Internal Aircraft Cavity Bay Tests in the Medium Speed Wind Tunnel (MSWT)

by

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Contents

Credit to David Eschamann:

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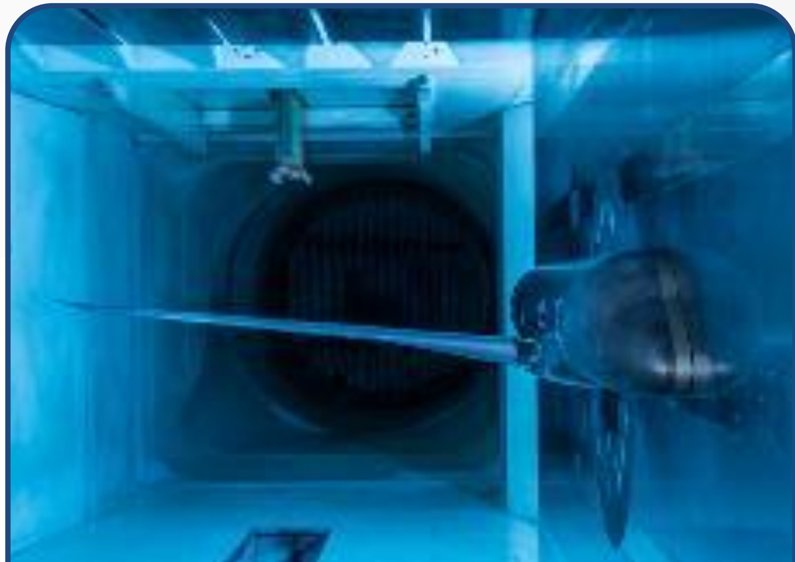
Introduction

“This is certainly enough to place it within the very highest reaches of important scientific instruments and tools developed over the entire length of human history,” Richard P Hallion an aviation historian

Continuous improvements in the wind tunnel facility capability gives a corresponding improvement and expansion on the types of tests that can be performed, and the accuracy, precision and quality of the data one can get from a wind tunnel test



Wind Tunnels

Critical Role:

Wind tunnel testing plays a crucial role in the validation and refinement of aircraft designs. It provides essential aerodynamic data, identifies potential issues, and helps optimize performance, stability, and control.

Validation:

Wind tunnel tests validate computational models and simulations (CFD - Computational Fluid Dynamics) by providing empirical data. This helps ensure the accuracy of predictions about how the aircraft will behave in real-world conditions.

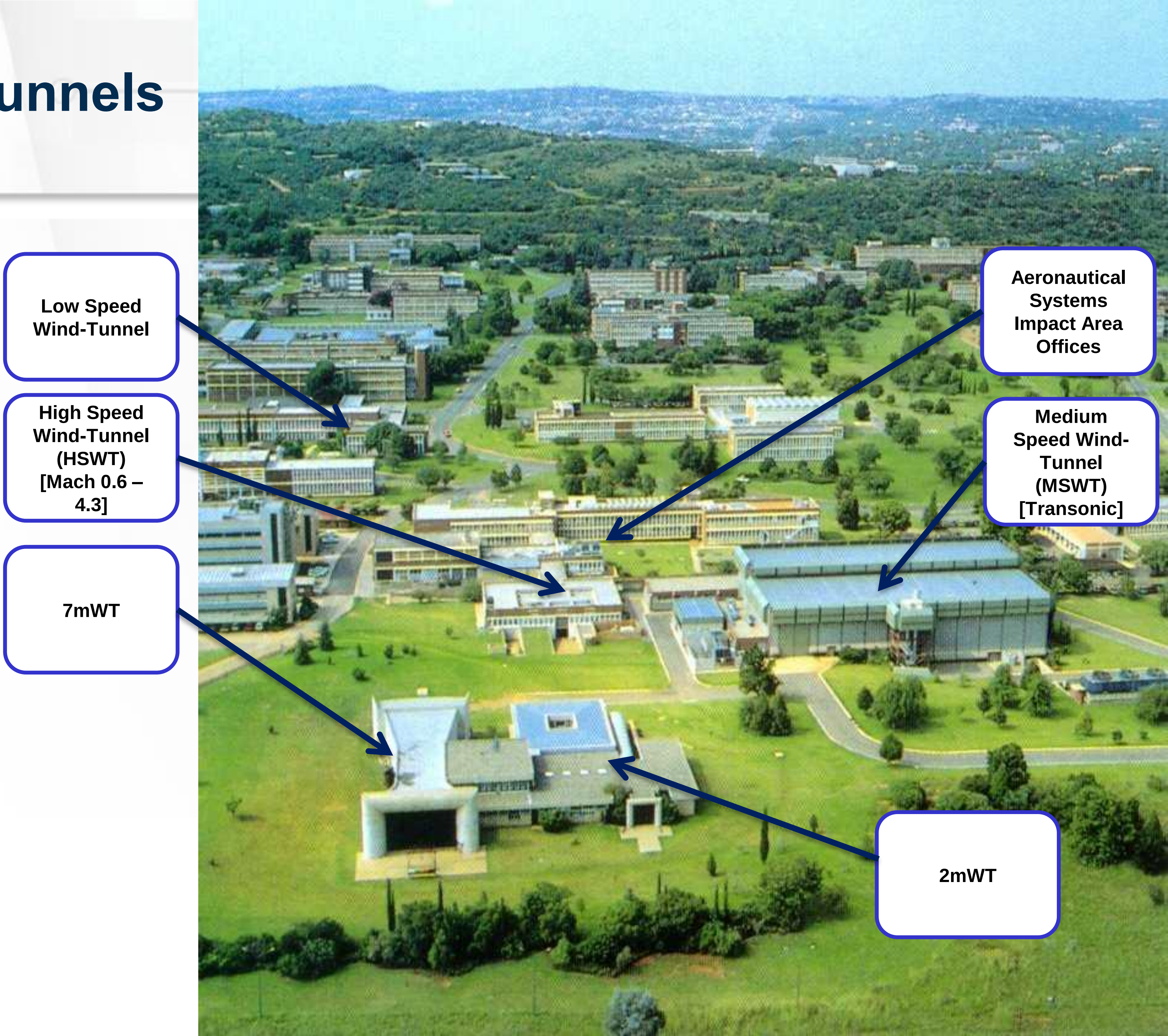
Design Iteration:

Data from wind tunnel tests often lead to design modifications and iterations to improve aerodynamic efficiency and enhance overall performance.

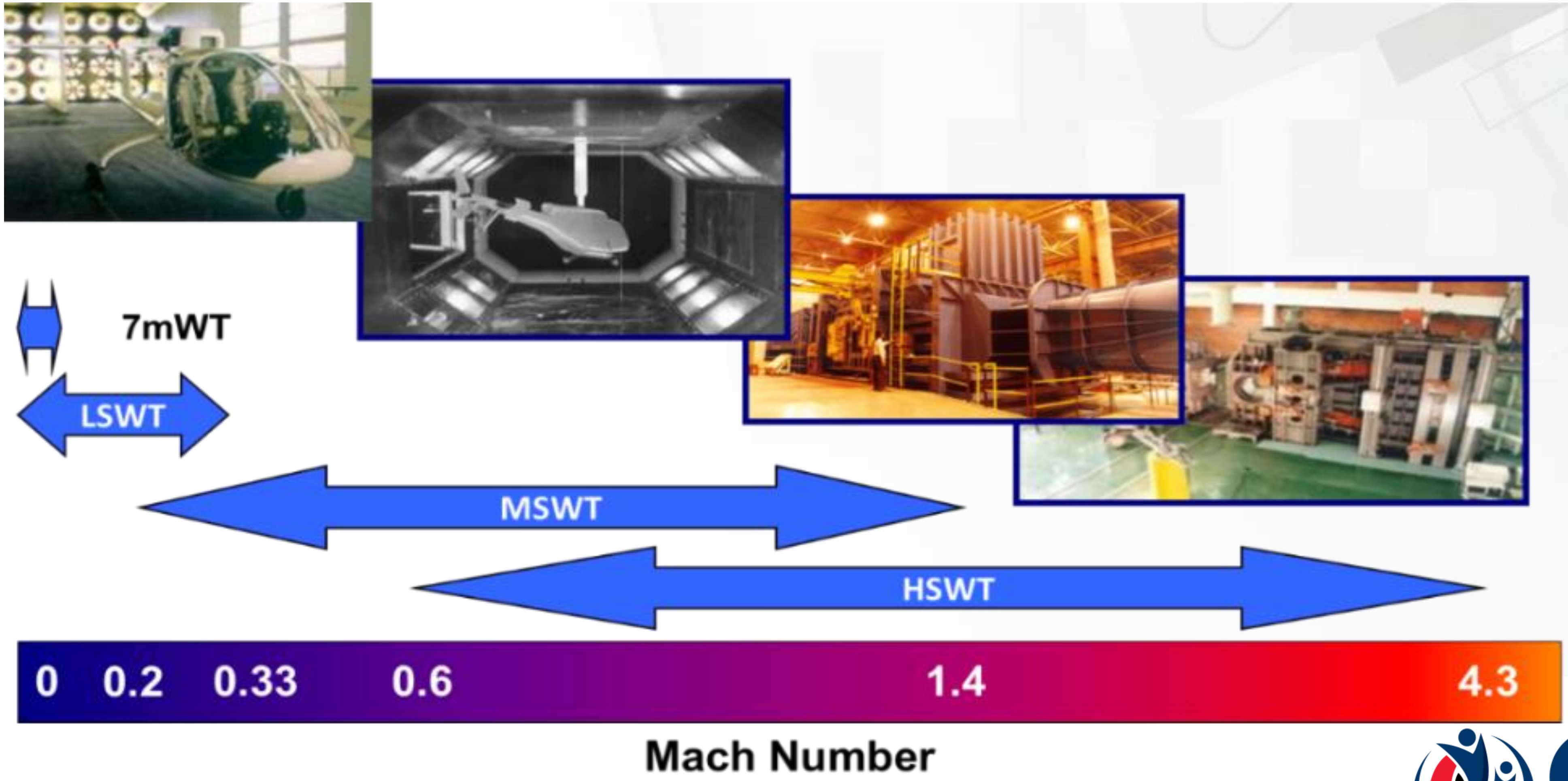
CSIR's Suite of Wind Tunnels

A suite of outstanding wind tunnels:

