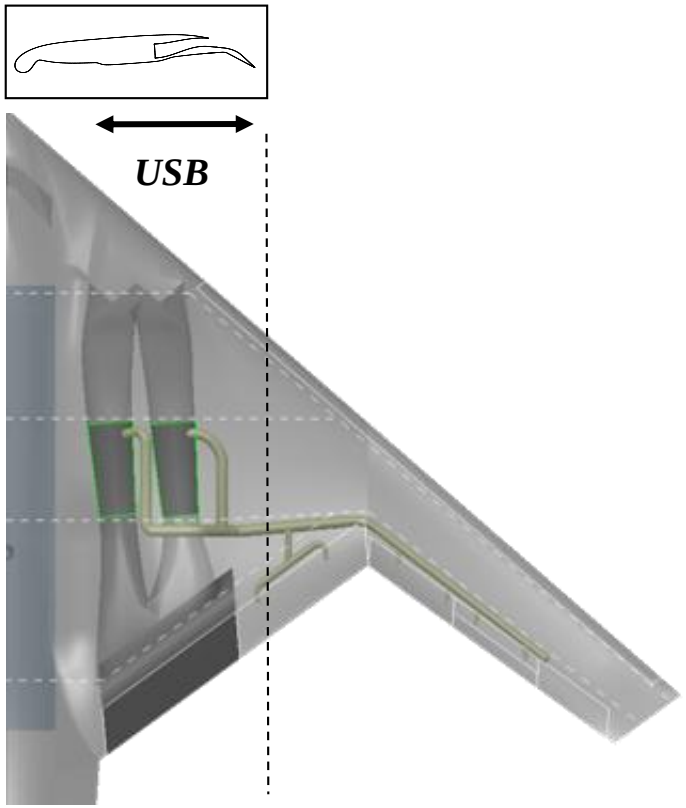
PROPELLING DEVICE

Filed Jan. 10, 1936 2 Sheets-Sheet 1

Fig: 1

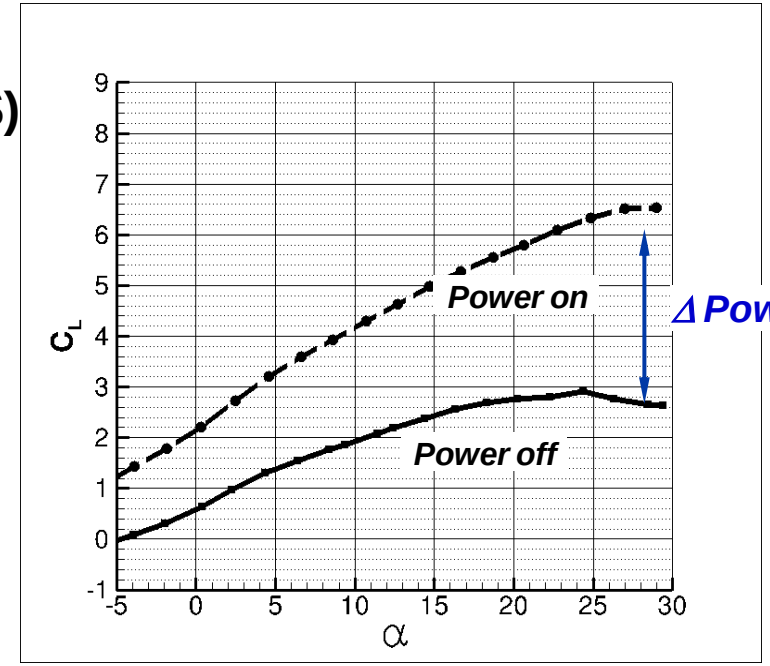
Experimental confirmation

Speed Agile Concept Demonstrator
- **AFRL**
- **Advanced Joint Air Combat System (AJACS)**



Single element, simple hinge flap

3-element slotted slat and flap



Boeing V/STOL (Philadelphia, July 2007)

Current study

- **Problem**
  - **Premature jet peeling-off degrades lifting capability**
    - **Ratio of Jet thickness to surface radius of curvature:**
      - Thin jet
      - Large radius of curvature
    - **Edge effects**
      - Spanwise extent of nozzle
      - Edge vortex formation
- **Objective**
  - **Develop technologies for enhanced USB systems**
- **Approach**
  - **Geometrical modifications**
  - **Active Flow Control**

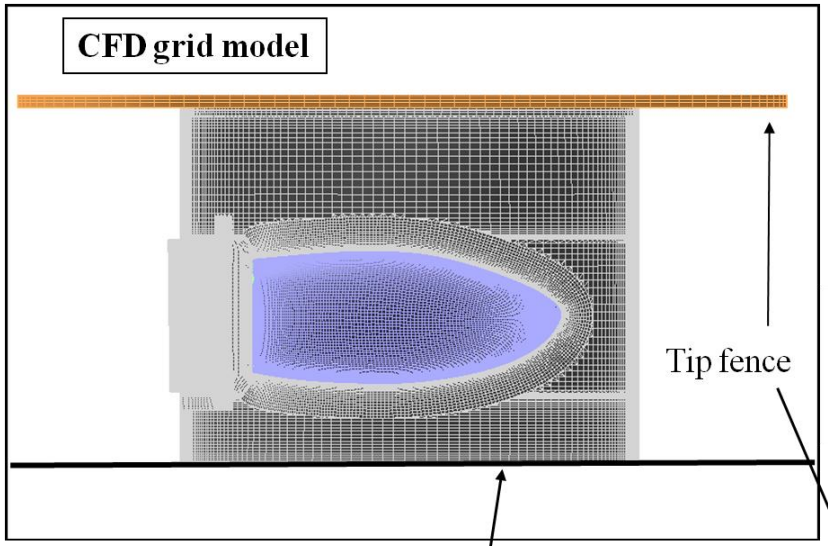
Analysis approach

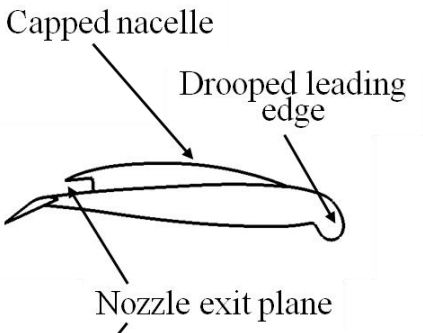
- **CFD based evaluation of the new technologies**
  - **Validation**
  - **Application to USB enhanced concepts**
- **Numerical tool**
  - **Unsteady RANS (OVERFLOW with Boeing's modification)**
  - **Overset grid system**
  - **Upwind scheme**
  - **One-equation (S-A) turbulence model**
  - **Time-varying boundary conditions**

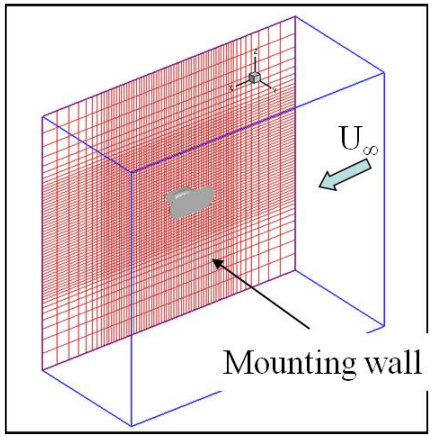
Numerical validation

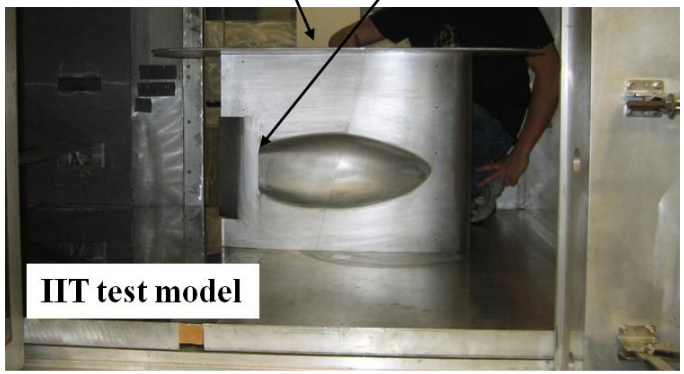
Illinois Institute of technology 2007 test:

