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ON THE HEAT TRANSFER CHARACTERISTICS OF HIGHLY COMPACT HEAT SINKS

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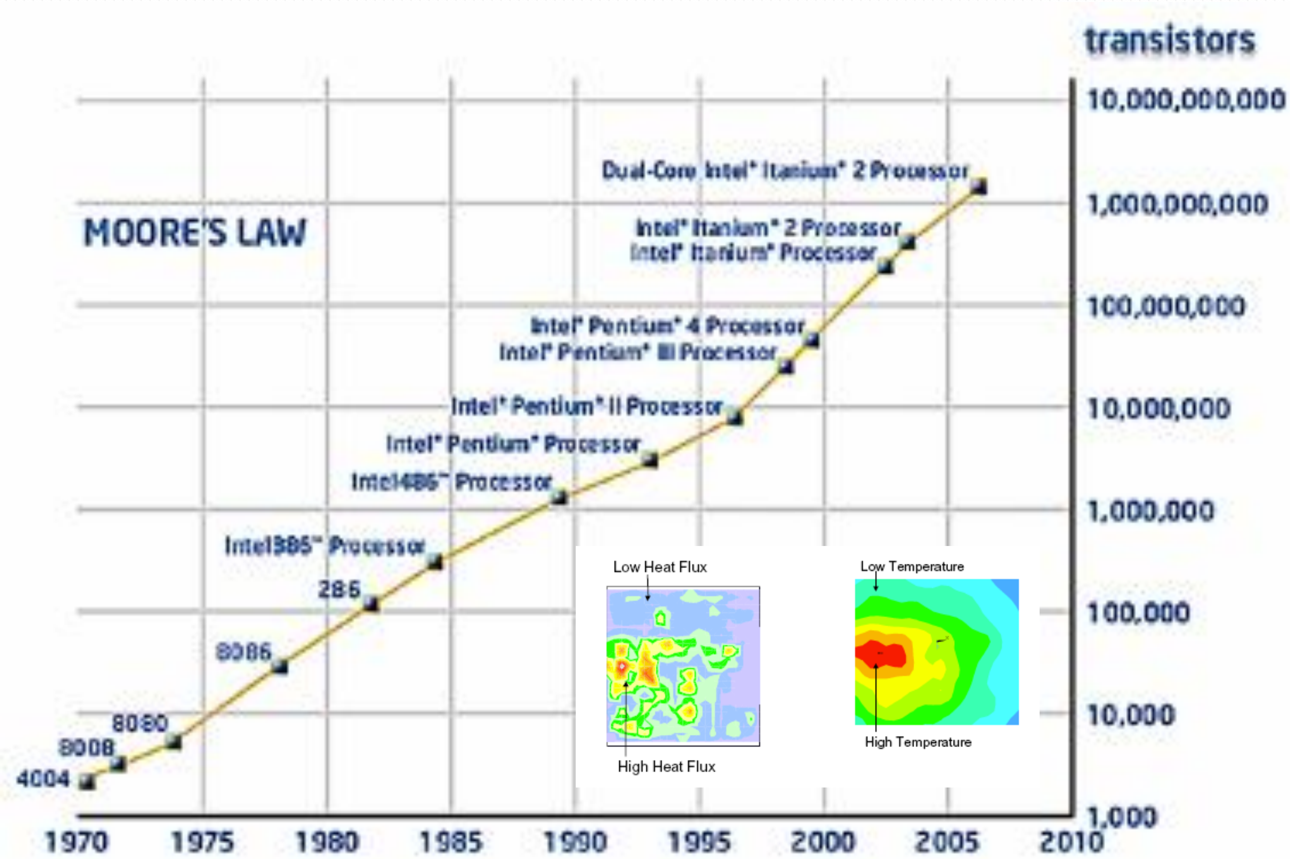
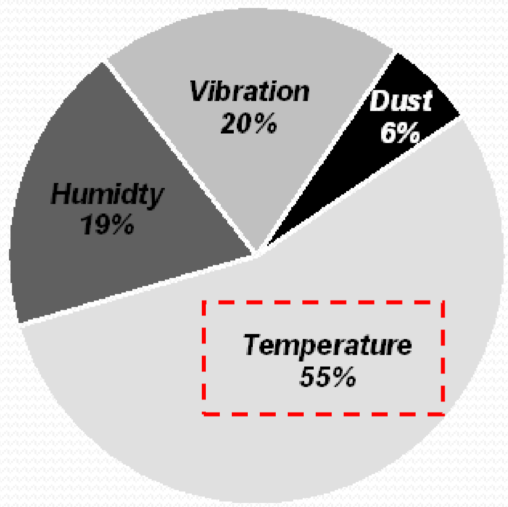
Outline

- Background
- Objective
- Ways to augment air-cooling applicable for electronic cooling
  - Interrupted surfaces
  - Vortex generator
  - Oblique dimple & cannelure channels
- Conclusions