- MSWT
- HSWT
- LSWT
- 7mWT
- 2mWT
- CalWT
- Water Tunnel



A Comprehensive Testing Capability



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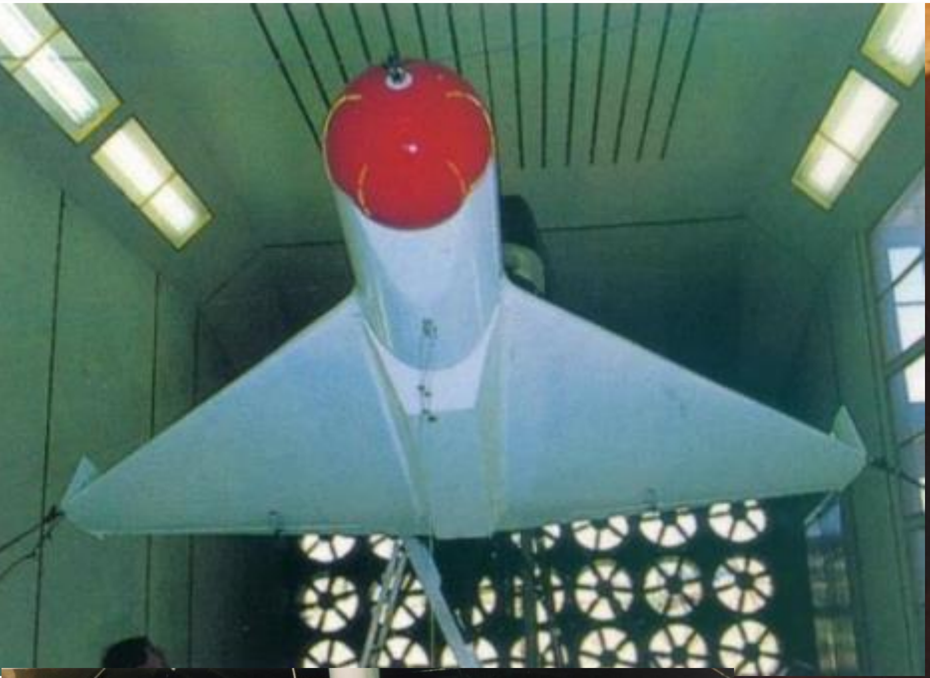
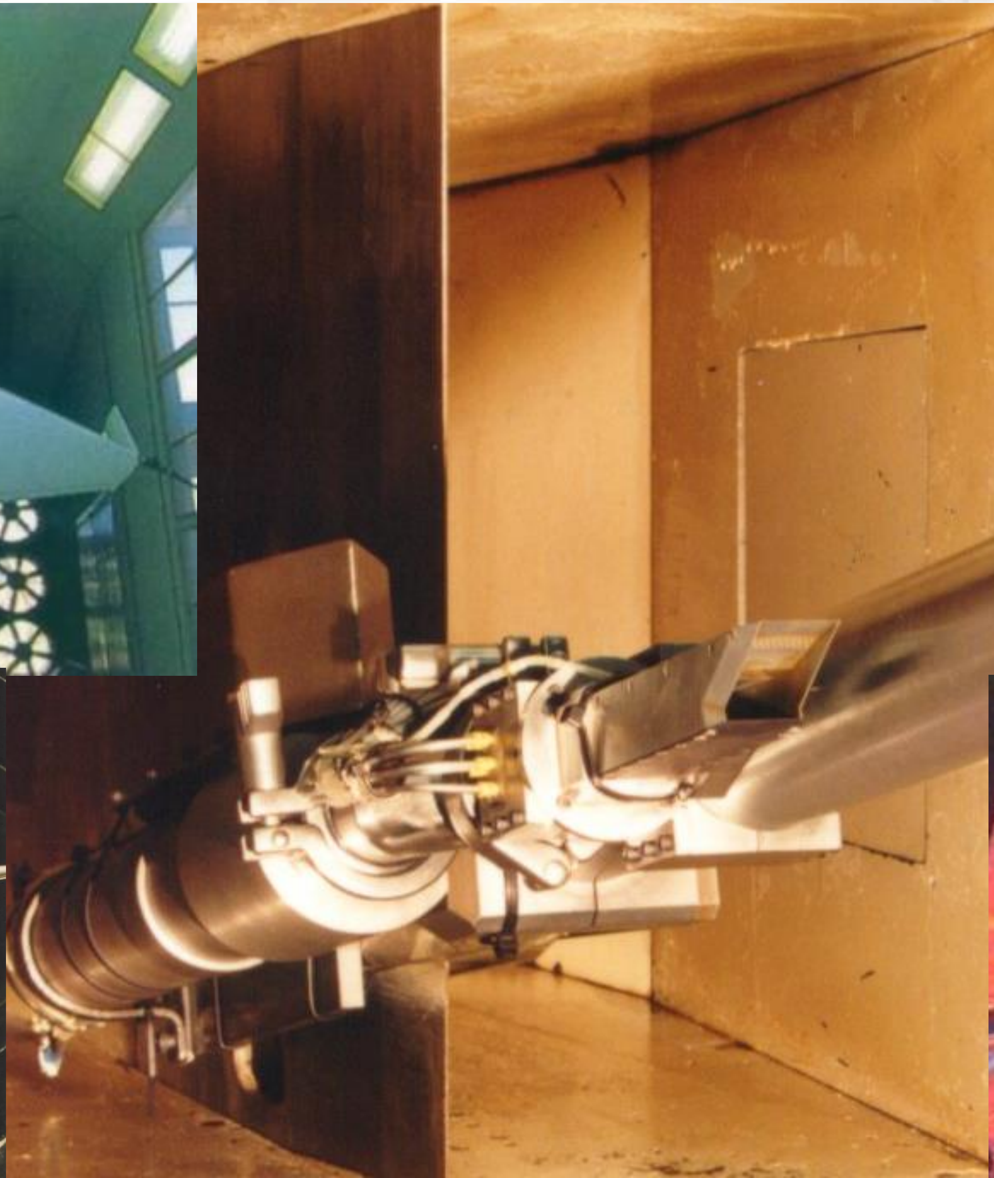
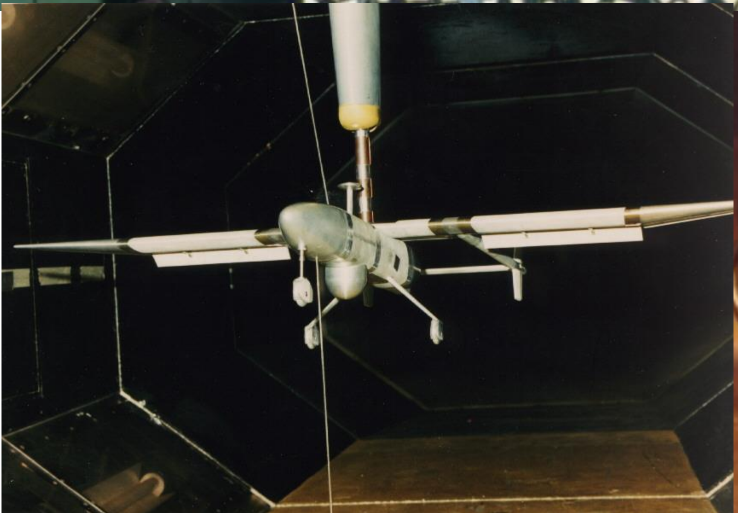
Diverse Wind Tunnel Applications







Internal Aircraft Cavity Bay

- The internal weapons bay of a modern fighter aircraft is extremely complex geometrically due to the presence of bulkheads, stores, bay doors and the storage of a variety of flight hardware in the bay.

- The flow in and near the weapons bay is highly unsteady. The flow field external to the bay is strongly influenced by both the internal and external aircraft geometry.