- CFD Model:
  - 10.5 million points
  - 34 zones





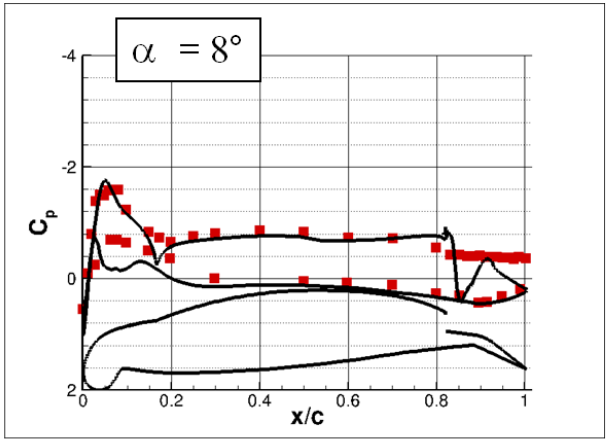


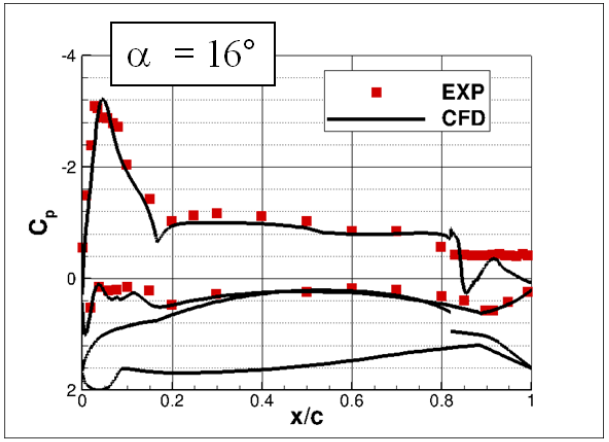


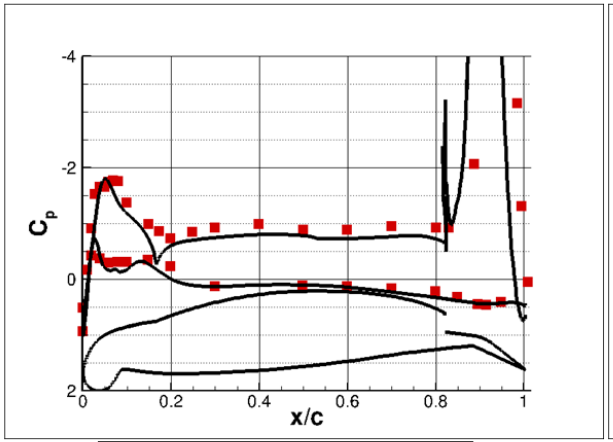
Numerical validation - sample

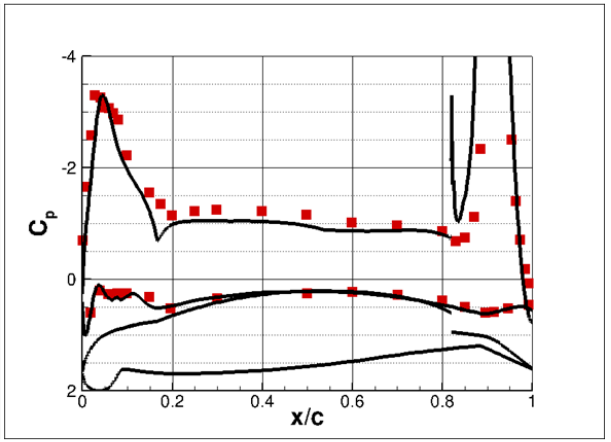
Power OFF

Power ON



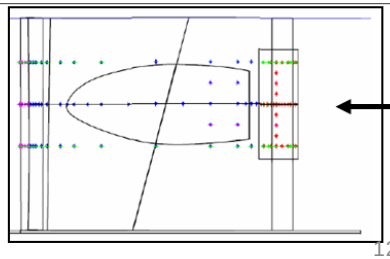






$C_T = 0.8$

- near sonic nozzle



cut at centerline row

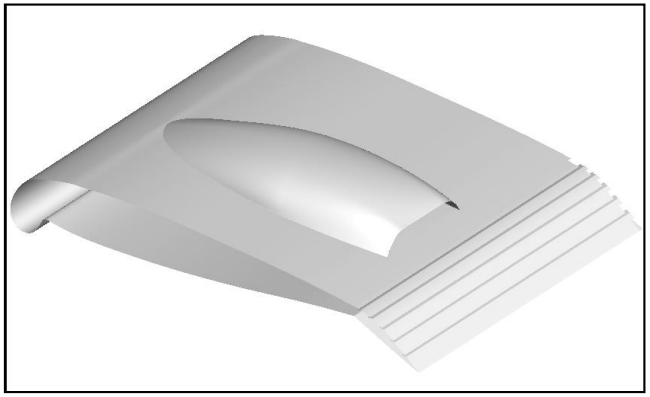
$U_\infty = 45$ m/s

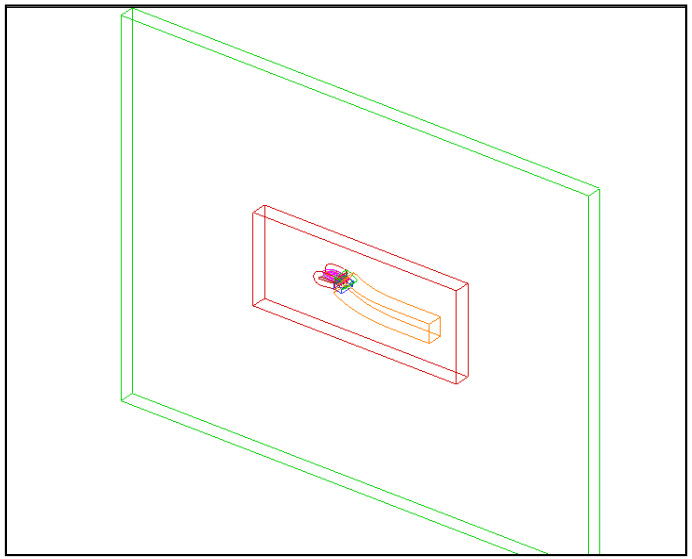
$M_\infty = 0.132$

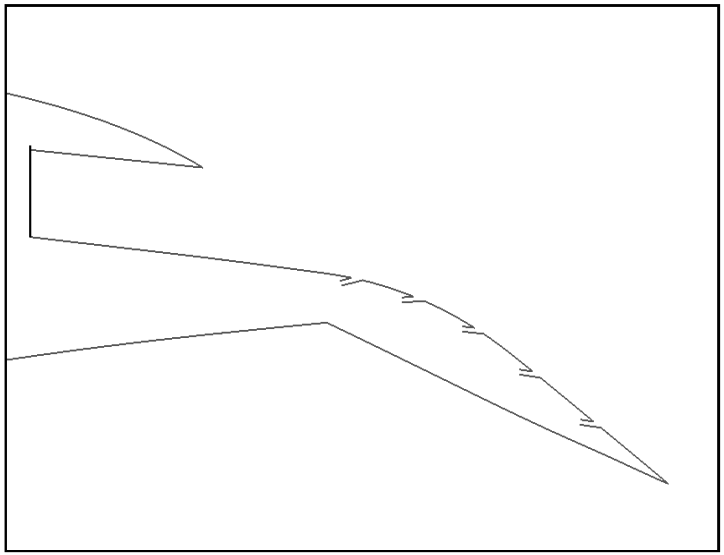
USB baseline configuration

Computational test bed is based on the IIT model

- Wing of constant chord between 2 vertical walls
- Full span flap
- Nozzle aspect ratio of 6
- AFC slots embedded in flap upper surface
- Height of slot is 0.2% chord



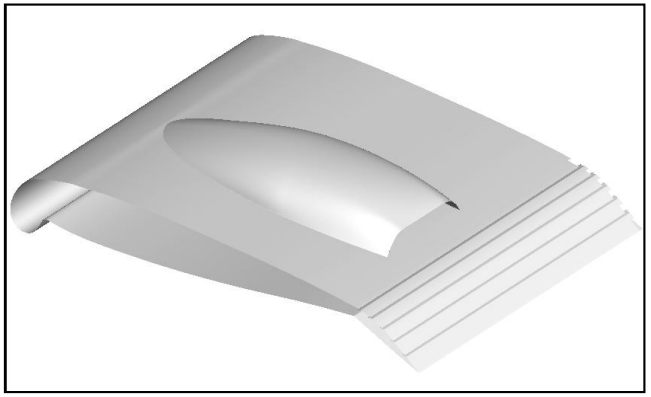


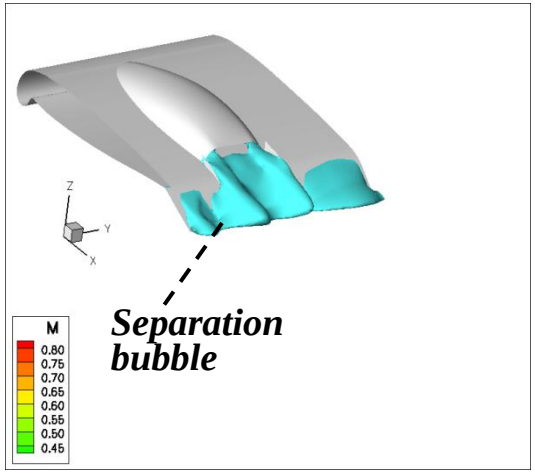


USB flow features

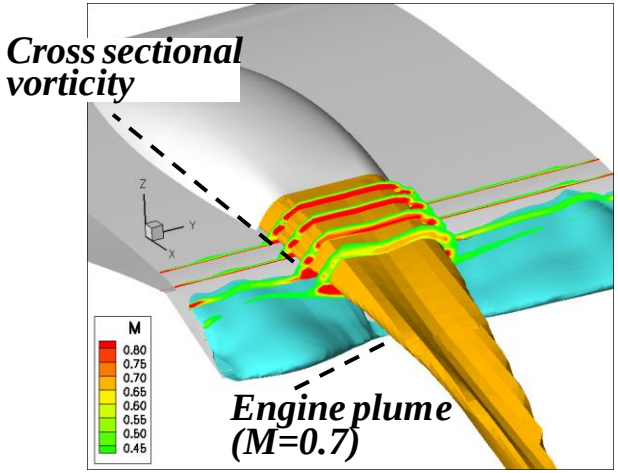
Flow Features

- Lift increment of 16%
- Flow reattachment behind engine
- Roll-up of engine plume at edge of nozzle

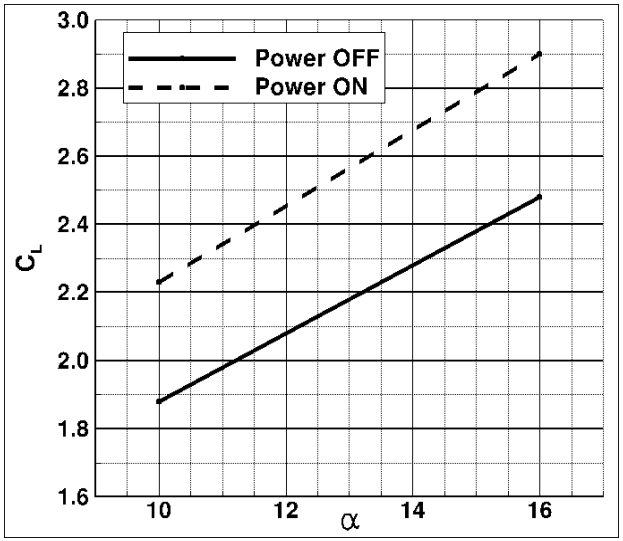




Power off



Power on (takeoff)



Techniques for enhanced USB

Enhanced Coanda effect:

- **Reshape flap upper surface**
- **Elongated nozzle**

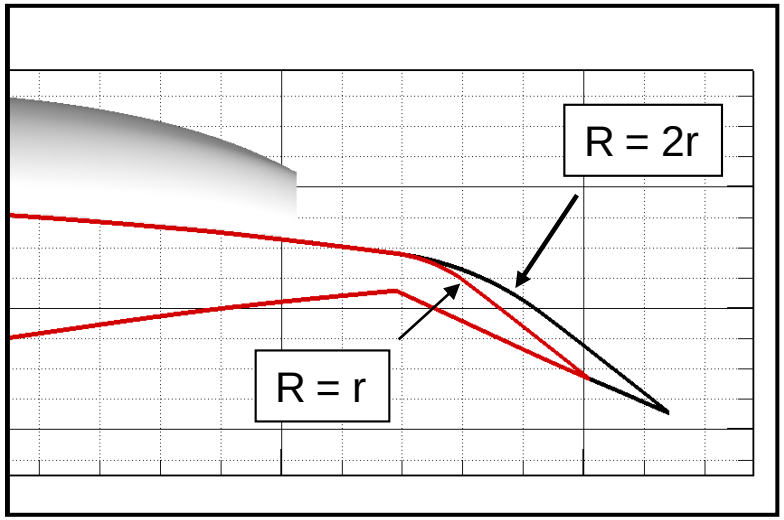
Mitigate nozzle edge effects:

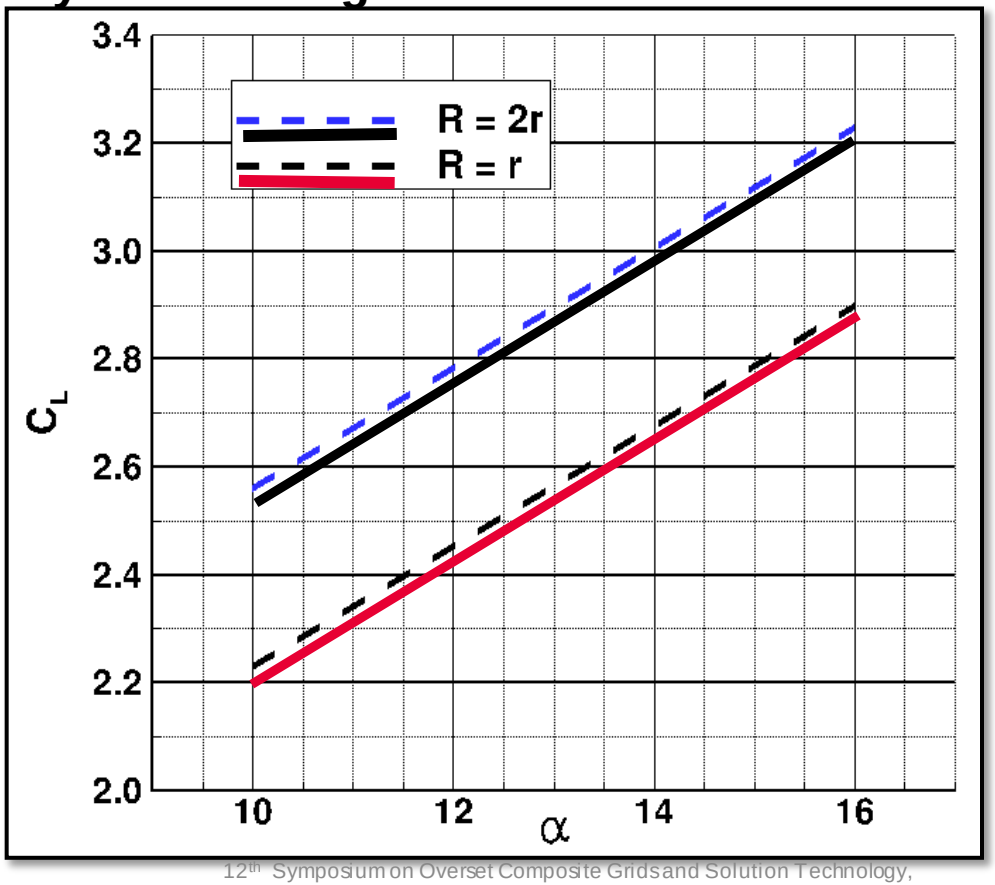
- **Nozzle edge effects**
- **Flow control methods:**
  - Constant blowing
  - Pulse actuation
  - Sprinkler actuation

High curvature flap

- **4.7% increase in wing chord**
- **Lift increase of 12%**

- **Augmented Coanda effect over only 28% of wing**

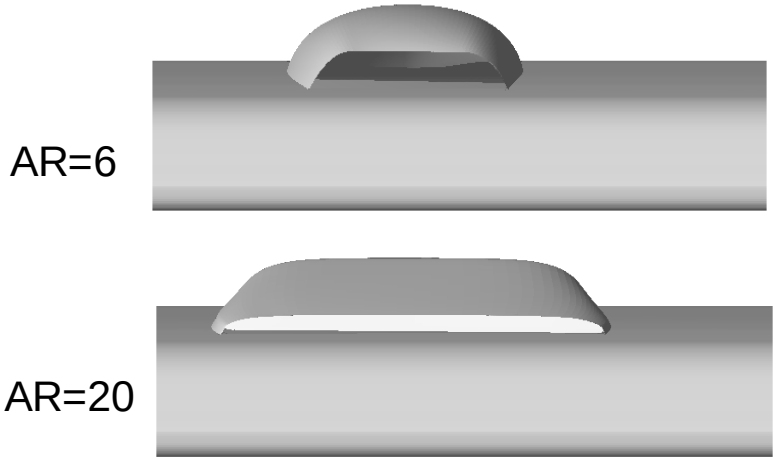


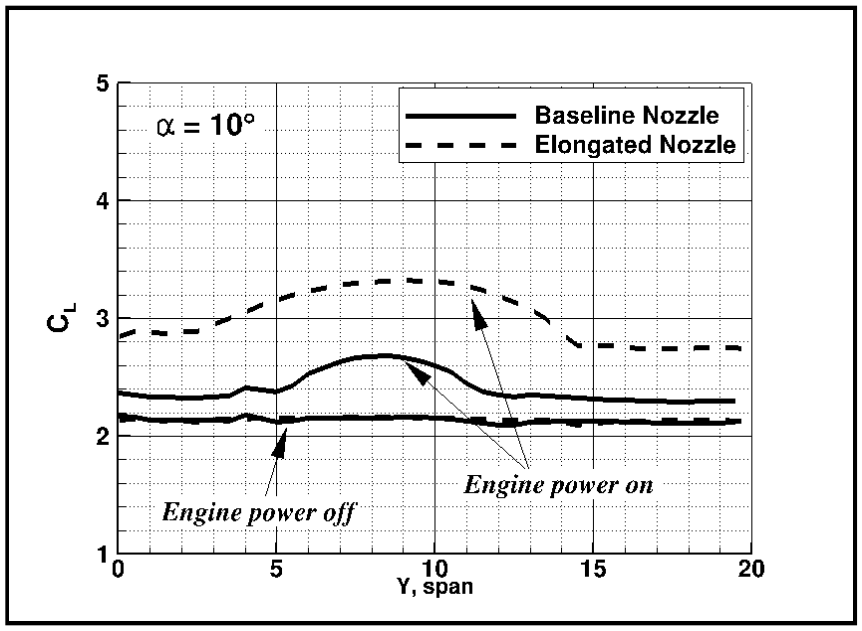


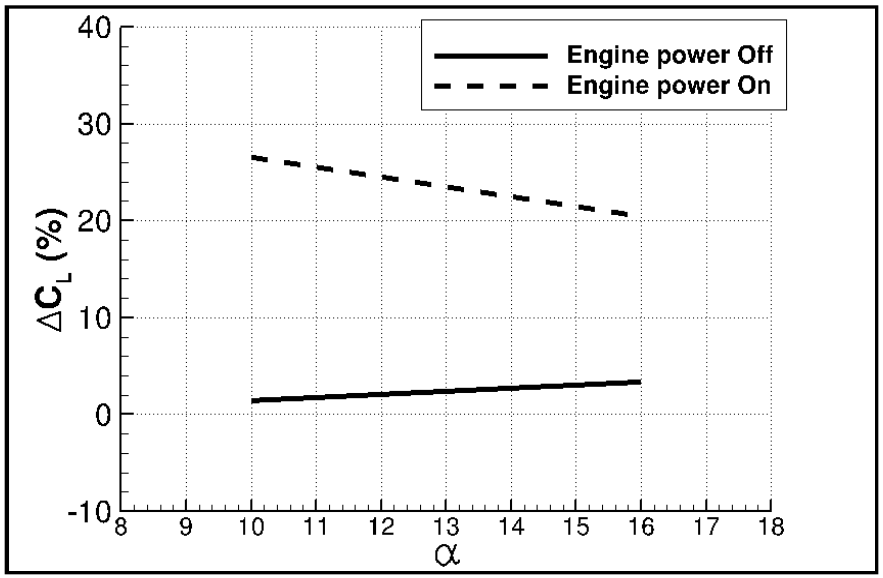
High aspect ratio nozzle

- **Double nozzle width**
- **Fix nozzle exit area (fixed $\dot{m}$)**

- **Reducing thickness of jet plume**
- **Larger USB affected area**
- **Flow is effectively more 2D**
  - **Smoother spanload distribution**