Background

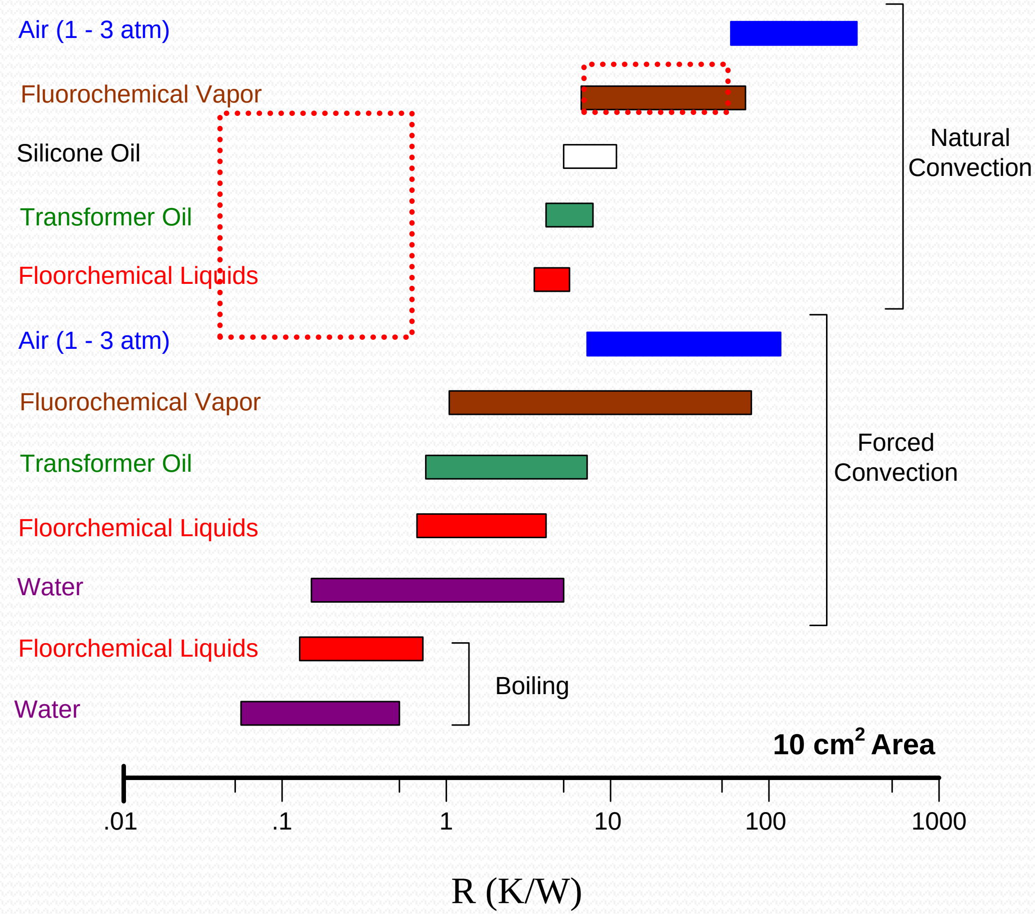




Source: *L. T. Yeh, ASME J. Electronic Packaging, vol.117, pp.333 –339, (1995).*

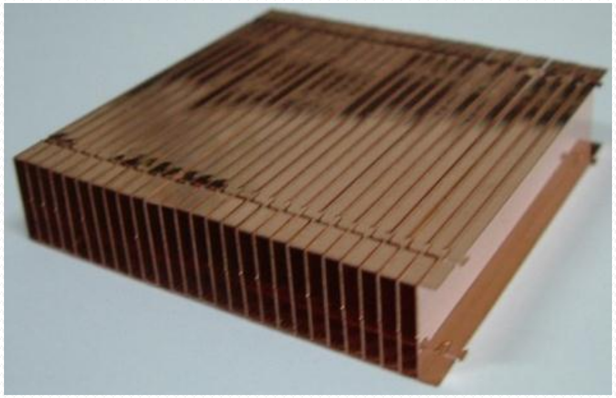
Background

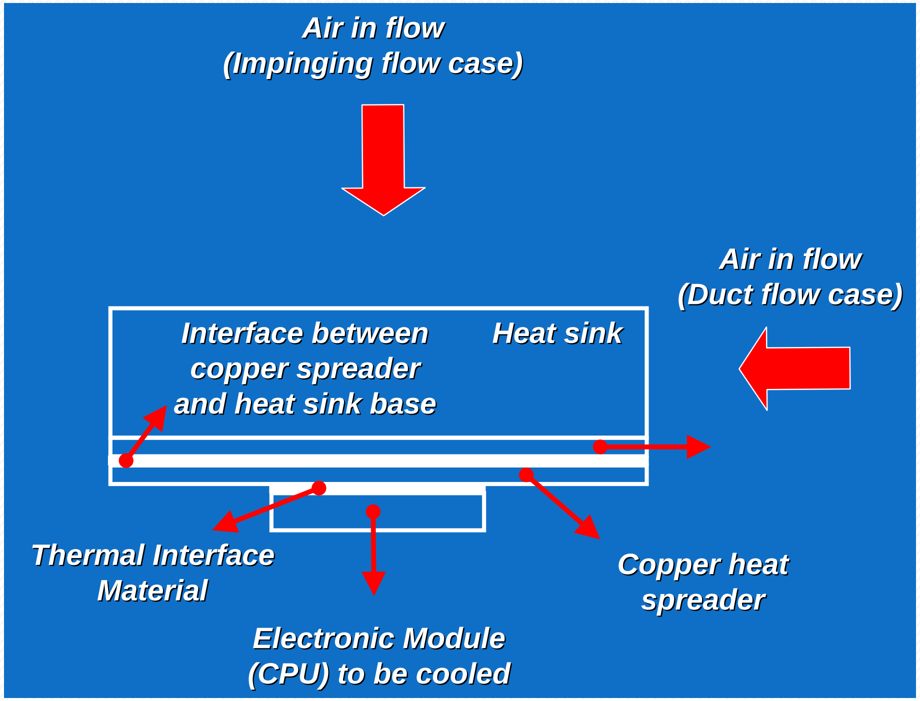
- Electronic cooling
  - Air cooling
  - Liquid cooling
    - Single phase
    - Two-phase
  - Refrigeration
  - Thermoelectric
  - …
- Direct air-cooling is still the most popular way for its simplicity, reliability, and low cost.
- Major Problems for Air-cooling
  - Poor heat transfer characteristics
    - Increase A (fins) to increase heat transfer (higher pressure drop penalty)
  - Noisy
    - Reduce air flow rate



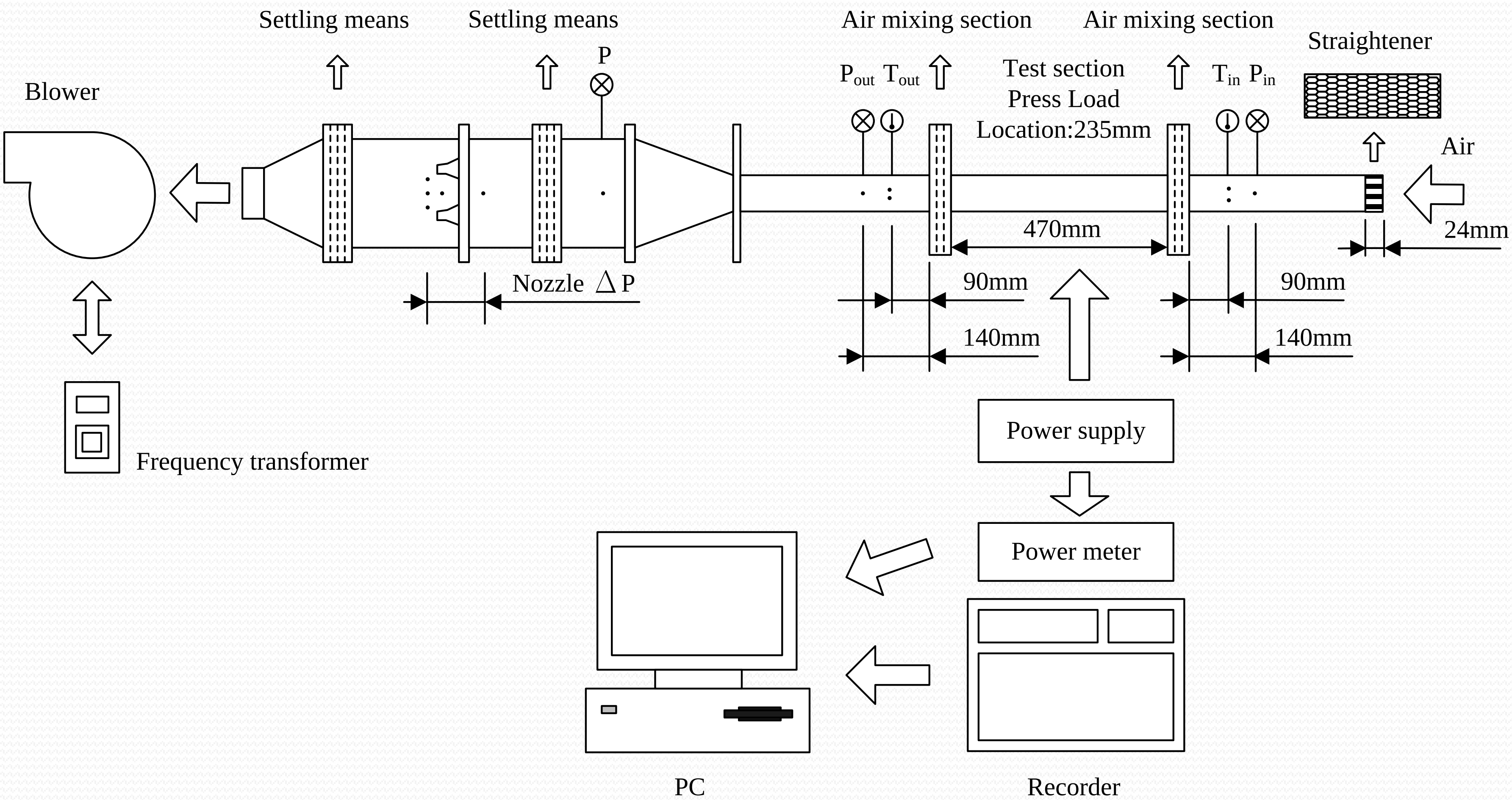
Objective

- Seeking ways to enhance air-cooling without considerable rise of pressure drop
  - Focus on cross flow applications
  - Focus at low velocity operation
  - Seeking specific fin patterns to tackle the problem