Credit to Raptor644 @flikr
For the F-22 weapons bay

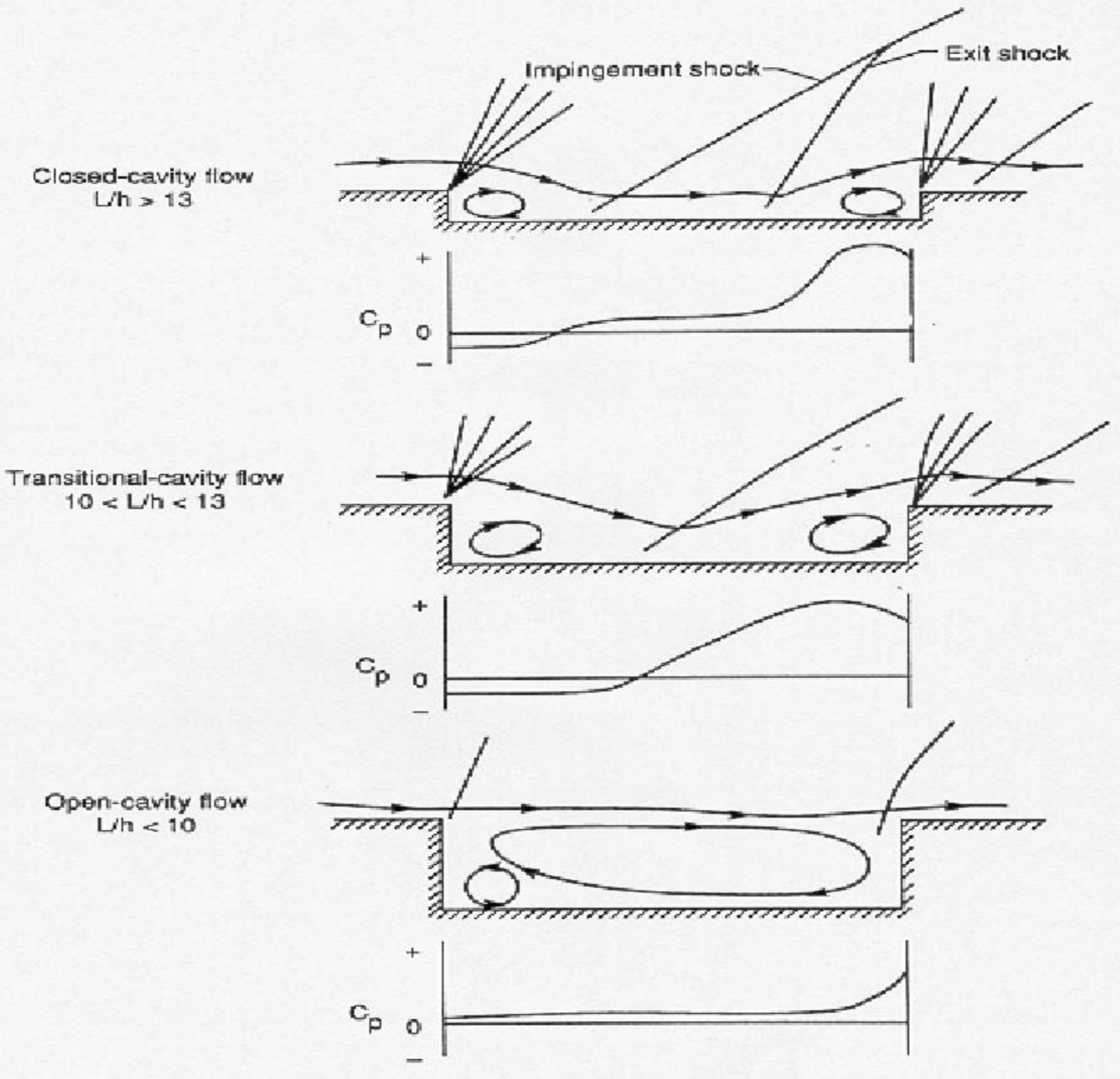
Cavity Classifications

Rossiter says a cavity is described as follows:

- in the context of its geometric characteristics and the dynamic interactions between the flow and the cavity structure.

Internal aircraft cavities in the sense of store integration: Weapon bays

1. are complex & have very unsteady flow fields
2. large velocity gradient across shear layer.
3. the presence of other stores in the bay has large effects.



Environment in an Internal Aircraft Cavity

Fluctuations in air pressure can excite vibrations in the local structure, leading to potential noise, fatigue, and structural failure.

Flow in a Cavity Bay

- The flow of air over an open cavity formed in the surface of the aircraft is usually unsteady.
- The flow starts to separate at the from the leading edge and reattach at some point along the roof of the cavity
- Large fluctuations may occur in the pressure acting on the walls of the cavity and the surrounding surfaces.
- The fluctuations in air pressure can excite vibration of the local structure , leading to potential noise, fatigue, and structural failure.

High-Speed Flow

Encounters Leading: Edge of the Cavity

Boundary Layer Separation: Due to Adverse Pressure Gradient

Formation of Shear Layer: Over Cavity Opening

Shear Layer Instabilities (Kelvin-Helmholtz Instabilities)

Vortex Formation and Vortex Shedding

Vortices Travel: Downstream Across the Cavity Opening

Interaction with the Trailing Edge

Generation of Pressure Fluctuations and Acoustic Waves

Acoustic Feedback Loop Reinforces Shear Layer instabilities

Possible Flow Reattachment or Recirculation Within the Cavity

Internal Aircraft Cavity Bay in the MSWT

MSWT

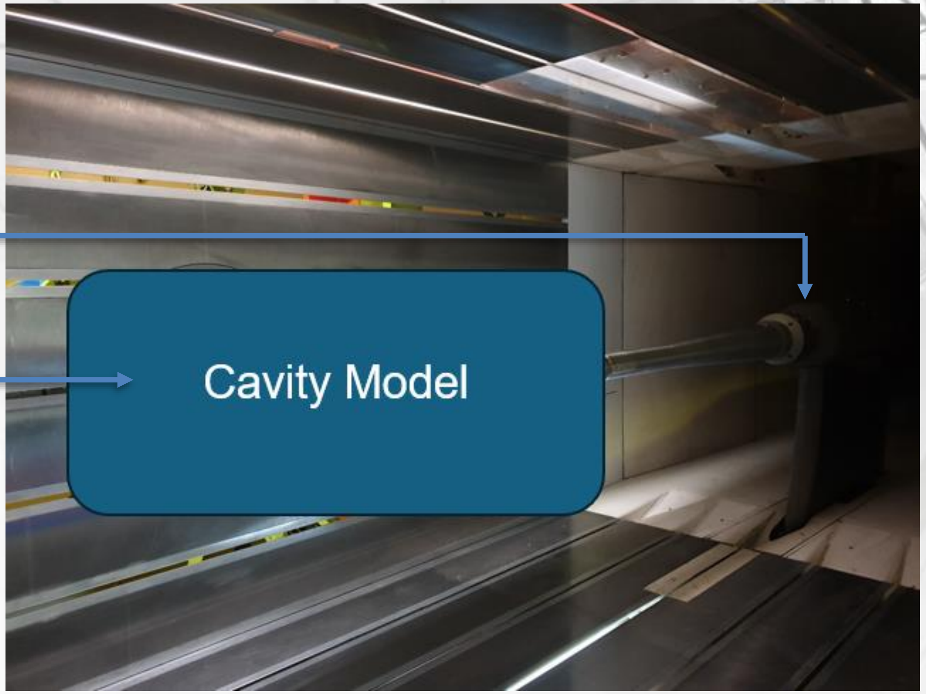
Facility	Continuous, closed-circuit, variable density wind tunnel
Mach Number Range	0.2 to 1.4
Test Section	1.5 x 1.5 x 4.5 m
Stagnation Pressure Range	20 kPa to 250 kPa
Reynolds Number Range	31 x 10^6 / m at Mach 0.8
Support System	**Pitch sector with** Standard AoA Range: -10° to 30° **Side Wall Support with** AoA Range: -30° to 30° **Captive Trajectory System with** Pitch Range: +45° Axial (X) Range: +560 mm Yaw Range: +45° Lateral (Y) Range: +410 mm Roll Range: +180° Vertical (Z) Range: +525 mm
Standard Test Capabilities	• Routine static force testing with models sting mounted on internal strain-gauge balances • Pressure measurements • Store release tests (grid, flow field measurement and captive trajectory)
Standard Flow Visualisation	N/A