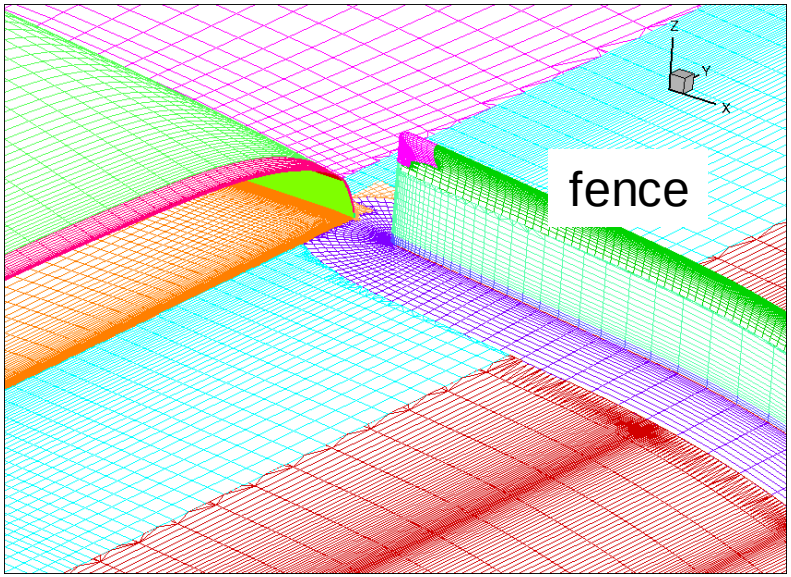


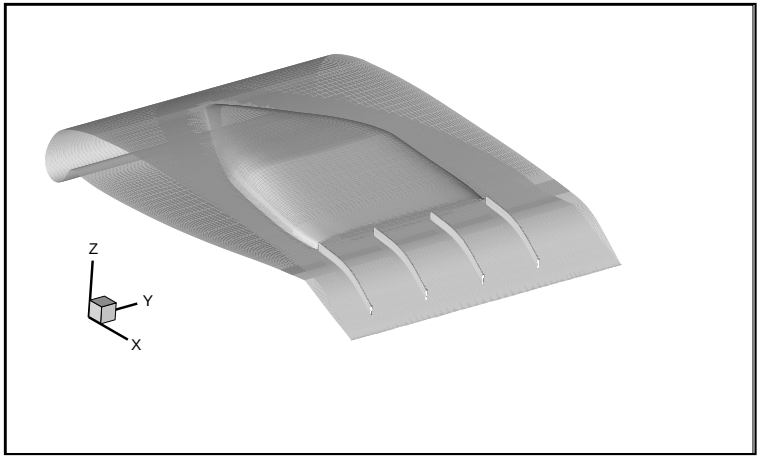


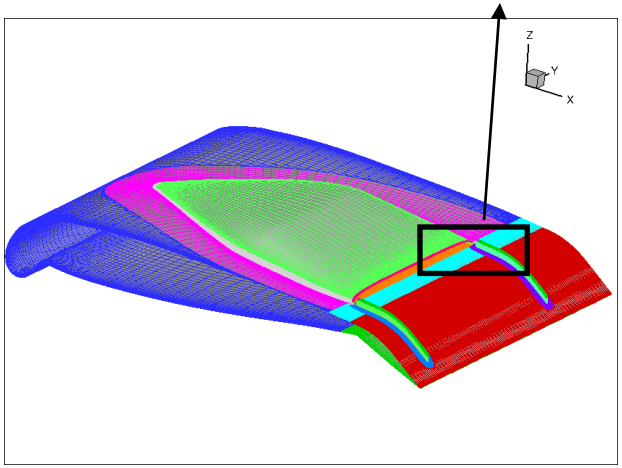
Flap fences

- **Control edge effects**
- **Prevent vortex roll-up**
- **Reduce three-dimensionality of flow**

- **Variable height**
- **Fixed or automatically deployed**



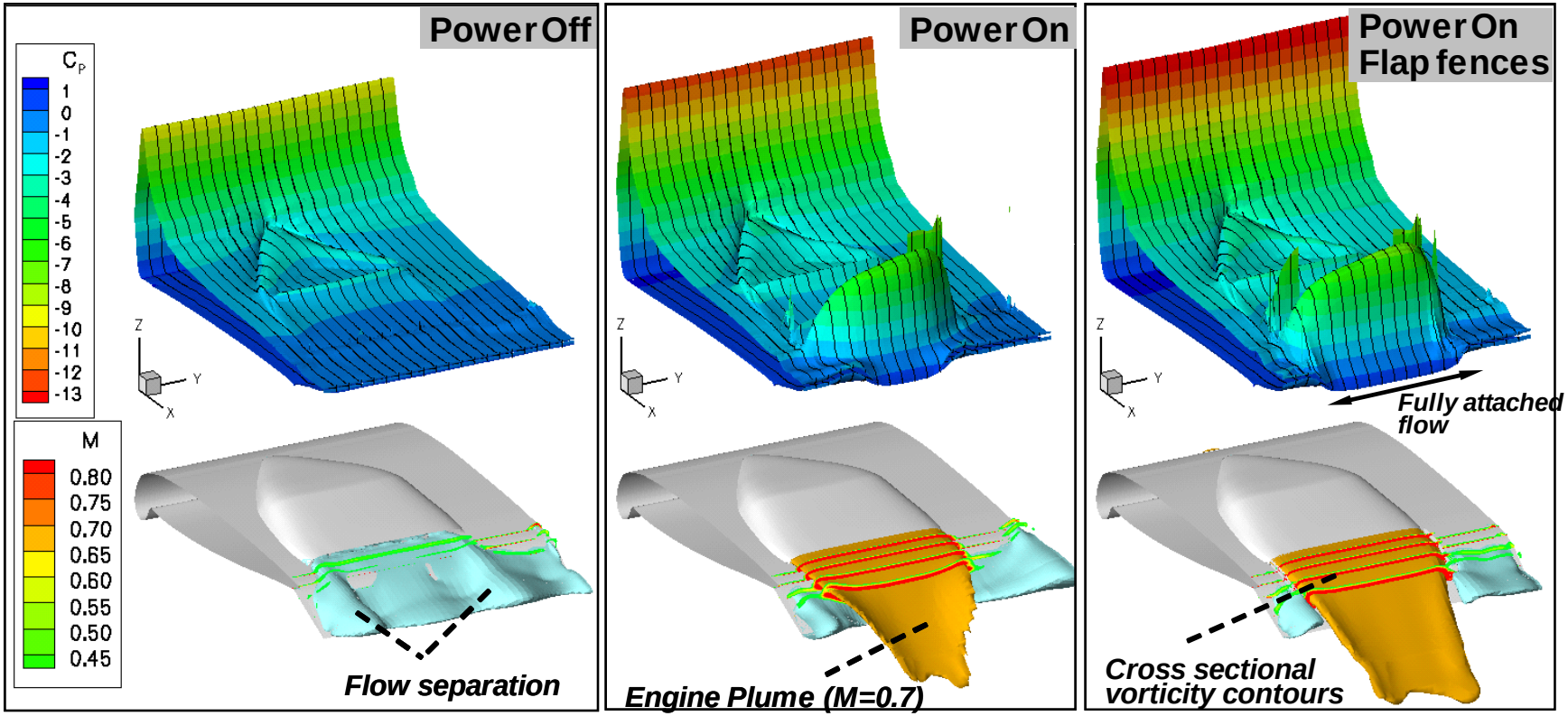




Flap fences effects

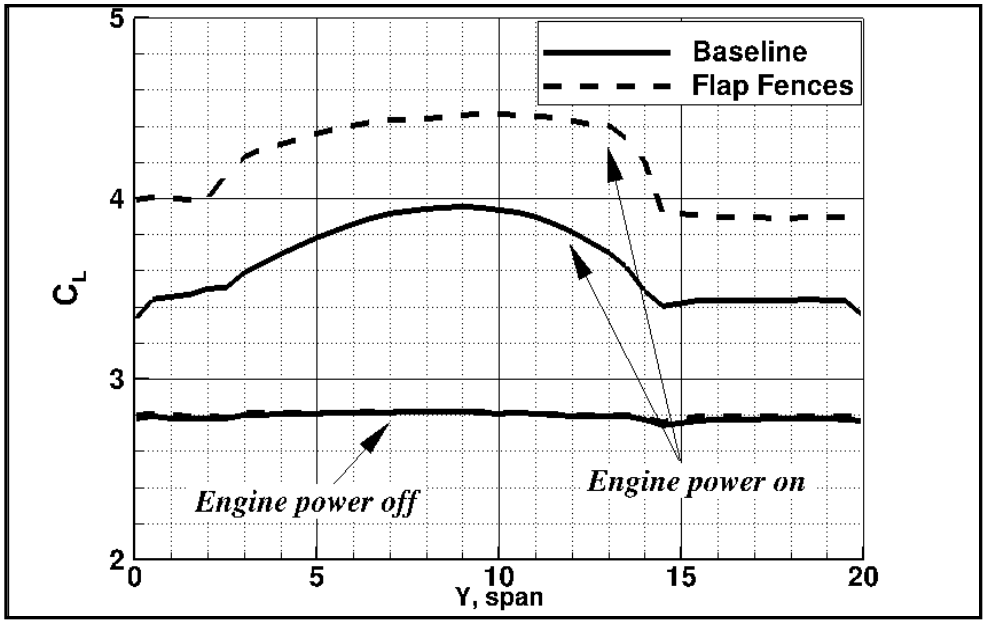
- **Wider plume**
- **Weaker edge vortices**
- **Fully attached flow over flap**
- **High LE pressure suction due to increased circulation**