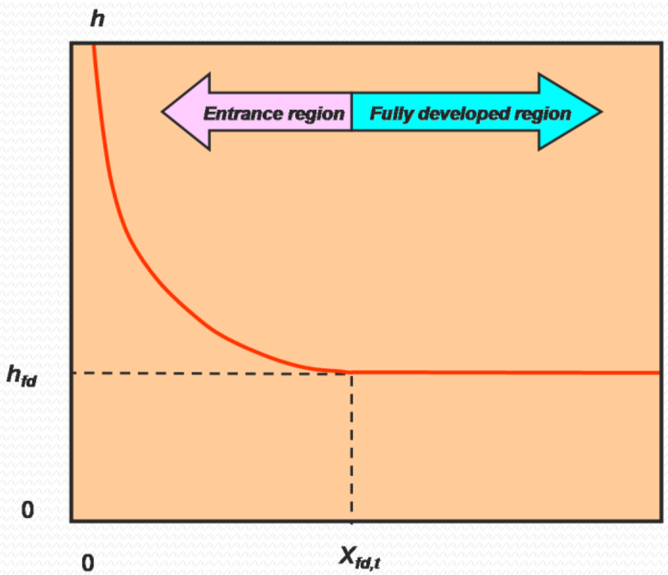


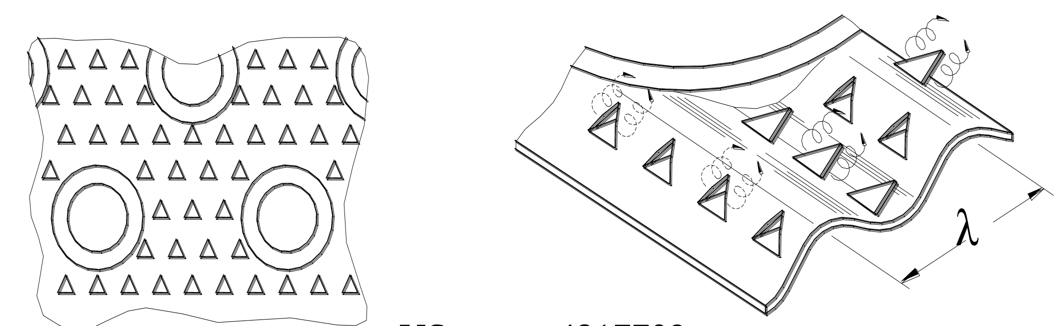
Experimental setup



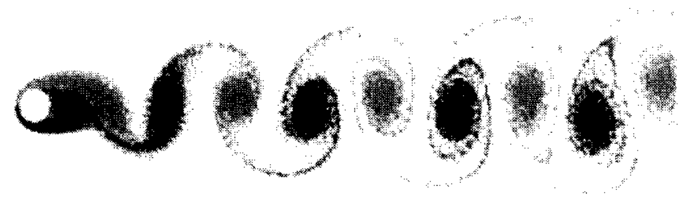
Some common ways for augmentation

- More Surface Area
- Thermal Boundary Layer Restart
- Instability
- Thermal Wake Management
- Swirl flow





US patent 4817709



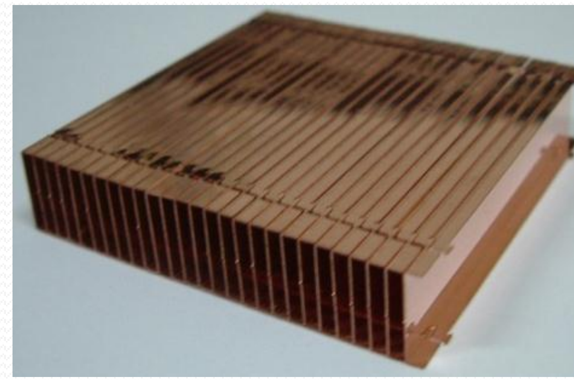
Various kinds of improvements
- Implementations

- Type I: Plate fin heat sink featuring heat transfer improvement by increasing heat dissipating surface. Generally, smaller fin spacing is used to accommodate more fin surface.

  Fin spacing can be lower than 1 mm

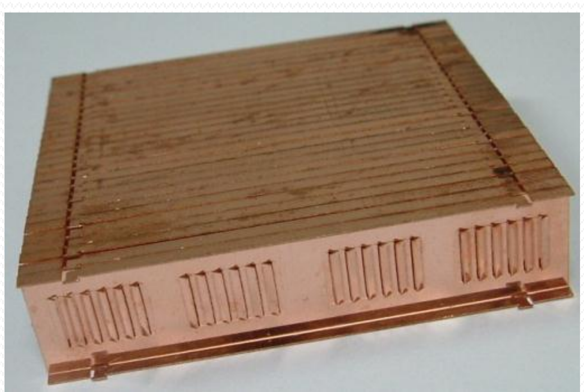
  (0.8 mm in this study)

  fin thickness 0.2 mm

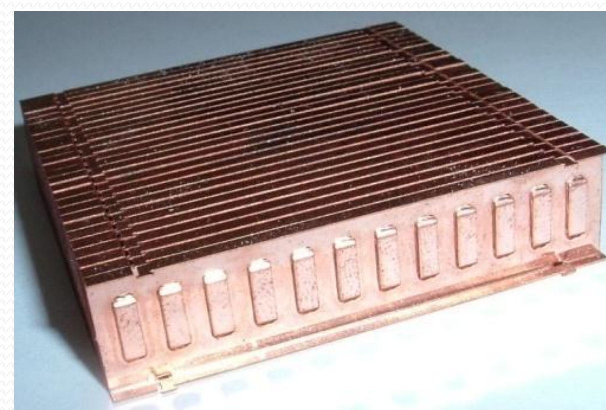


- Type II: Heat sink with interrupted fin geometry which improves convective heat transfer coefficient via periodical renewal of boundary layer such as slit or louver fin.