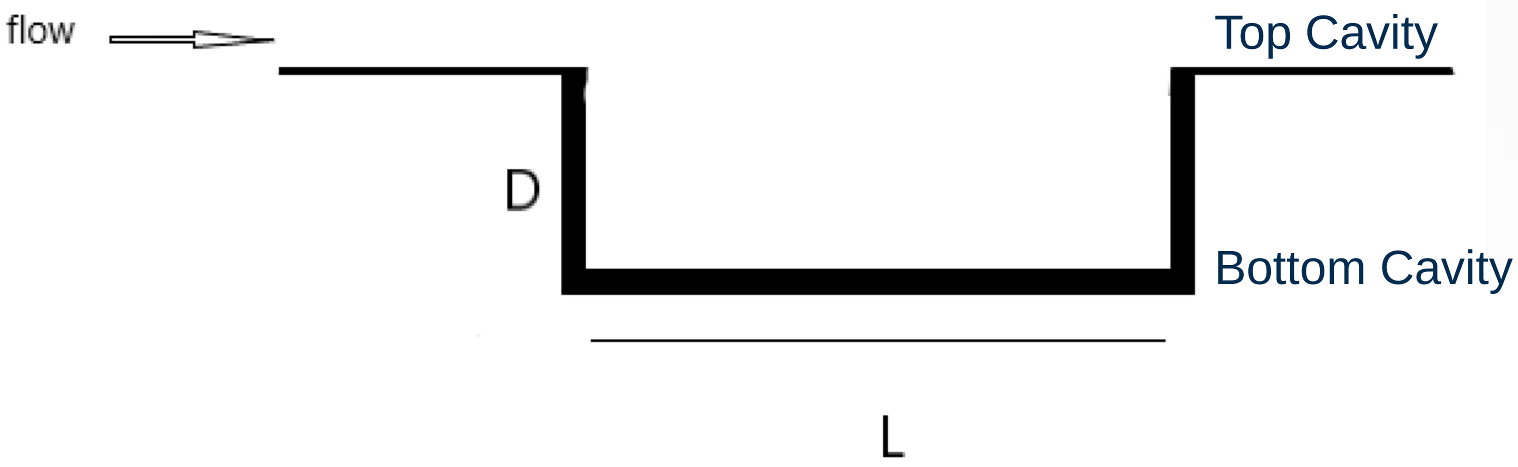
Aim of the Study

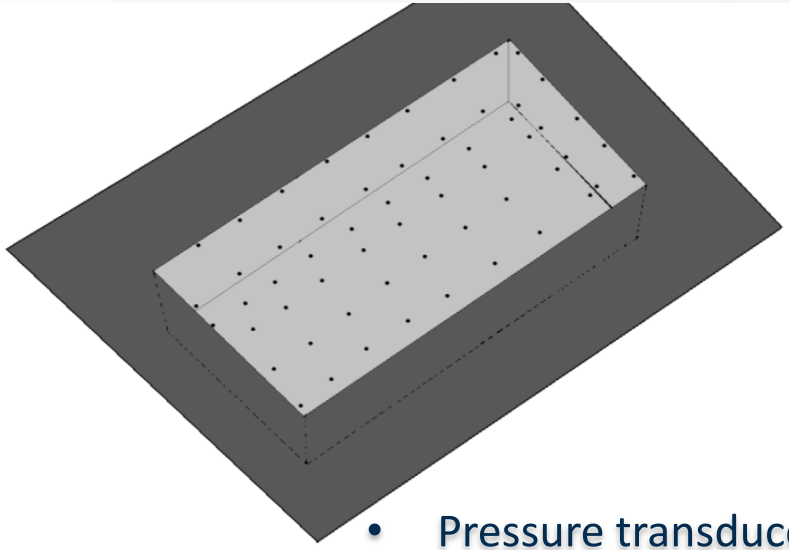
- The study aim to characterize the behavior of flow over a rectangular cavity over a range of Mach numbers from Subsonic to Supersonic regime.
- To understand the effect of applying passive flow control mechanisms on the cavity configuration.

Wind Tunnel Setup and Cavity Definition

- Main Model Support (MMS) system
- Open cavity classification (L/h <10)
- Various locations for pressure transducers
- Kulite Unsteady Pressure transducers used in the cavity pressure measurement.