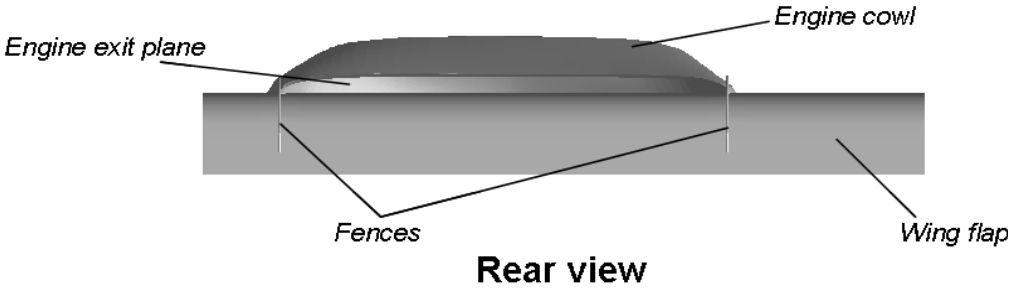
Elongated nozzle
$\alpha = 16°$

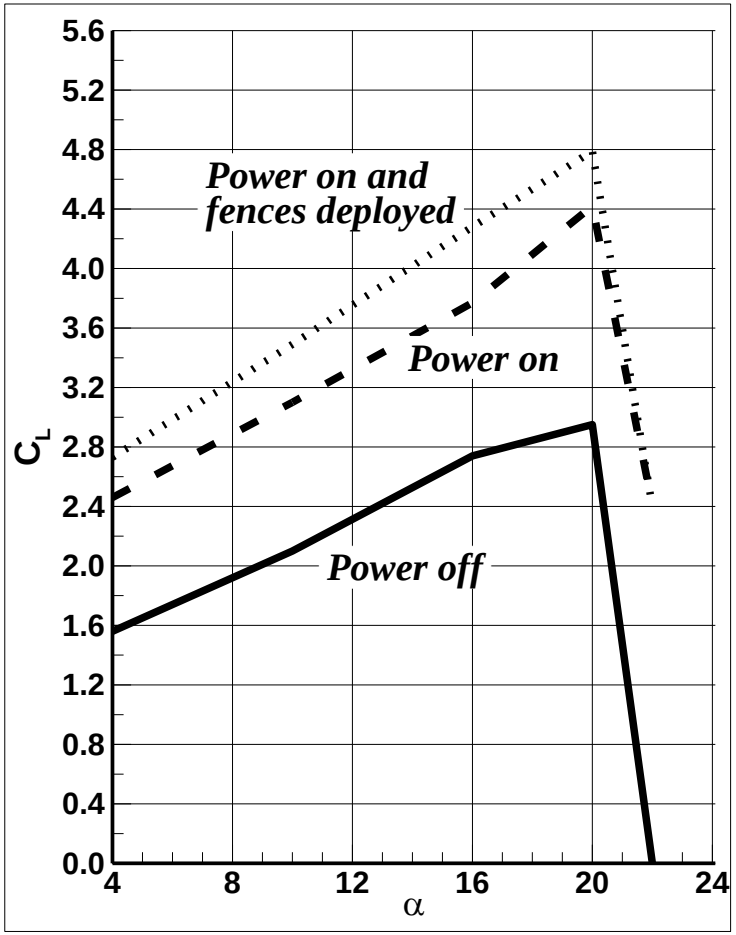


Flap fences performance

- **Higher load distribution is achieved across the entire span**
- **The flow becomes more "2d"-like between fences**



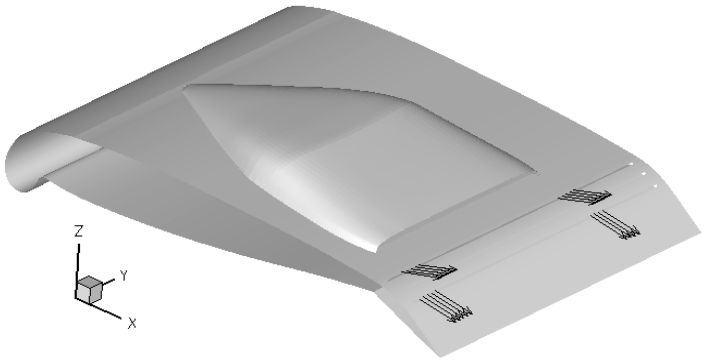




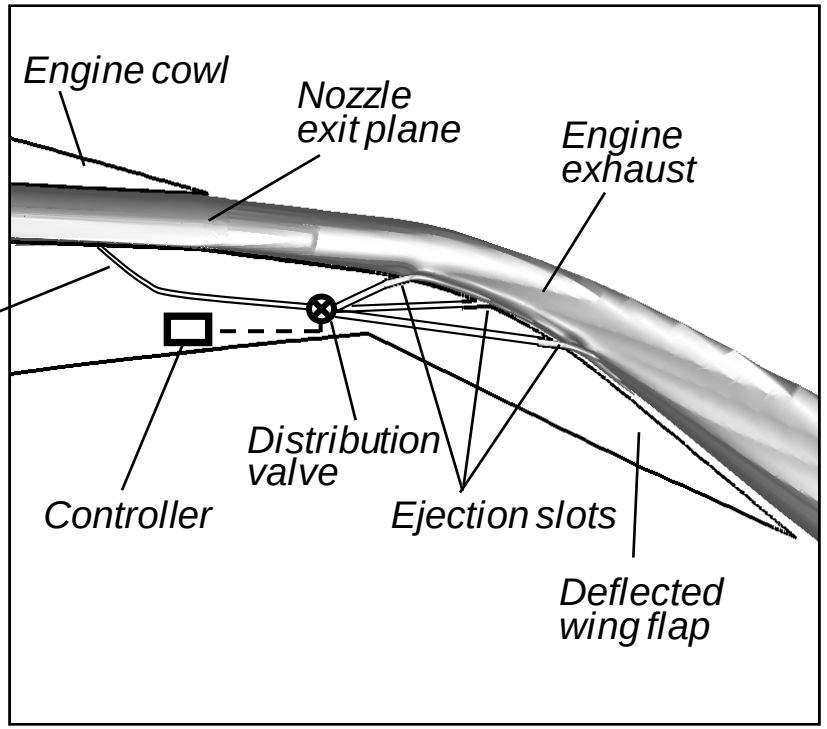
Active Flow Control

- **Lift enhancement through delayed flow separation at high angles of attack**
  - **Zero mass flow devices**
  - **Fluidic device**
    - Source of air
      - Engine bleed
      - Dedicated compressor
    - Actuation type
      - Constant blowing from a fixed orifice
      - Variable blowing
        - Pulse actuation ---periodic variation of jet velocity
        - Sprinkler actuation ---continuous swiveling of blowing jet

Active Flow Control setup



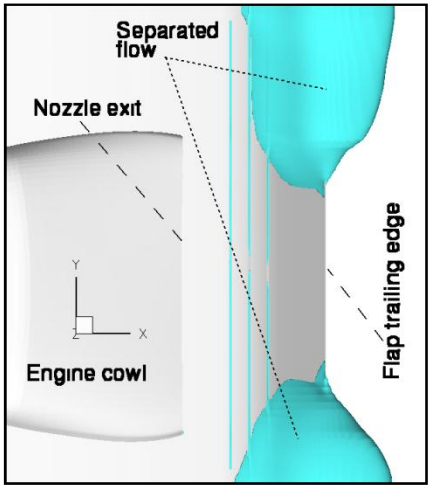
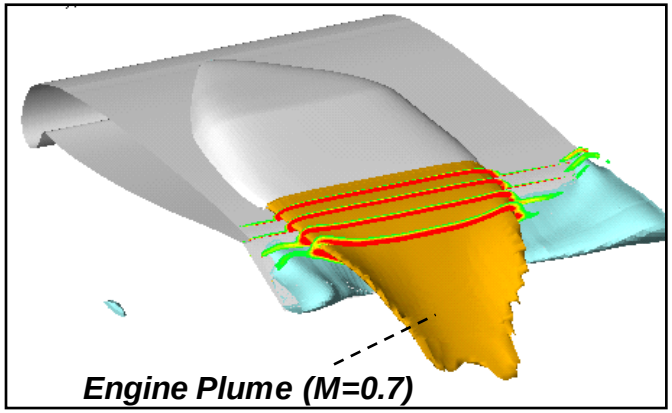
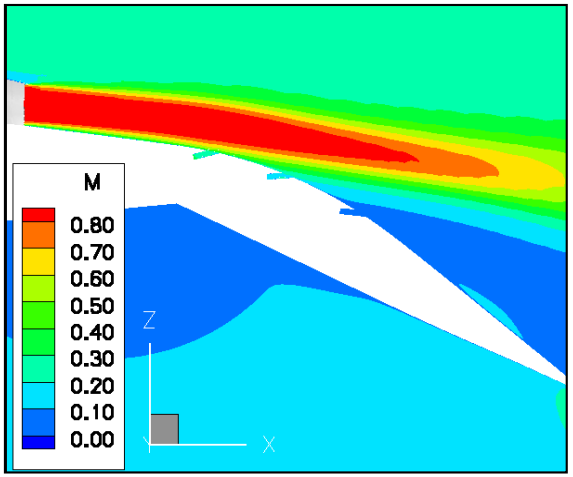
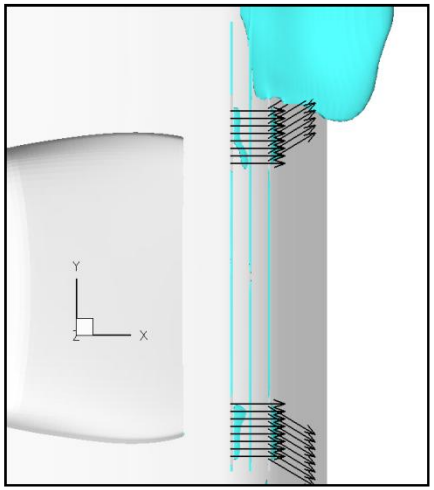
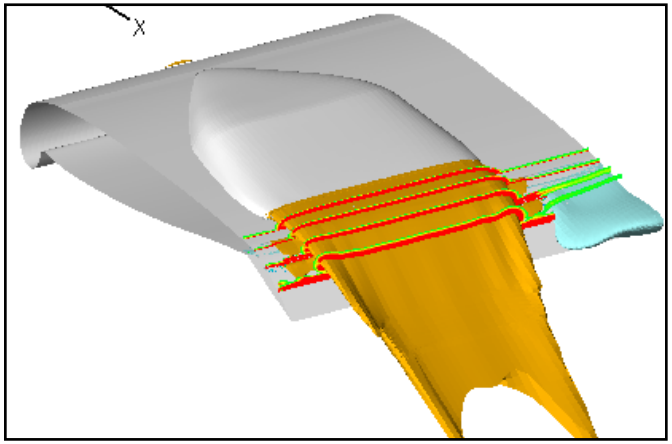
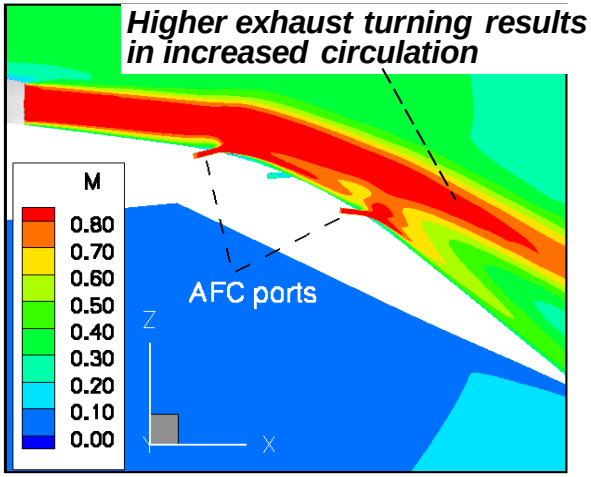
Bleed off engine exhaust for actuation at plume's edges