louver fin

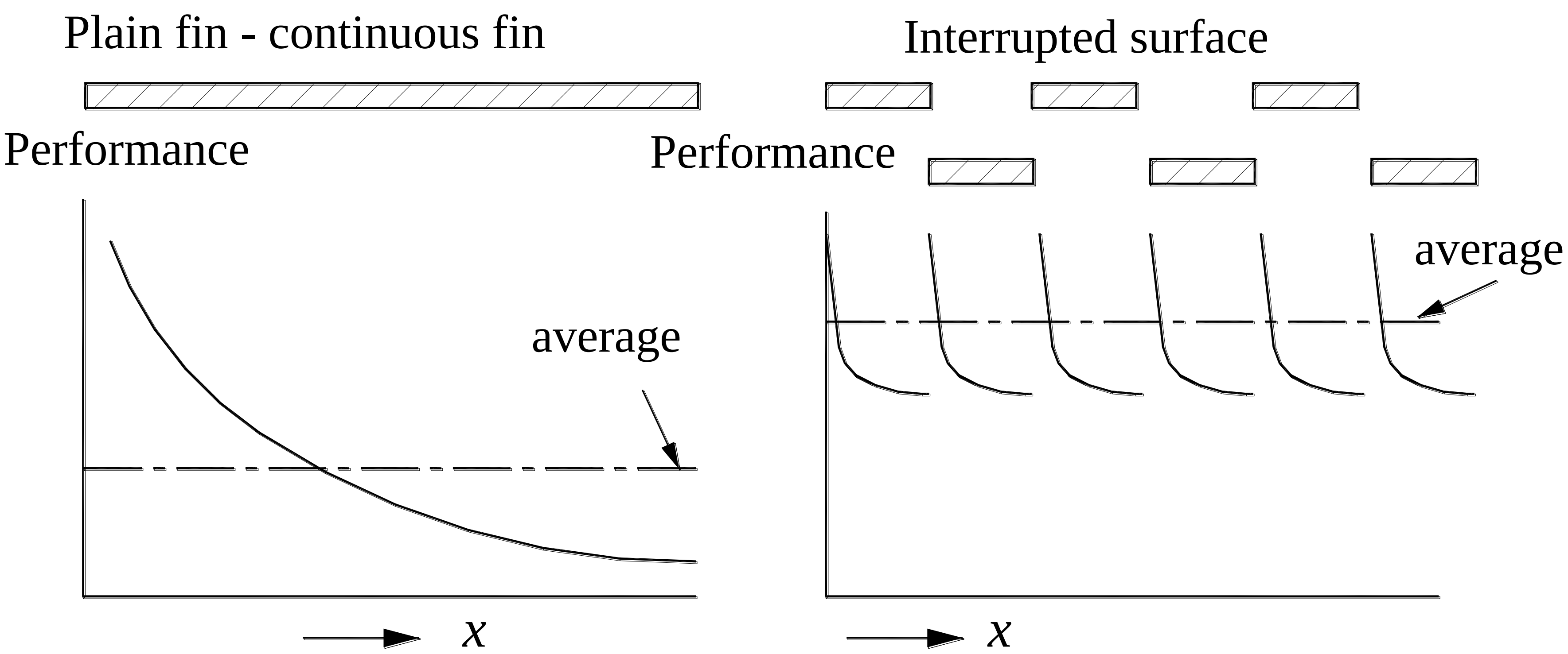


slit fin



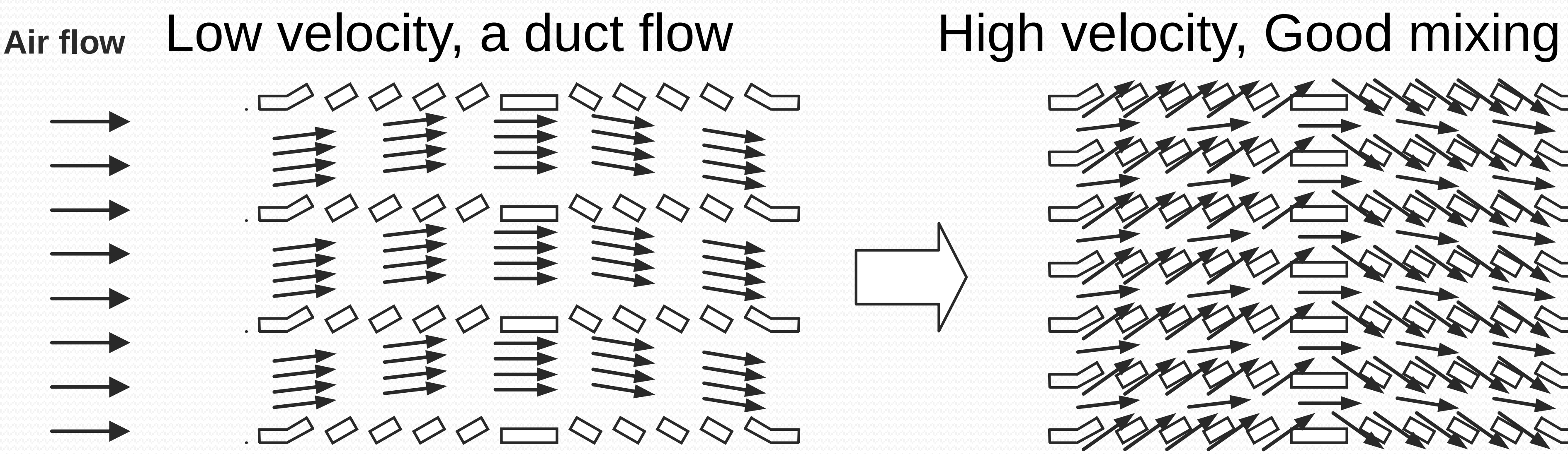
Concept of Interrupted surfaces

Boundary restart & Mixing



Interrupted surfaces..