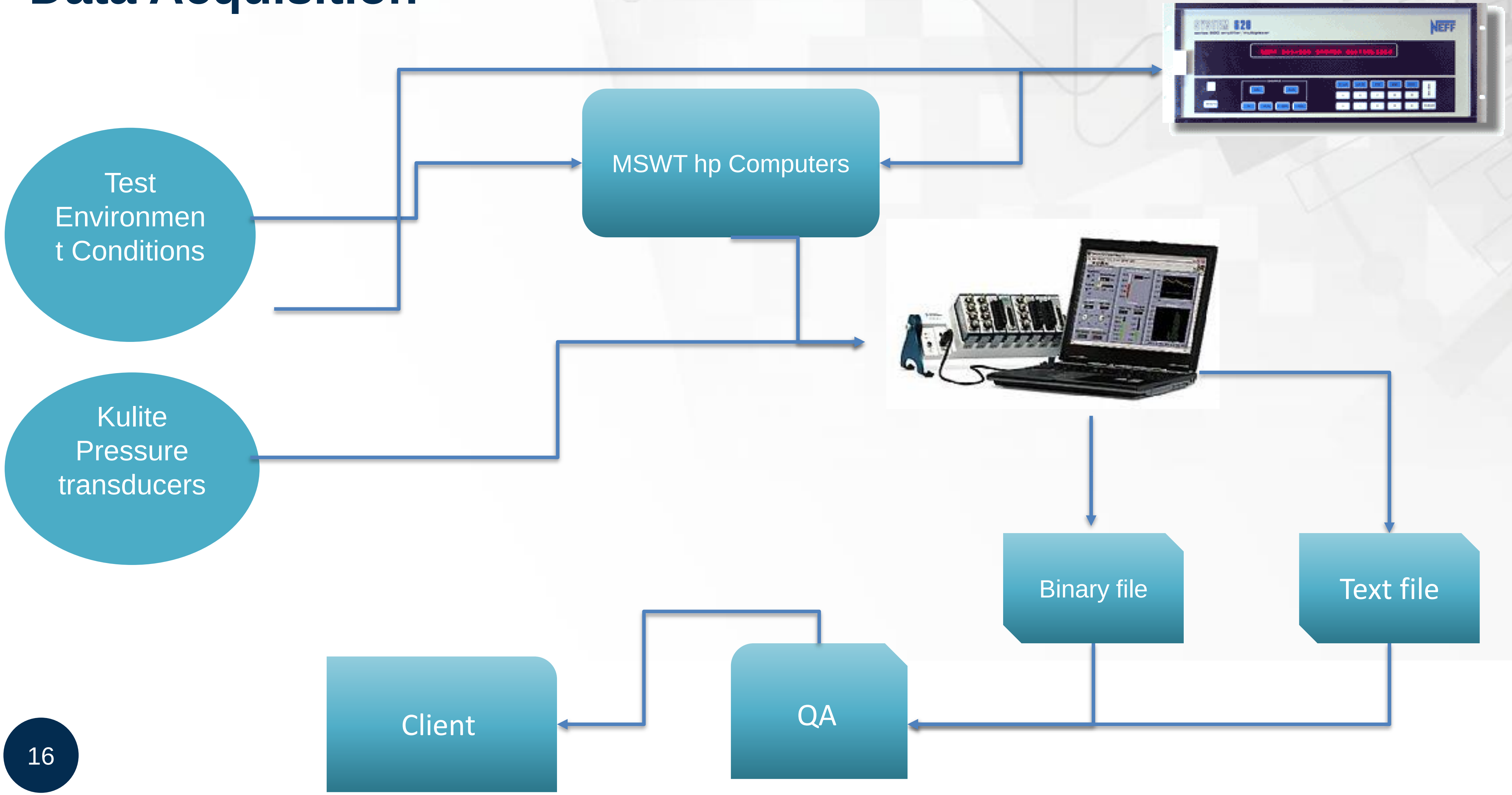






- Pressure transducers

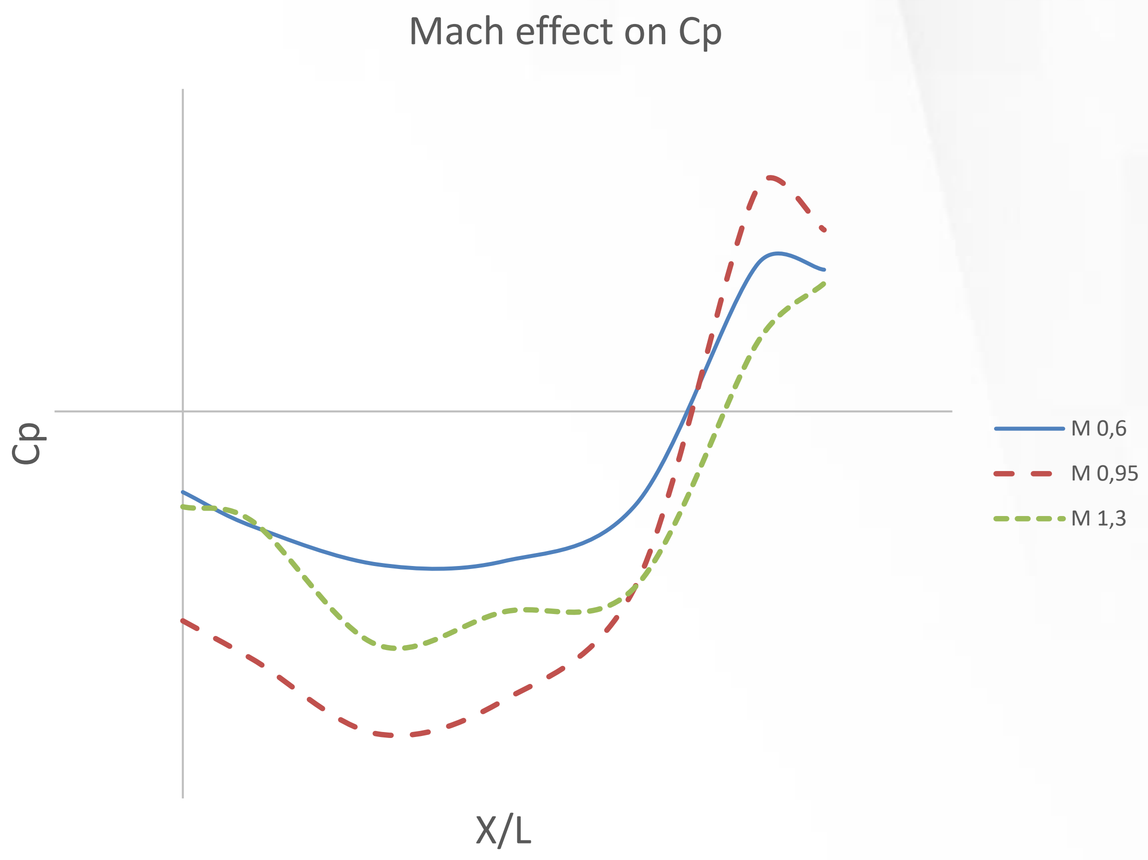
Data Acquisition



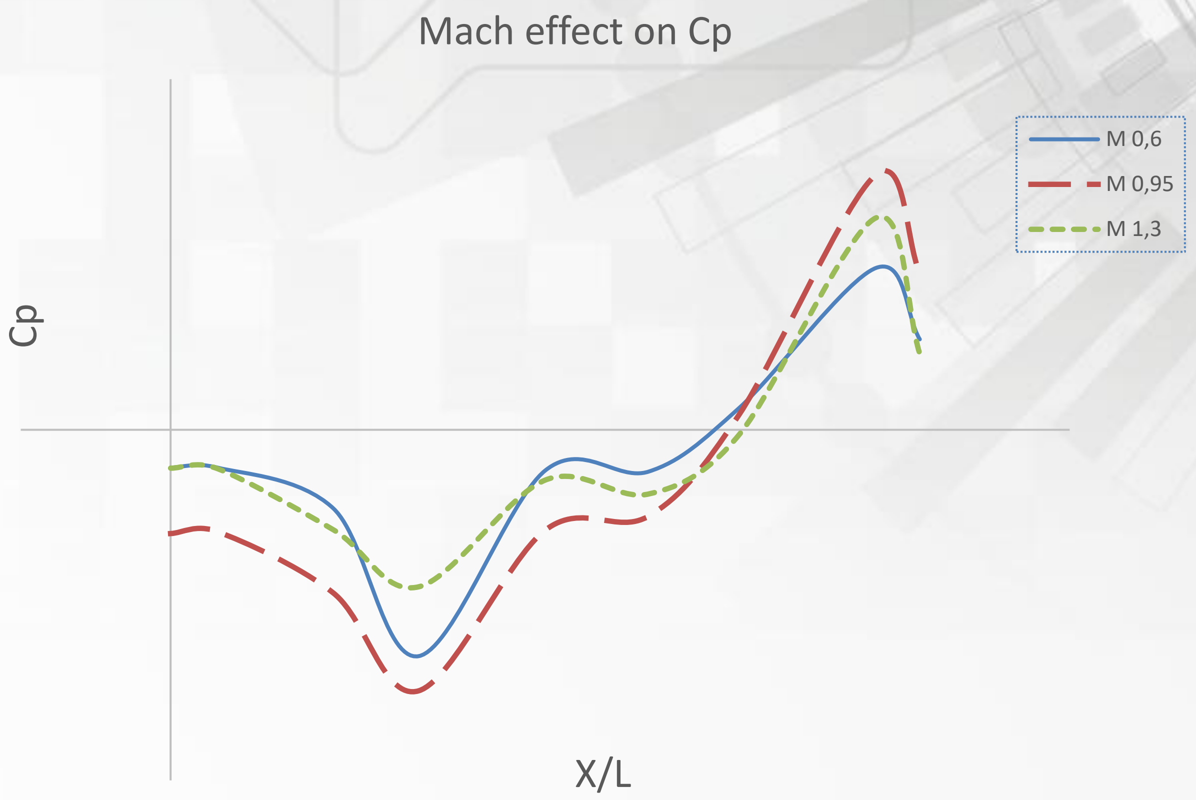
Experimental Results

- Mach [0.6 , 0.95 and 1.3]
- Open Door
- Empty Configuration (Top and Bottom Cavity)
- Flow Conditioning Mechanisms (Top and Bottom Cavity)
- Empty vs Flow Conditioning (Top Cavity)
- Empty vs Flow Conditioning (Bottom Cavity)

Experimental Results – Empty Configuration



Top cavity section



Bottom cavity section

Mach Number Effect on Cavity Cp – Open Door (Mach 0.6 , 0.95 and 1.3)

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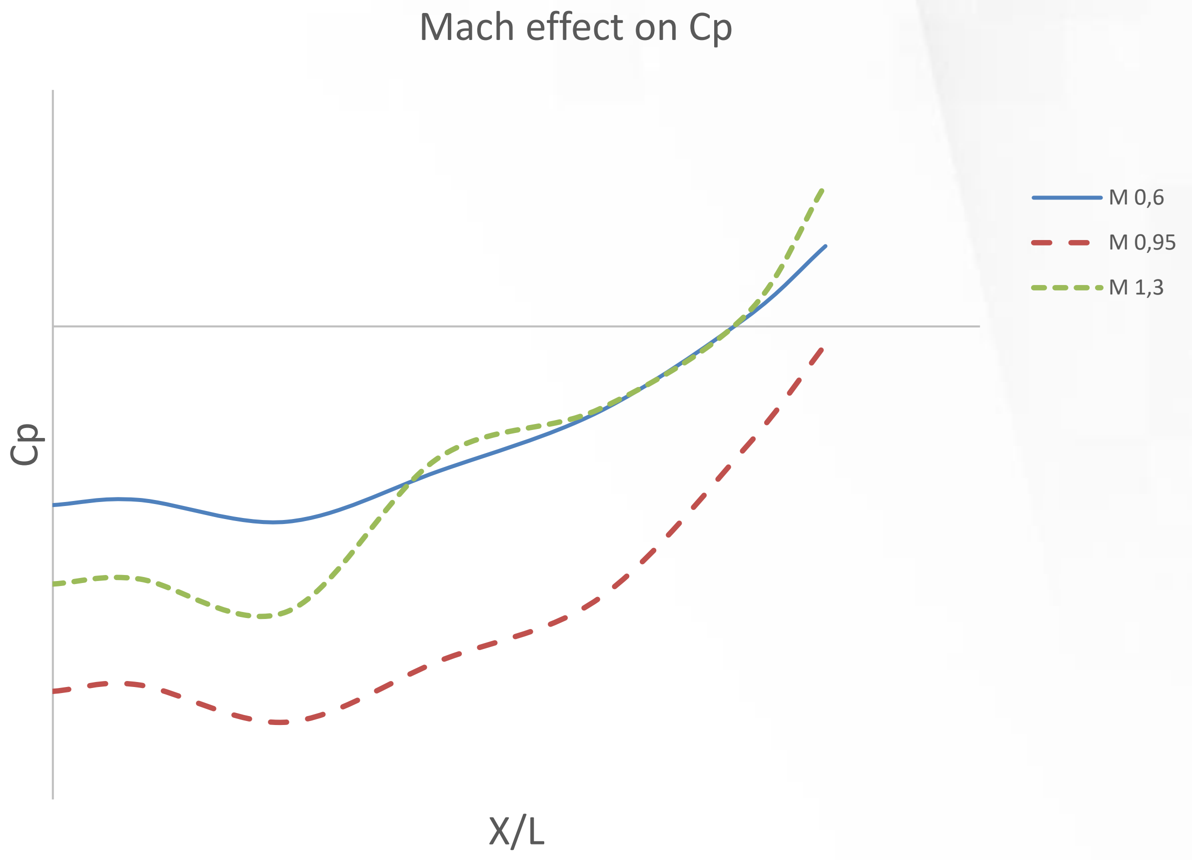
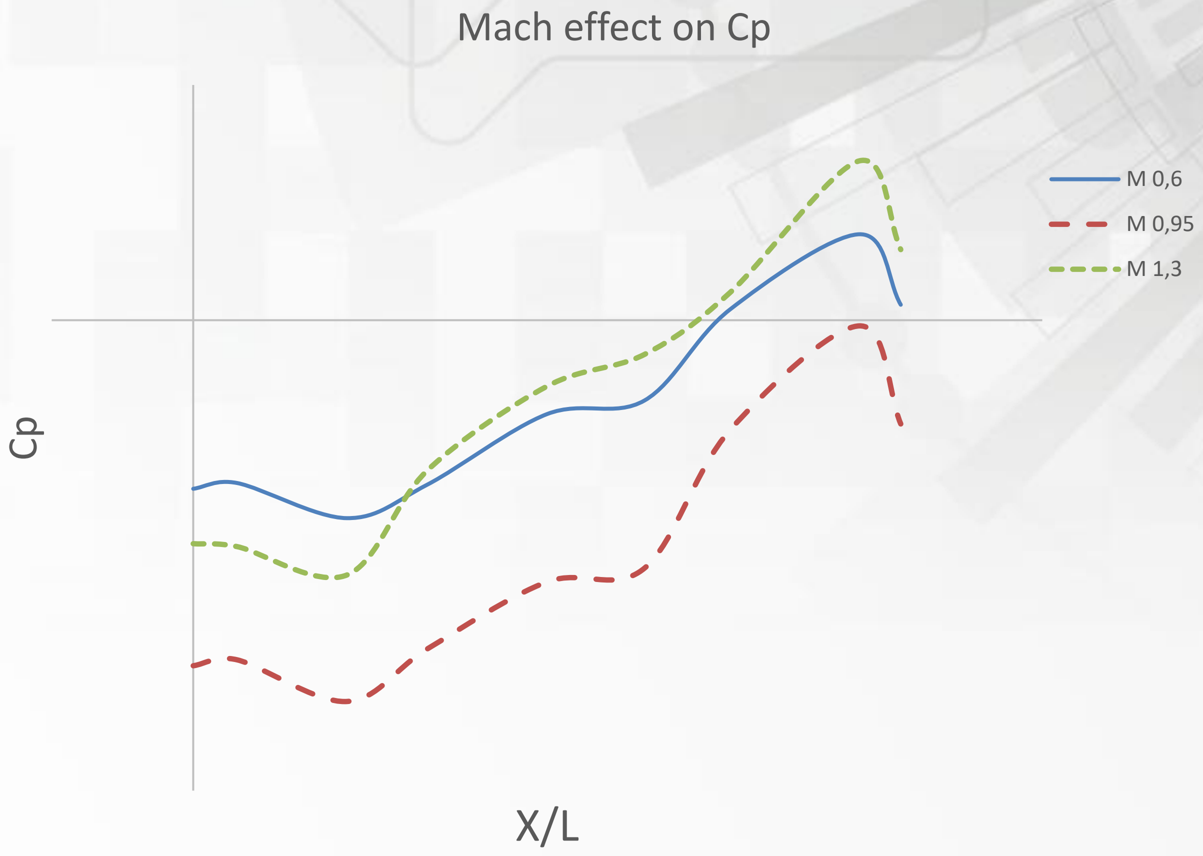
Experimental Results – Flow Conditioning Mechanisms