Cut through the engine

Constant blowing

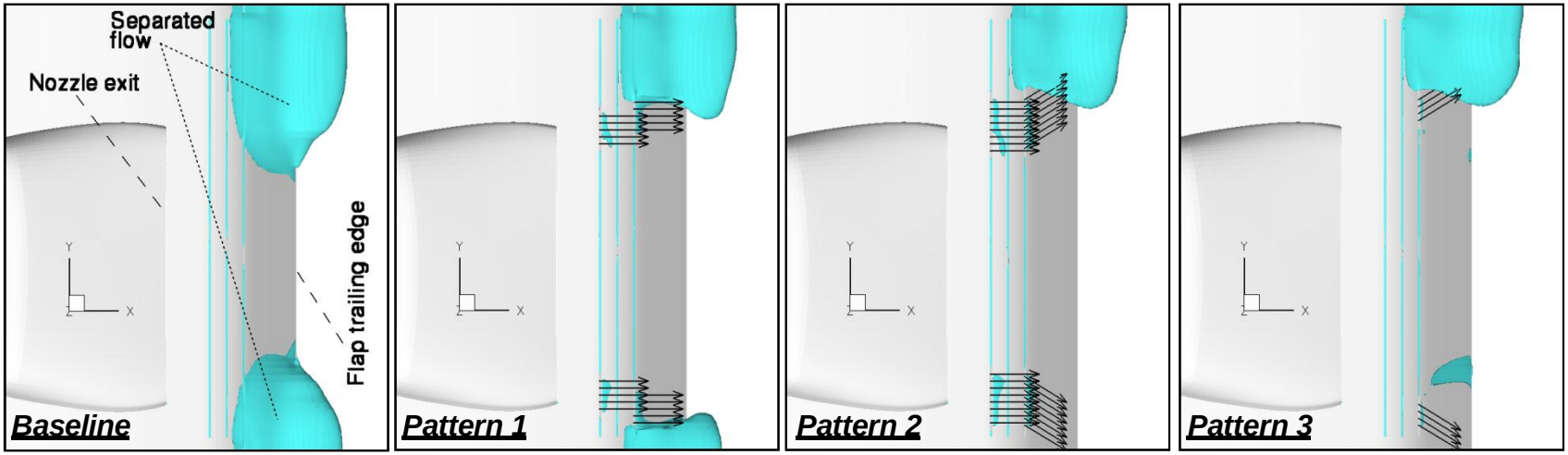
Actuation results in increased USB effectiveness

	Top view	*Exhaust plume*	*Vertical cut through ports*
Control Off			
Control On			

Constant blowing (cont.)

Alternative actuation patterns:

- **multiple flight conditions**
- **uncertainties in plume location**

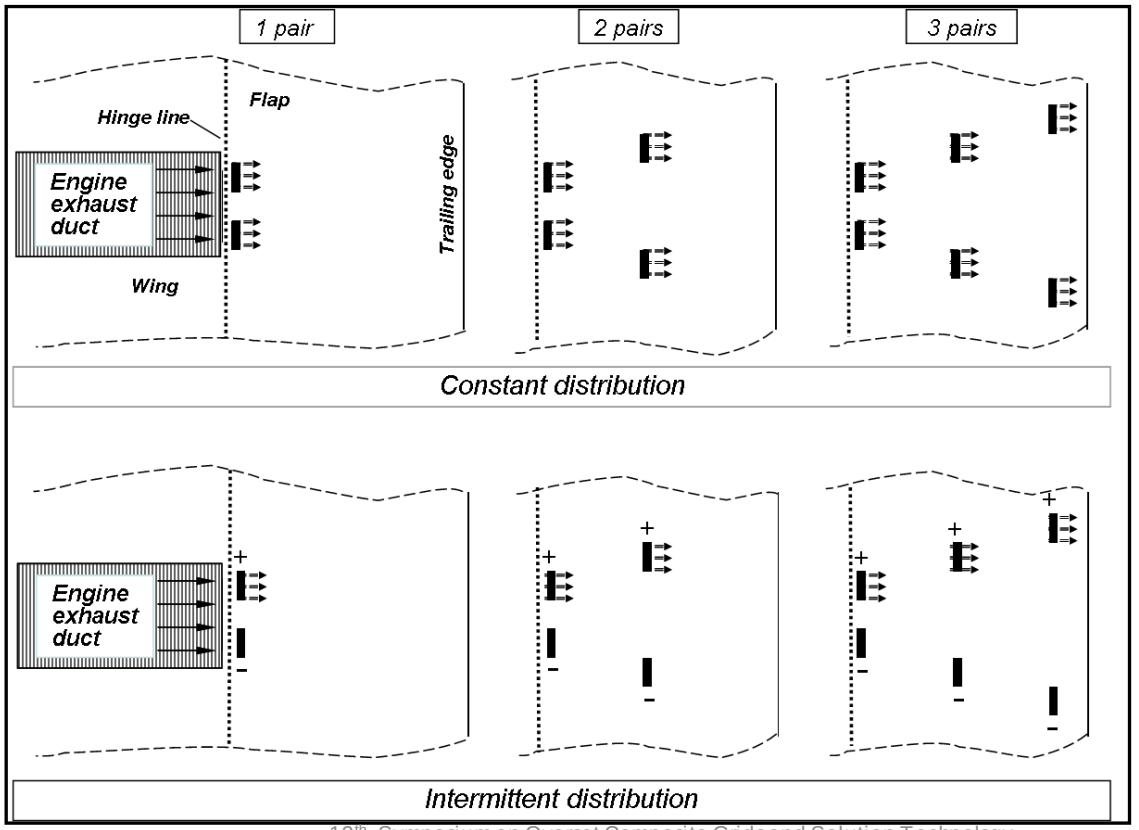


no actuation

Pulsed actuation

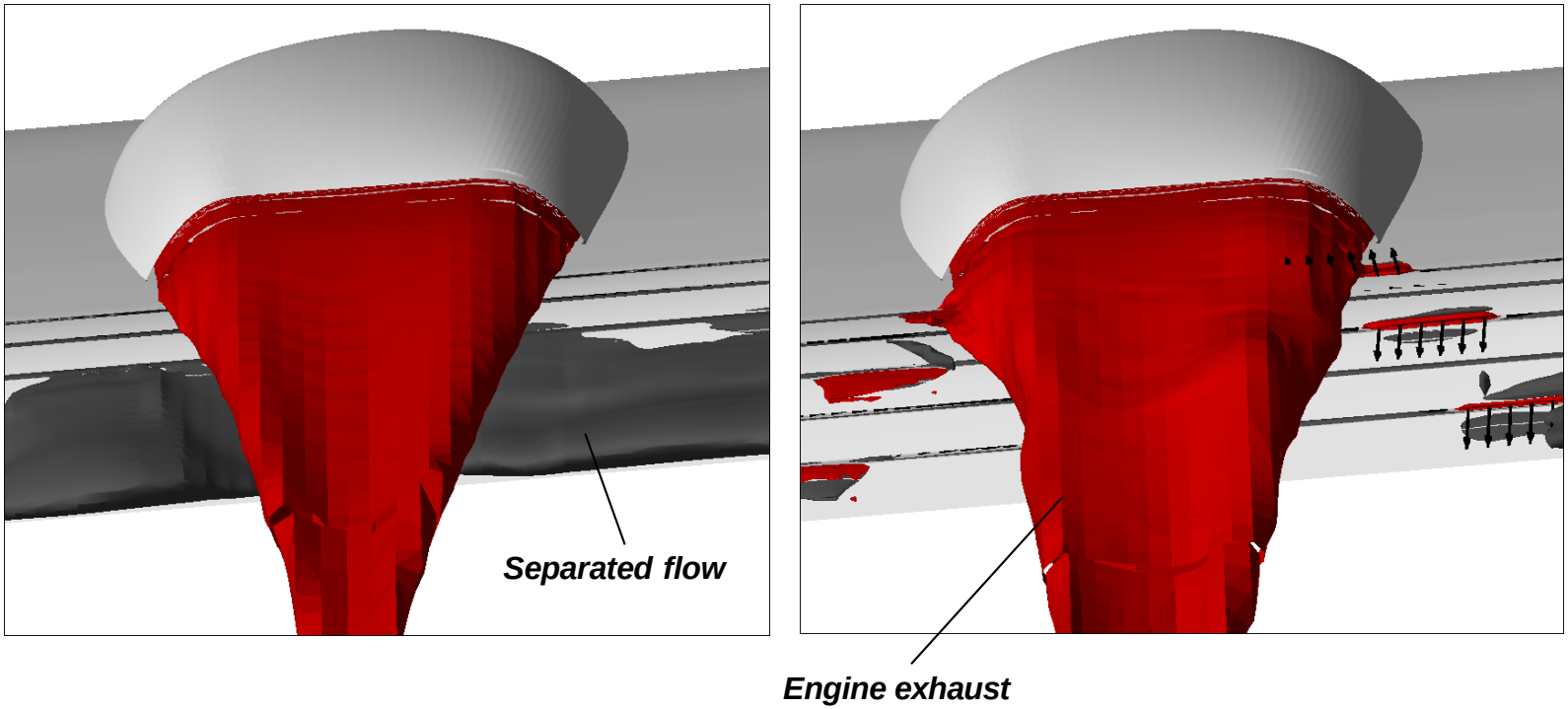
- **Reduce bleed air requirement**
  - **Reduce engine size/weight**

- **Wide range of actuations modes**
  - **Physical distribution**
  - **Frequency**
  - **Phase**