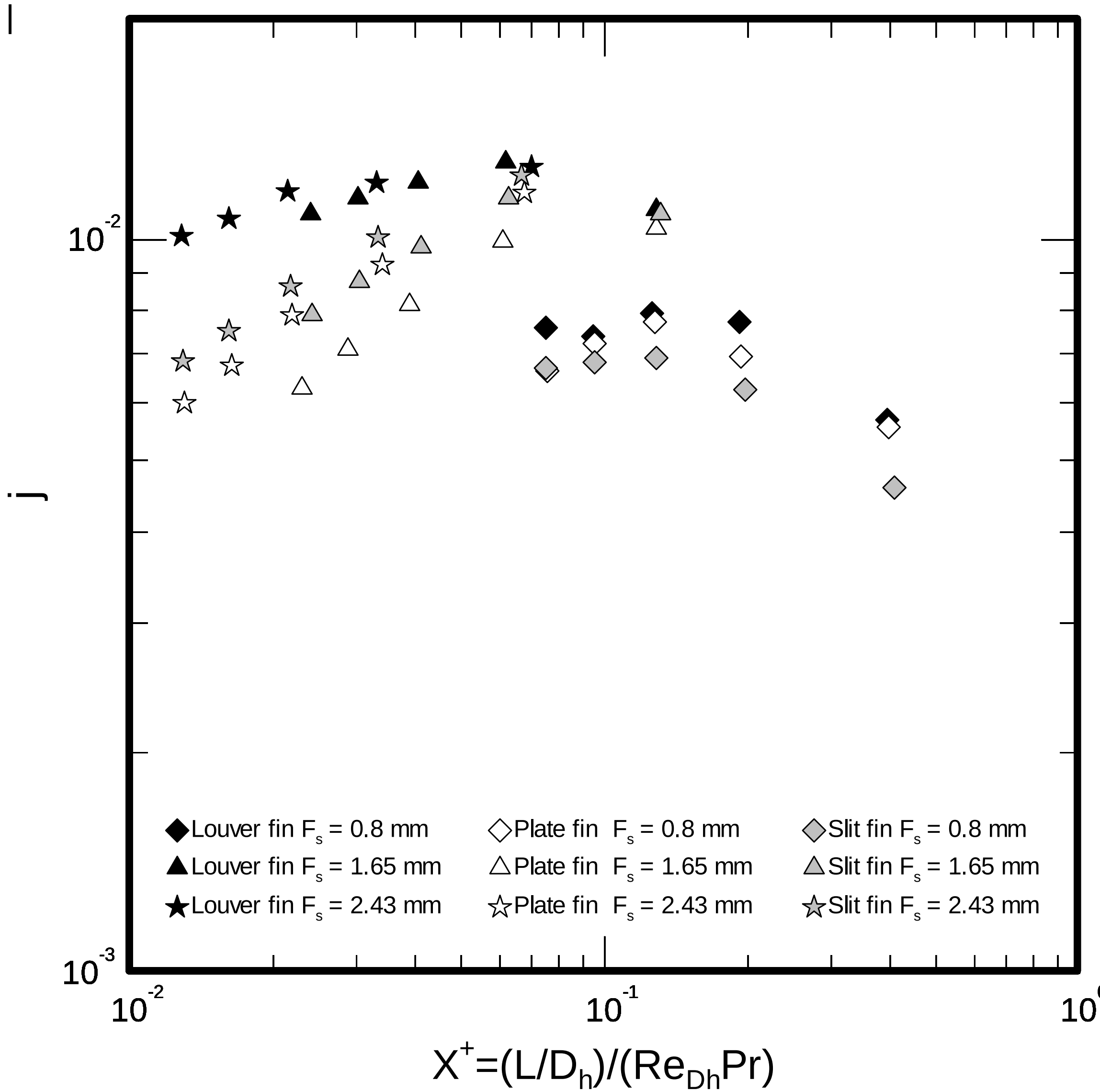
- Provide effective heat transfer augmentations at medium and high velocity with significant pressure drop penalty.
- Nearly ineffective at low velocity but still suffer from considerable pressure drop.
  - Duct flow effect.



SCHEMATIC OF DUCT FLOW VS. FIN-DIRECTED FLOW FOR LOUVER FIN GEOMETRY AT SMALLER AND LARGER FLOW VELOCITIES. (Yang et al. IJHMT, 2007)

Interrupted surfaces..

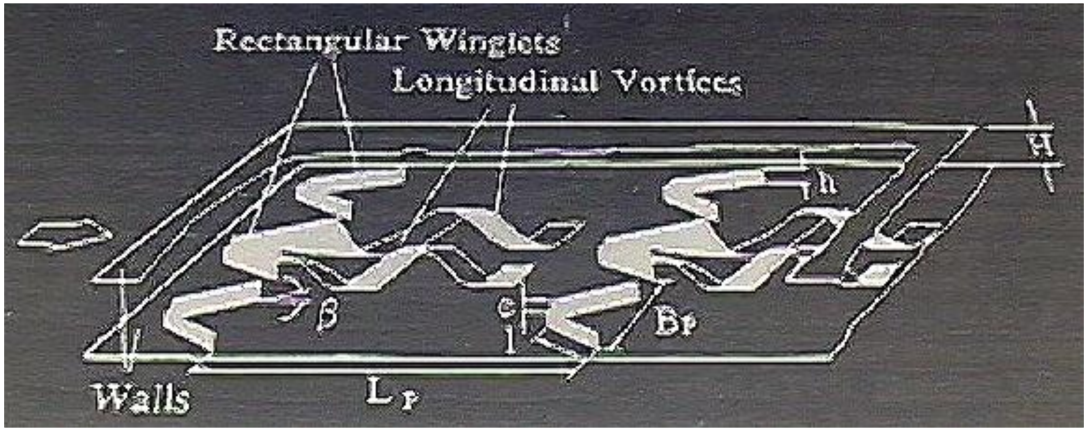
- Smaller fin spacing accentuates the duct flow effect, resulting in fully developed flow and deteriorate the heat transfer performance.



INVERSE GRAETZ NUUMBER NUMBER X^+ VS. *j* FOR LOUVER, SLIT AND PLATE FIN. (Yang et al., IJHMT, 2007)