Top cavity section



Bottom cavity section

Mach Number Effect on Cavity Cp – Open Door (Mach 0.6 , 0.95 and 1.3)

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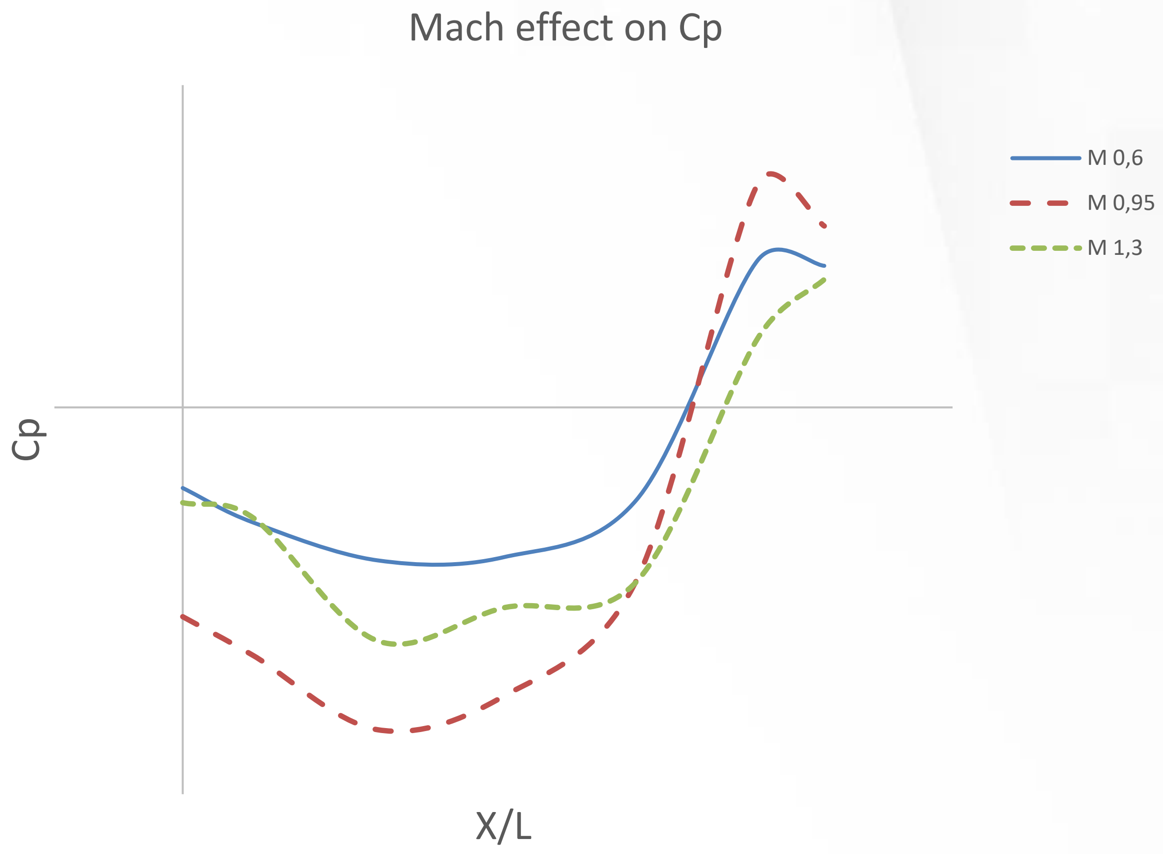
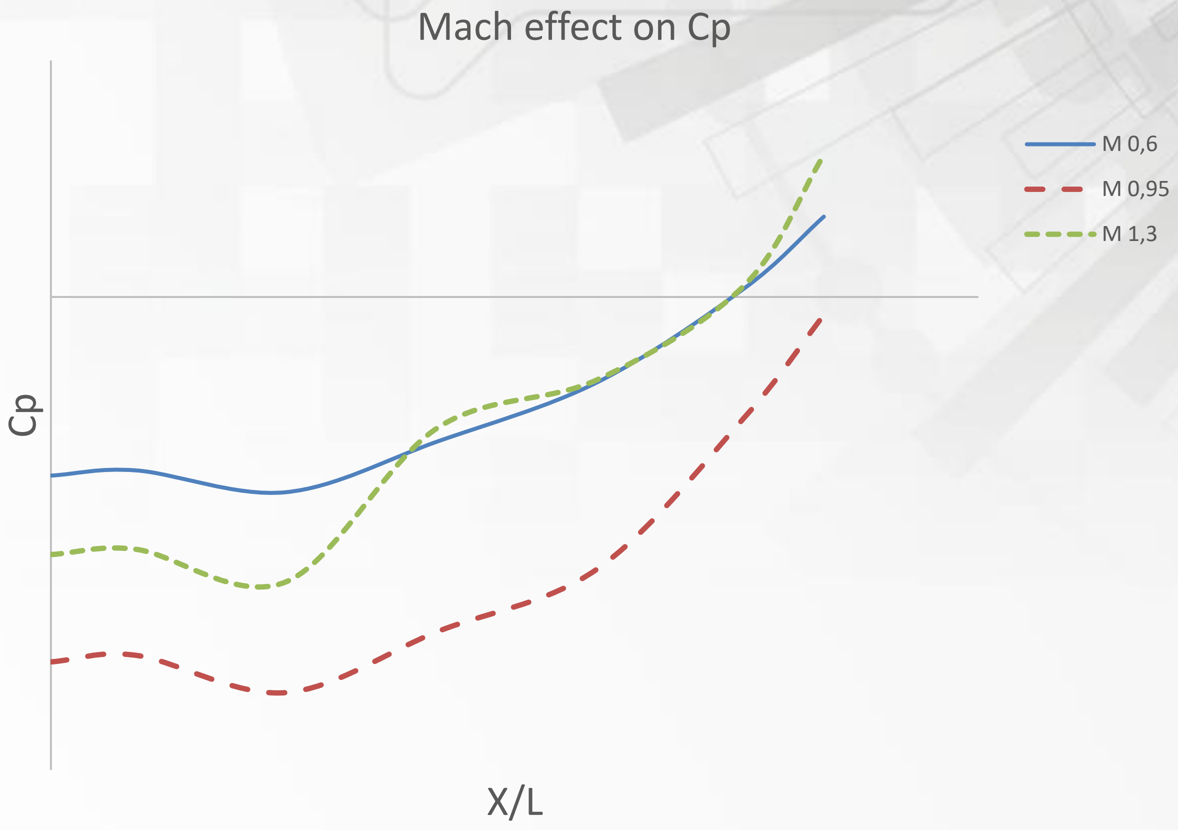
Experimental Results – Empty vs Flow Conditioning (Top Cavity)