Pulsed actuation flow field

Pulsed actuation cleans up flow separation

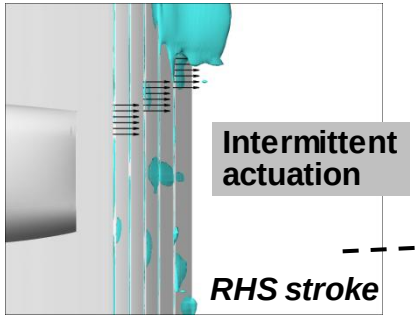


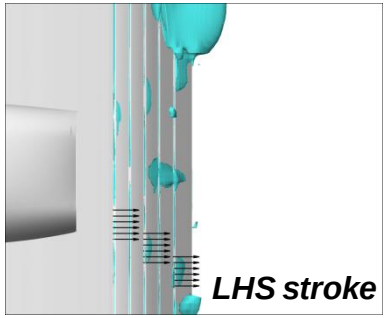
Baseline

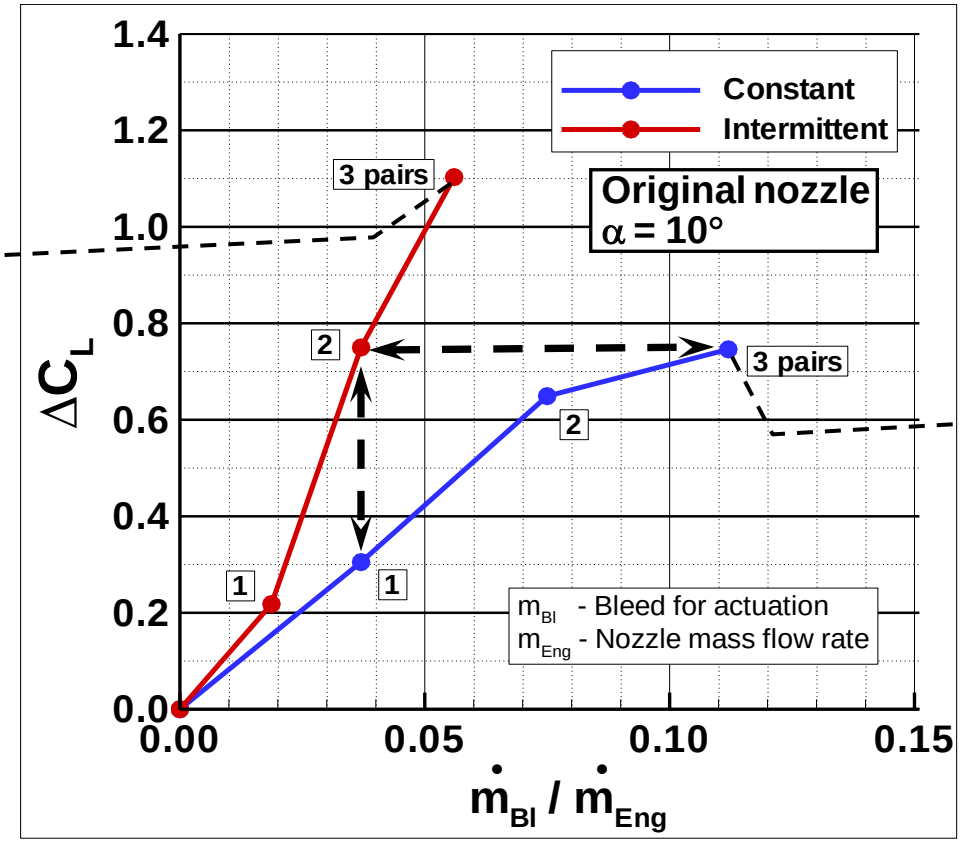
Intermittent (instantaneous)