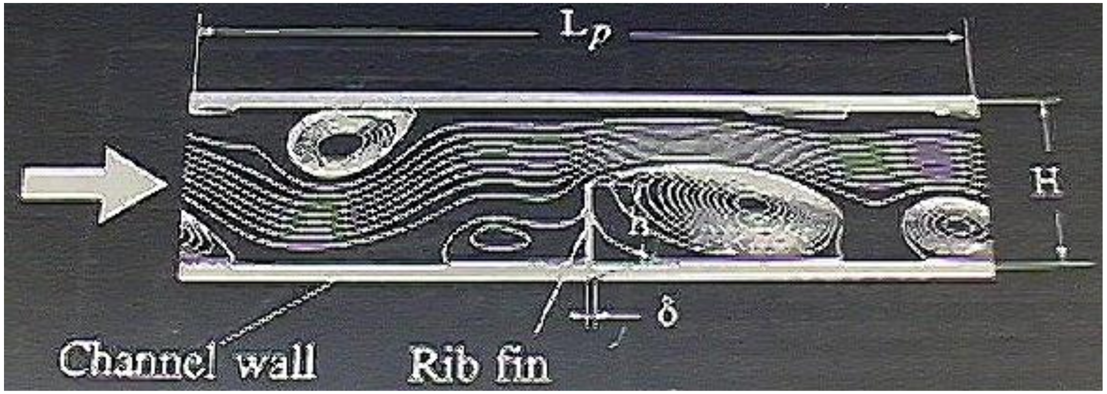
Concept of vortex generators

Longitudinal vortex outperforms the transverse vortex

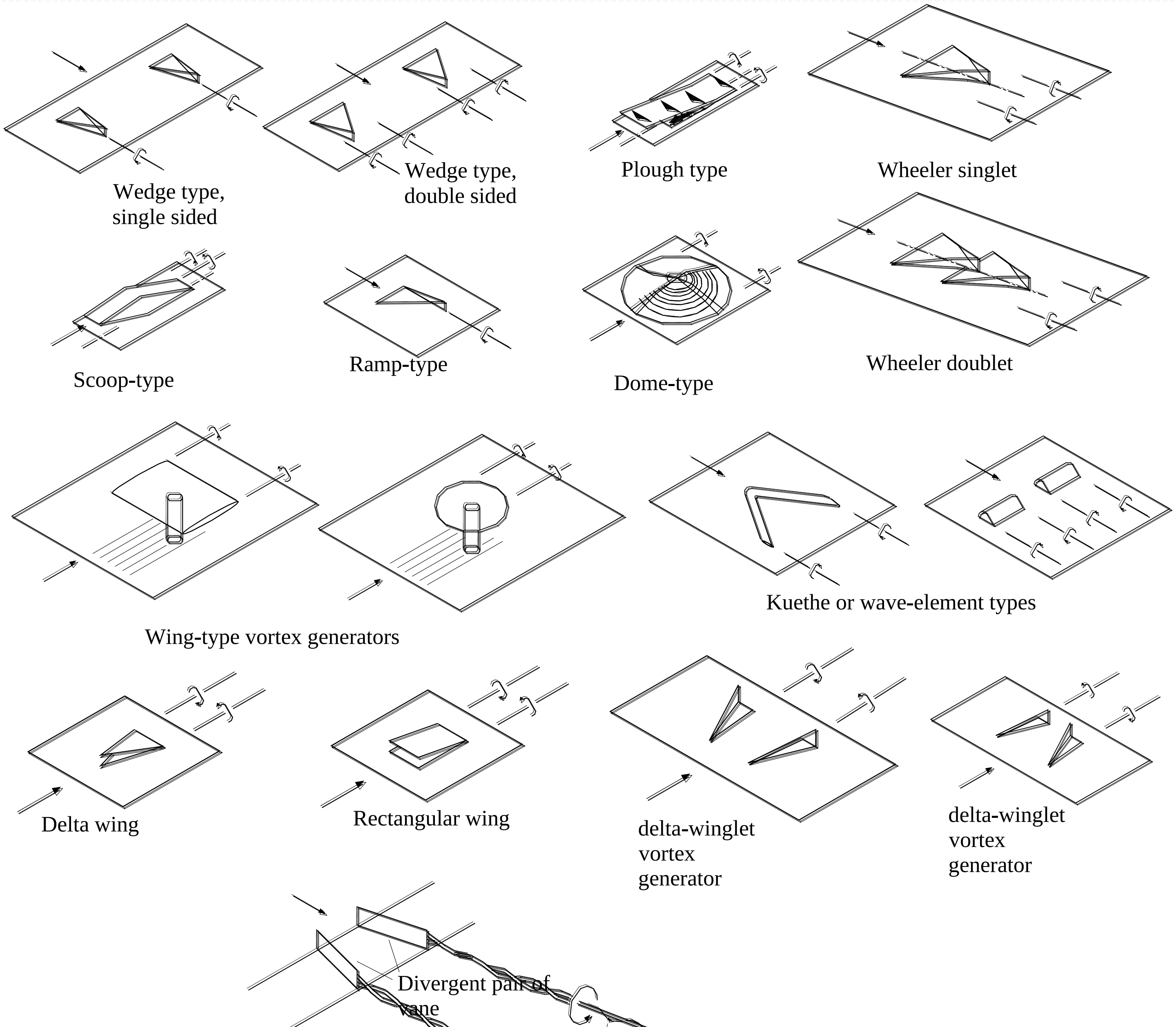


Longitudinal vortex

Transverse vortex



Typical LVGs

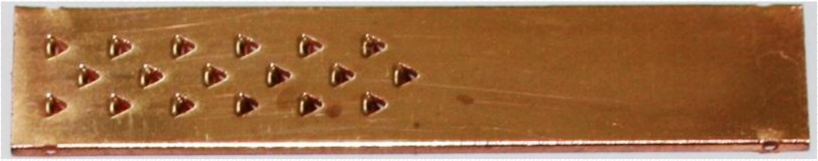


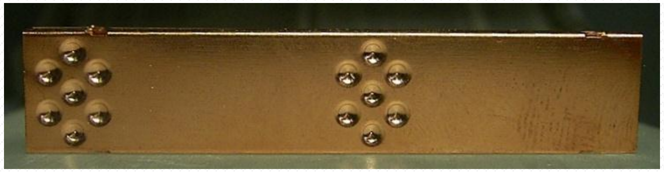
Vortex Generators..

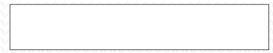
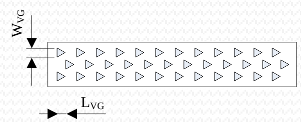
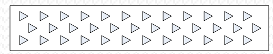
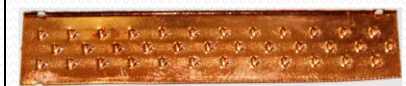
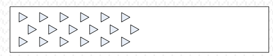
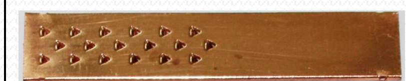
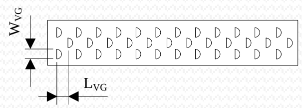
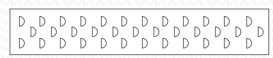
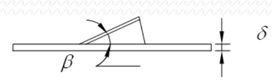
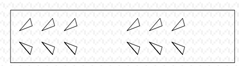
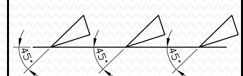
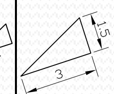
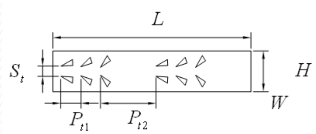
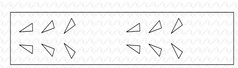
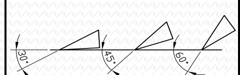
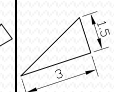
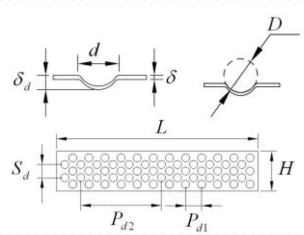
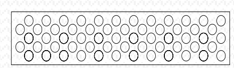
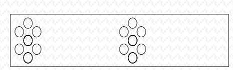
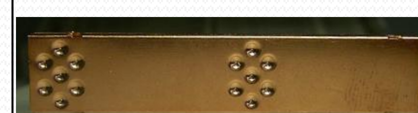
- Implementations

Type III: Heat sink with dense vortex generator. The enhancements introduce swirl flow, Coanda deflection flow or destabilized flow field from vortex generators or dimple/protrusion structure. The general arrangement is using inline or staggered layout such as semi-circular, delta and dimple vortex generator.

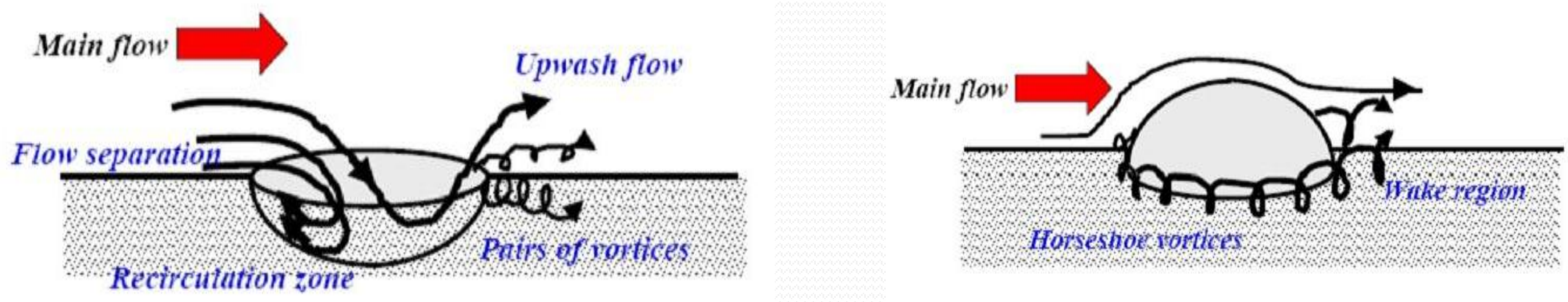
Type IV: Heat sink with loose vortex generator: The enhancements of this category are still vortex generators or dimple/protrusion structure but with sparse arrangement of vortex generator.