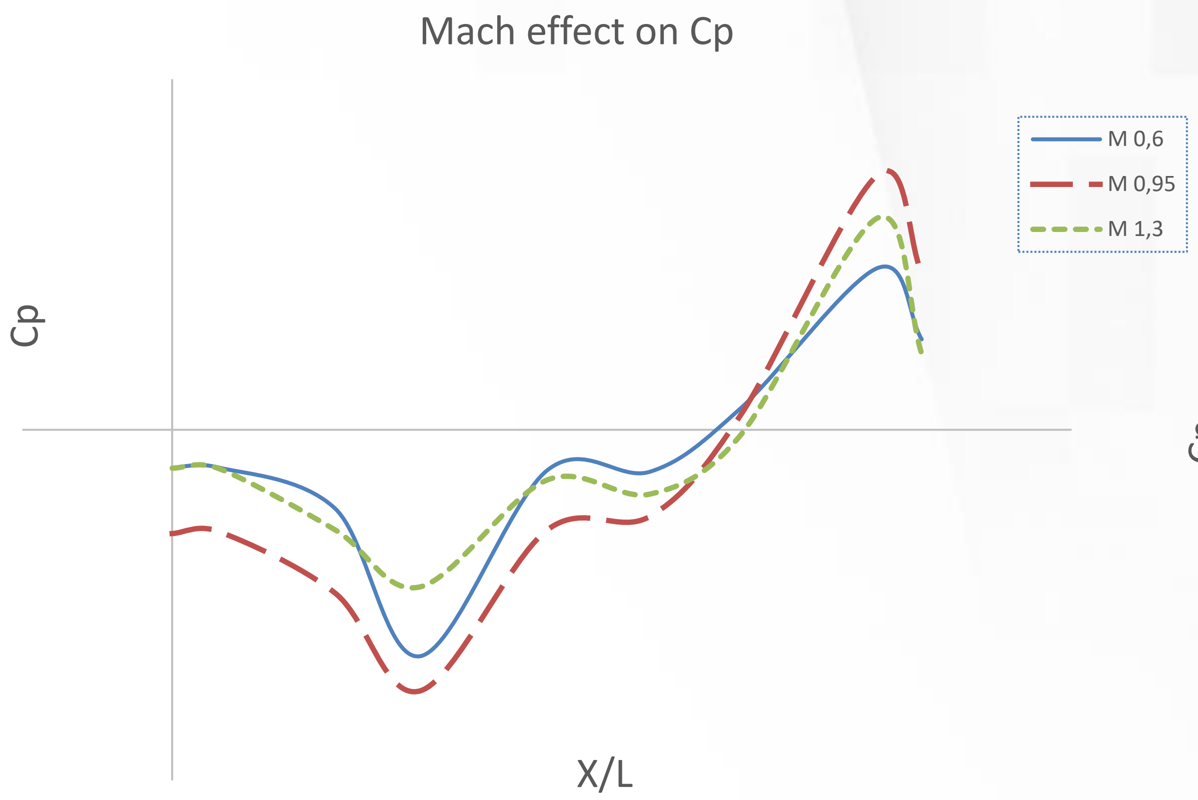
Flow without control mechanism



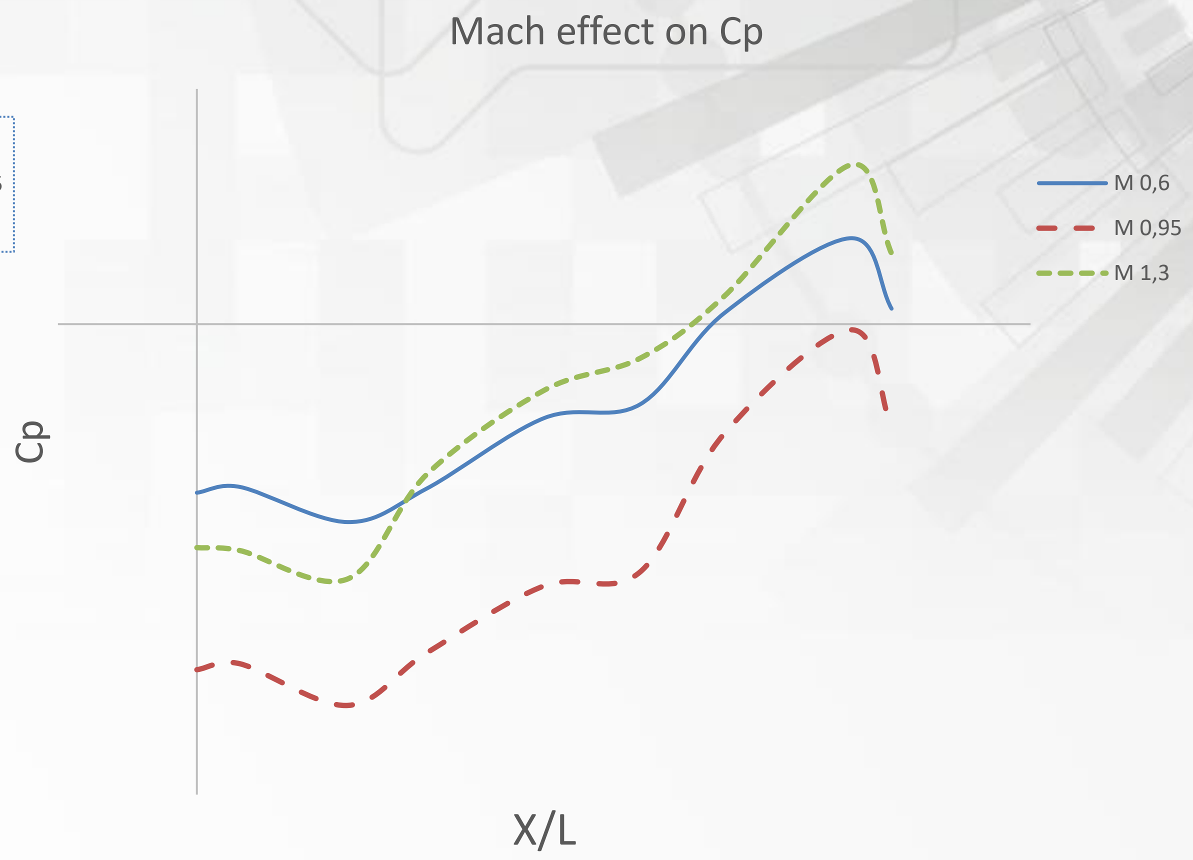
Flow with control mechanism

Comparison on Cavity Cp –
Open Door (Mach 0.6 , 0.95 and 1.3)

Experimental Results – Empty vs Flow Conditioning (Bottom Cavity)



Flow without control mechanism



Flow with control mechanism

Comparison on Cavity Cp –
Open Door (Mach 0.6 , 0.95 and 1.3)