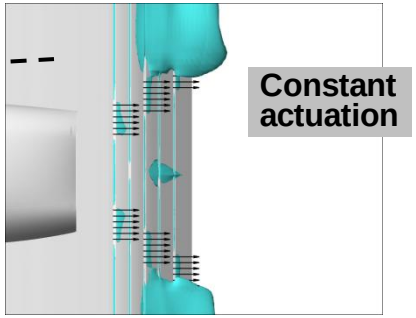
Pulsed actuation effectiveness

Alternate between left and right blowing

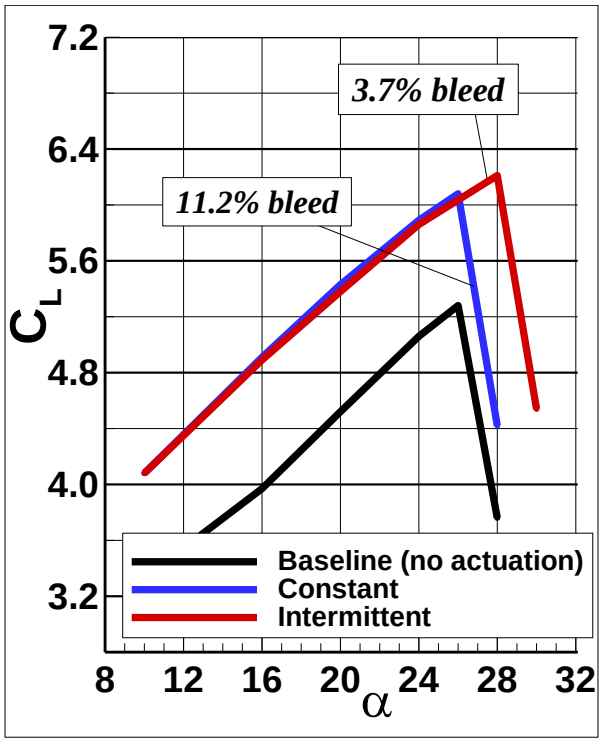




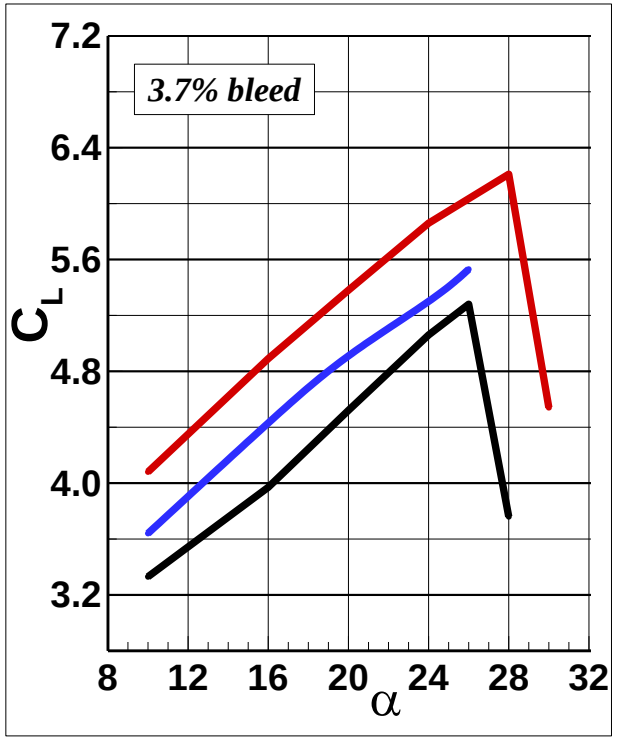




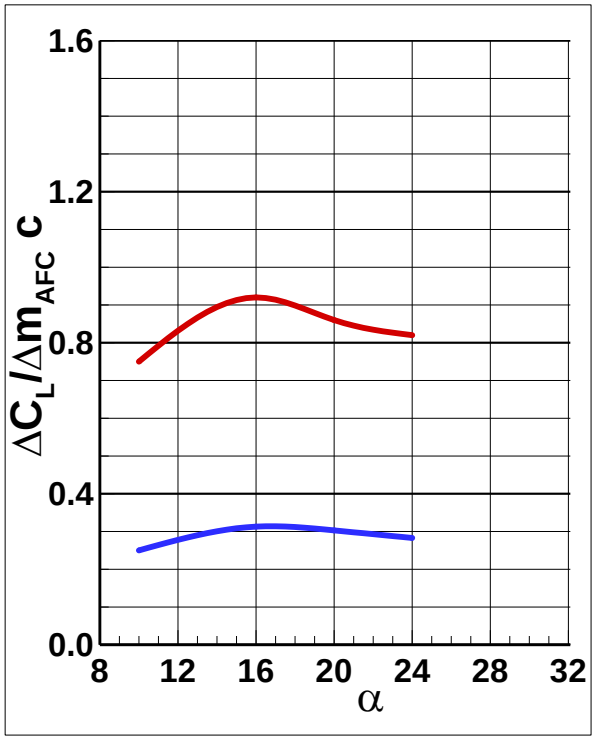
Advantages of pulsed actuation



Constant lift increment



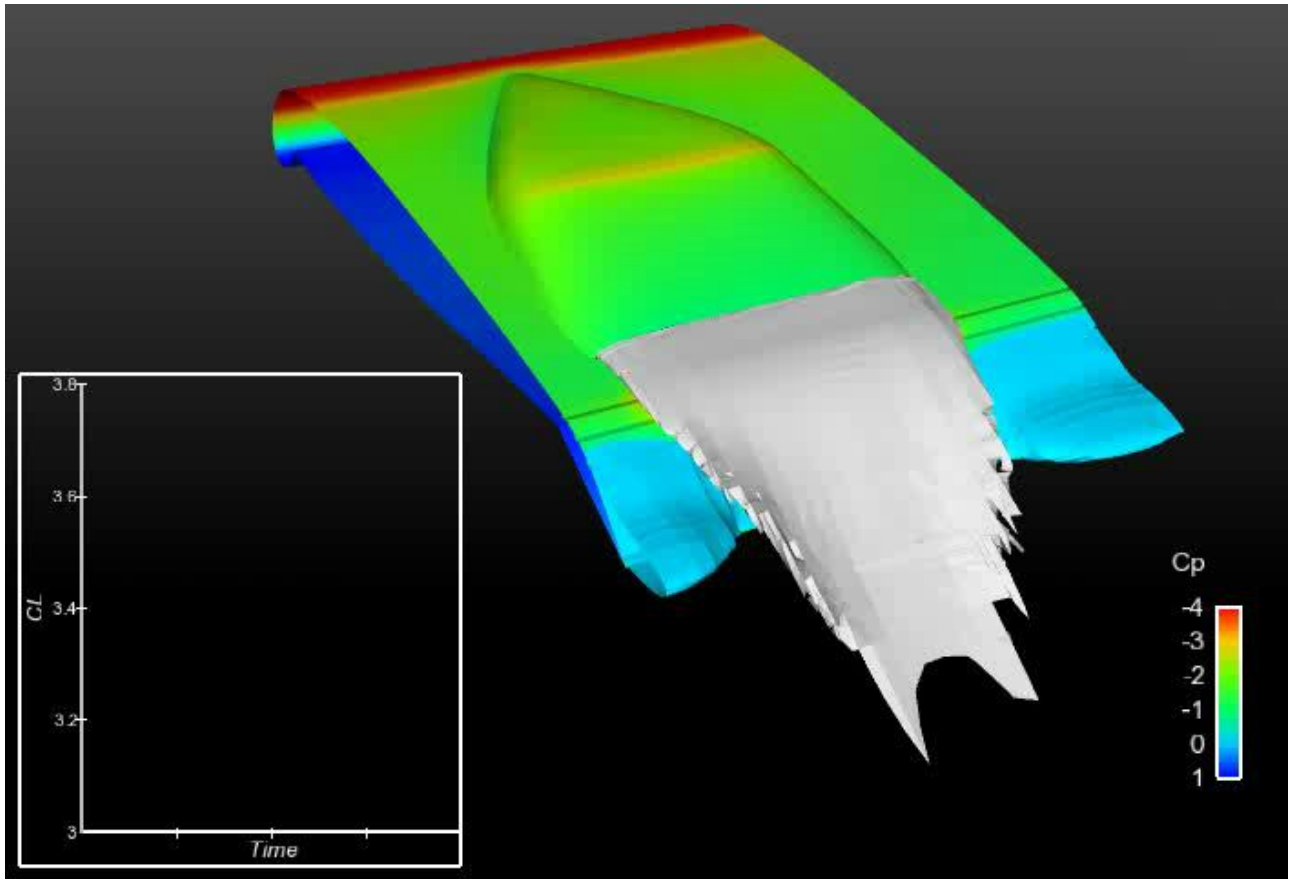
Constant engine bleed



Efficiency

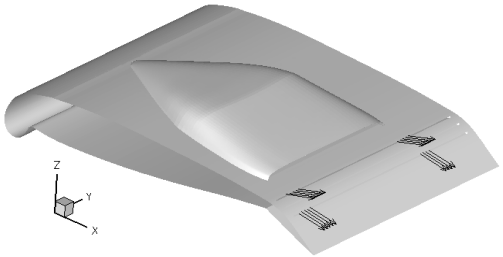
Pulsed actuation animation

Elongated nozzle

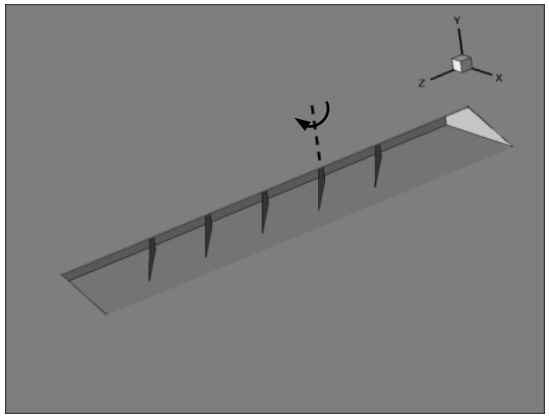


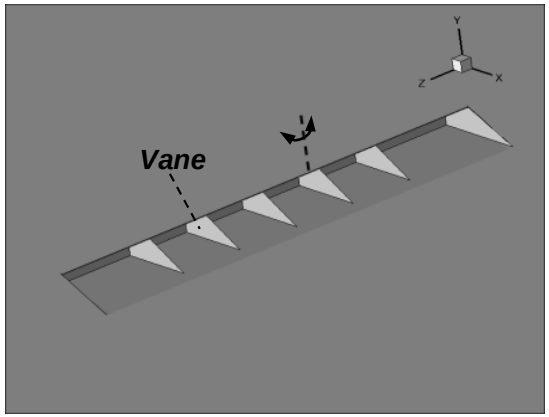
Sprinkler Actuation

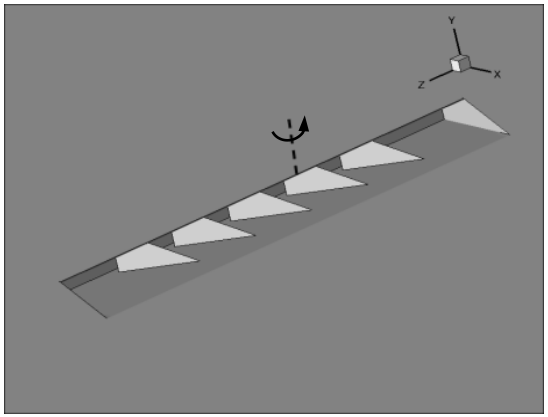
- **Multiple flight conditions requires flexibility:**
  - Edge of jet plume might vary
  - A-priori placement of ports may not be practical
  - Need a "wide area coverage" device



Sprinkler actuator:
- Continuous/swiveling blowing
  - Swiveling nozzle
  - Louver/vanes system

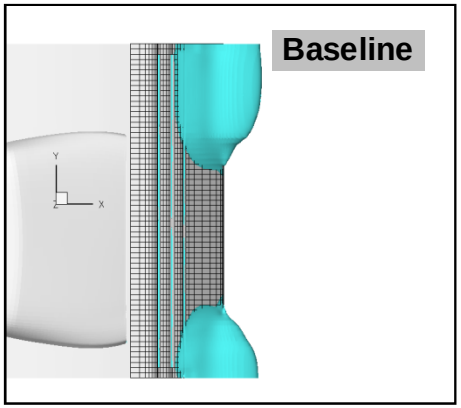


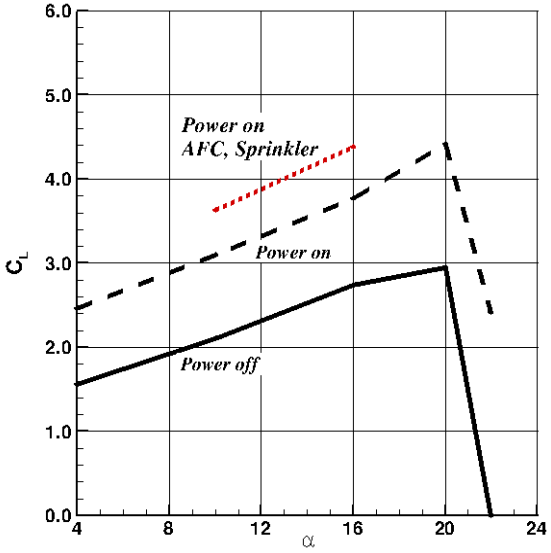


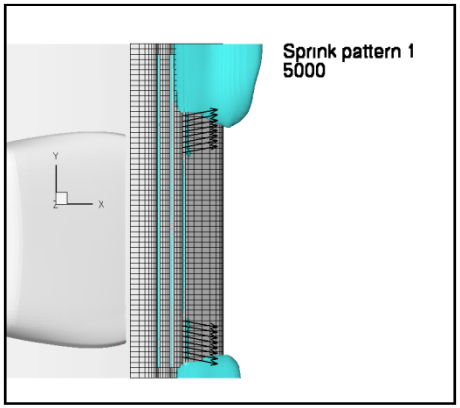


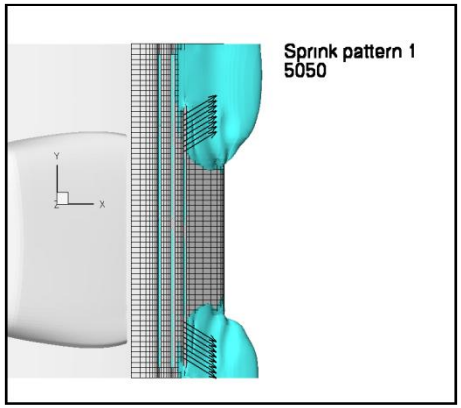
Sprinkler actuation - results

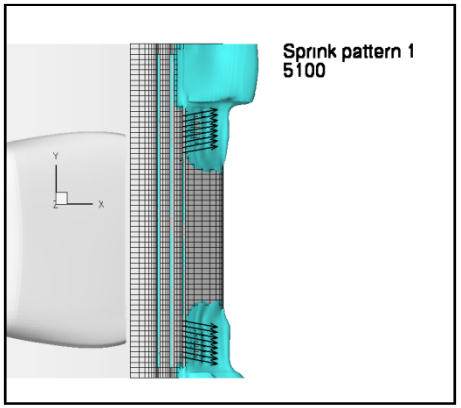
- Pair of jets
- Oscillating ±30º from side to side
- Frequency of 10Hz

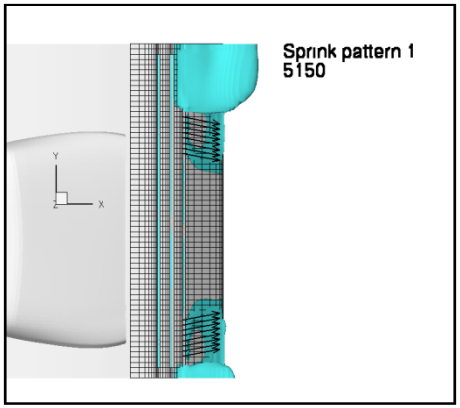












Instantaneous flow structure (limit cycle)

Summary

- **Upper surface blowing is an effective tool in lift enhancement**
- **Degradation in USB effectiveness due to**
  - Premature separation
  - Nozzle edge effects
- **Techniques for lift enhancement:**
  - Geometrical modifications:
    - Flap upper surface
    - Larger aspect-ratio nozzle
    - Flap fences
  - Active Flow Control
    - Constant actuation
    - Pulsed actuation for increase efficiency
    - Sprinkler actuation for increased flexibility