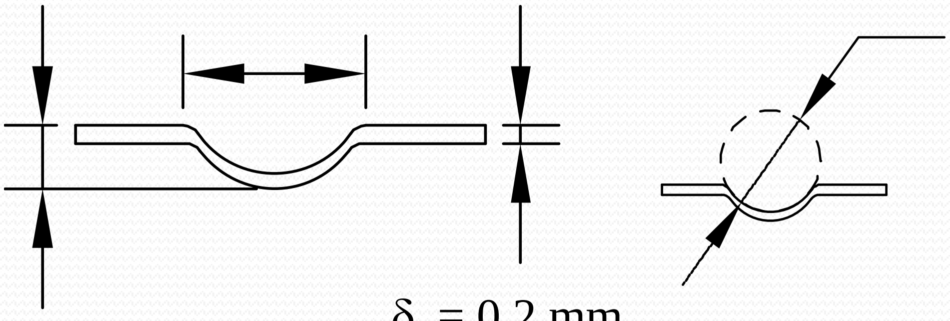
Heat sink	Nomenclature	Side view	Dimension		Photos of test sample
(a) Plate	-		-	-	
(b) Delta VG			-	-	
(c) Delta VG+Plate			-	-	
(d) Semi-circular VG			-	-	
(e) Triangular VG					
(f) Triangular Attack VG					
(g) Dimple VG				-	
(h) Two Groups Dimple VG				-	

The original concept of Using dimple..



(a) Dimple

(b) Protrusion



- Drag reduction
- Longitudinal Vortices
- In this study, fin thickness is 0.2 mm,
- the length of cavity is 2 mm, effective cavity depth is 0.3 mm

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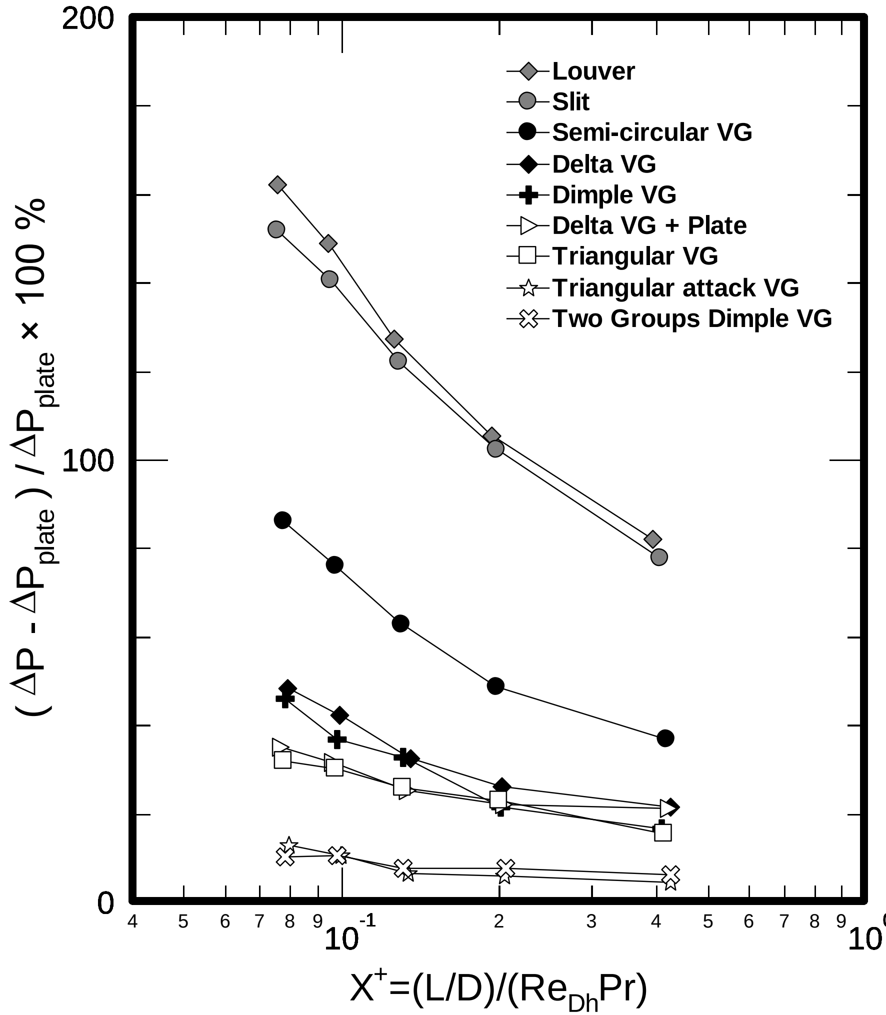
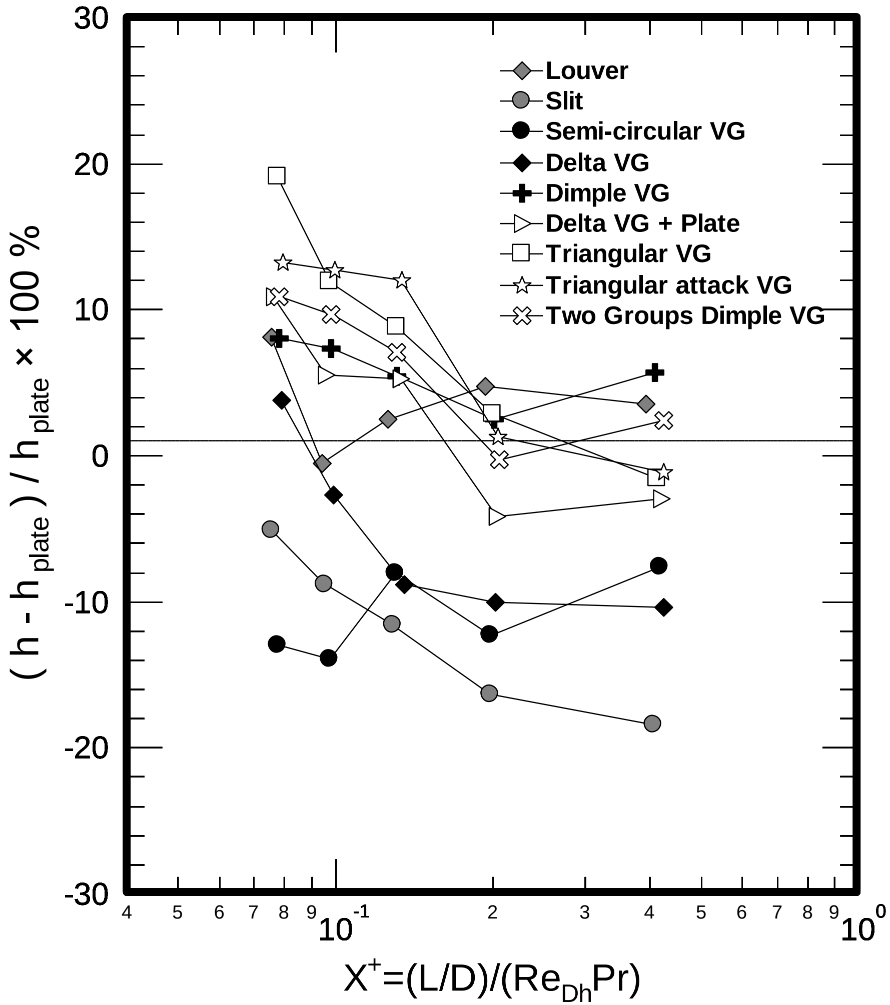
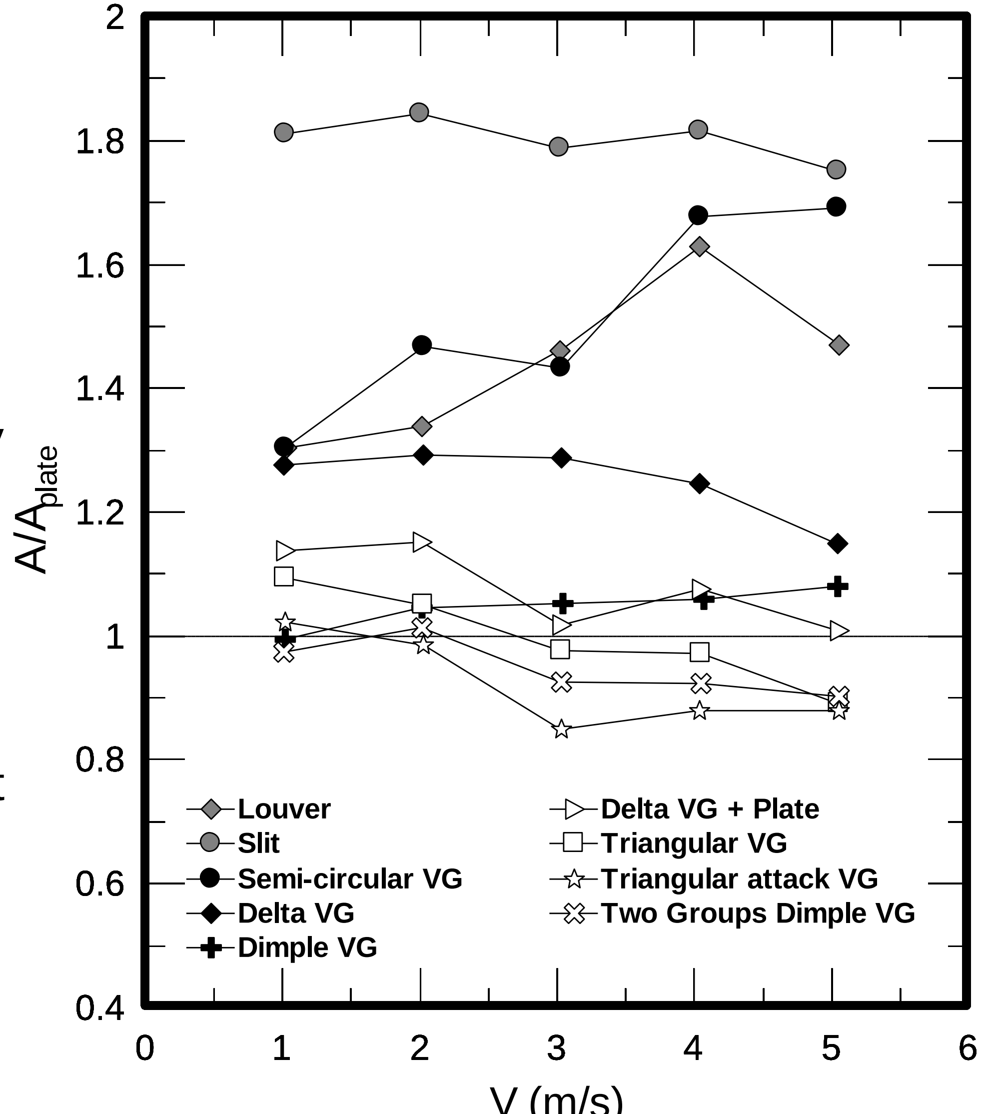
Performance comparison
Fin spacing = 0.8 mm