Rossiter Equation

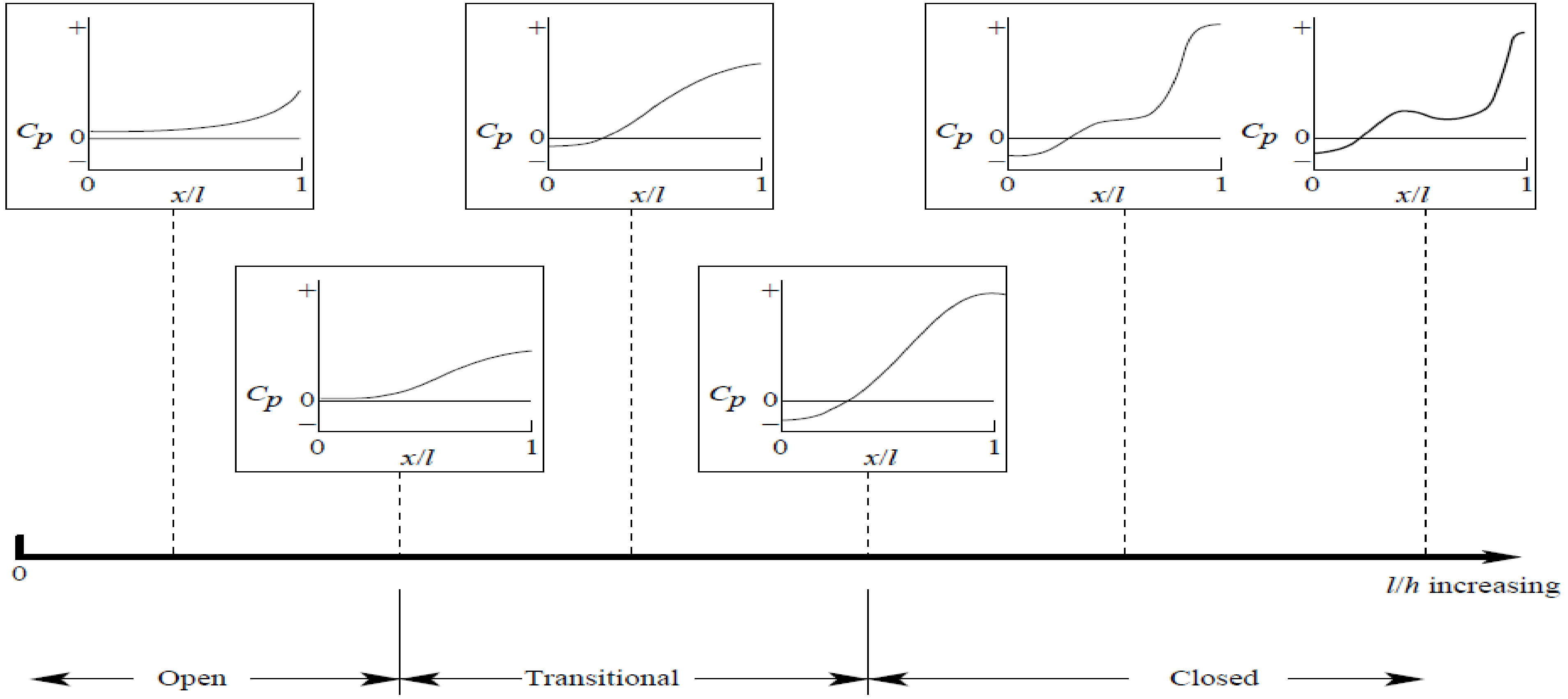
$$St = \frac{n - \alpha}{1/(M + \kappa)}$$

Strouhal Number and Oscillations:

1. **Frequency of Oscillations**: The frequency of cavity oscillations increases with the Mach number. This is due to the higher flow speeds interacting with the cavity geometry, leading to more rapid oscillatory modes.
2. **Mode Shifts**: The Strouhal number (St) for the cavity shows distinct modes of oscillation, which shift as the Mach number changes. Higher Mach numbers typically excite higher modes of oscillation, resulting in more complex flow patterns within the cavity.

- **As the Mach number increases to 0.95 and 1.3, the Strouhal numbers for higher modes become more significant, leading to higher frequency oscillations.**

Comparative Results



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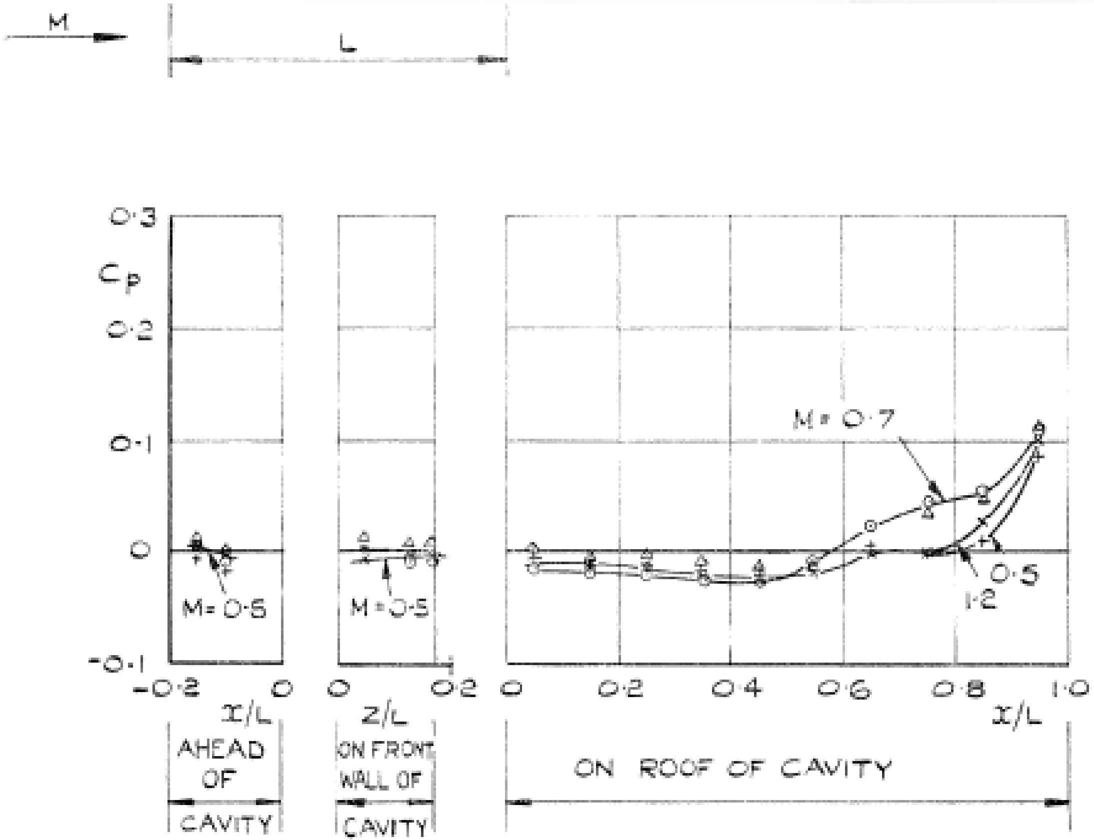
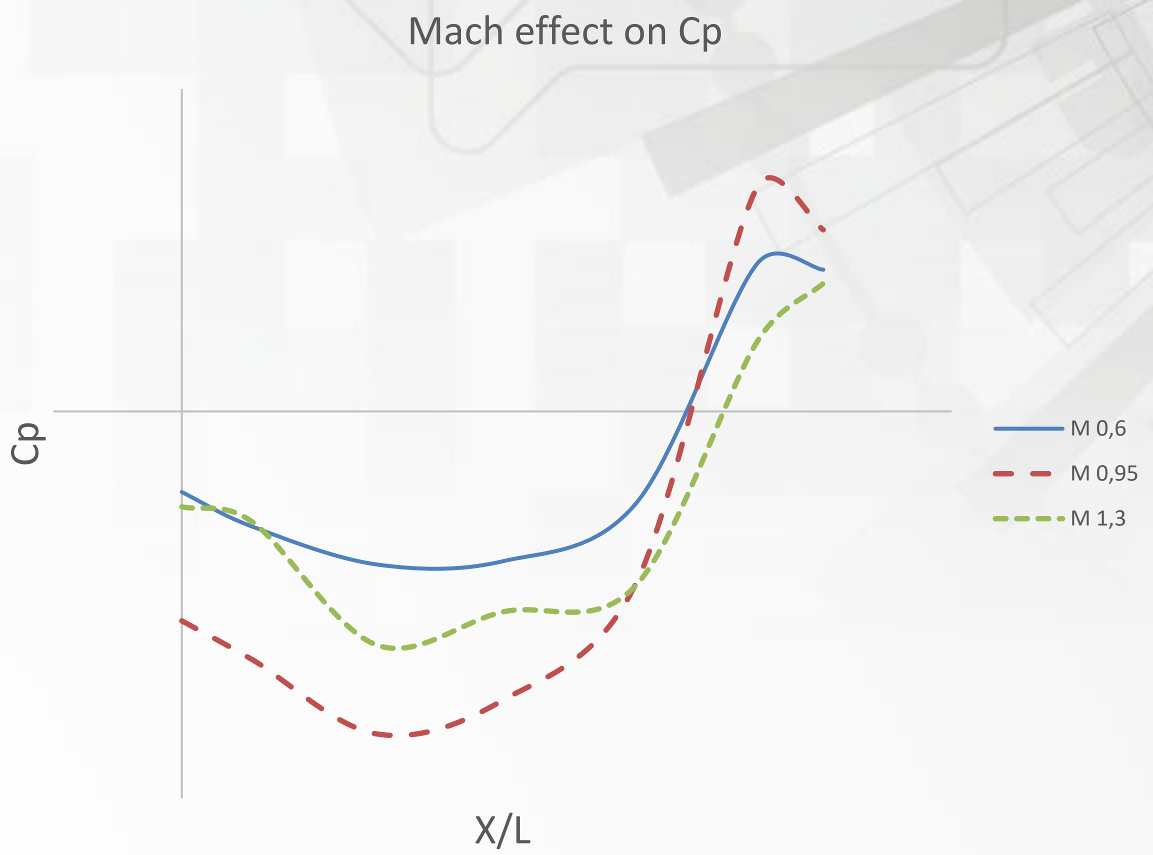
Comparative Results and Conclusion – Top Cavity Section





- Comparative results

Conclusion:

- At higher Mach numbers (0.95 and 1.3), the flow becomes more unstable with significant pressure fluctuations, indicating the presence of stronger shear layer interactions and potential flow oscillations within the cavity,

- This emphasizes the need for effective flow control strategies to manage adverse effects in high-speed applications.


Thank You
Questions?