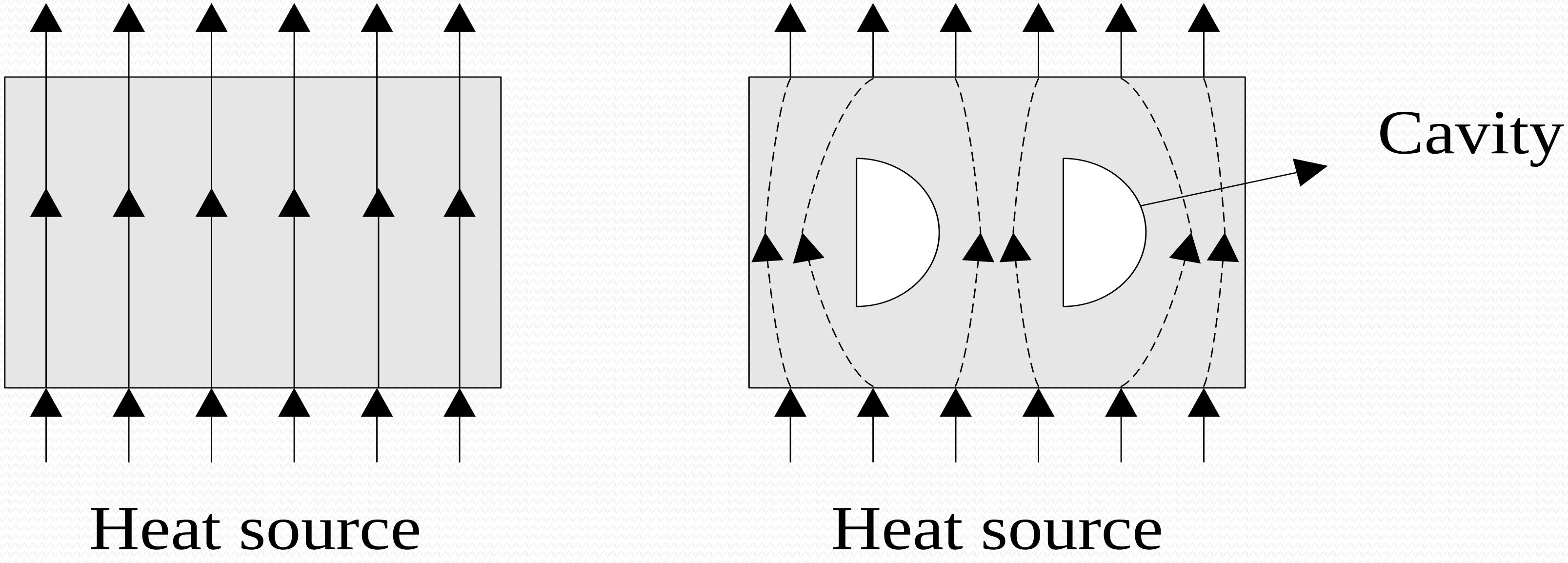


Performance evaluation based on VG-1 Criterion

- Vortex generators fin operated at a higher frontal velocity and arrangement of loose vortex generator is more beneficial.
- The results show that when frontal velocities as 3~5 m/s and the fin with enhancement as triangular, triangular attack and two-groups dimple effectively reduce required surface area. The type II and type III fin geometry possesses the lower heat transfer coefficient in most situations along with their significant pressure drops lift them out of the choice of vortex generator subject to the VG-1 criteria.
- The asymmetric combination using heat sink with loose vortex generator (Type IV) fin can be quite effective.



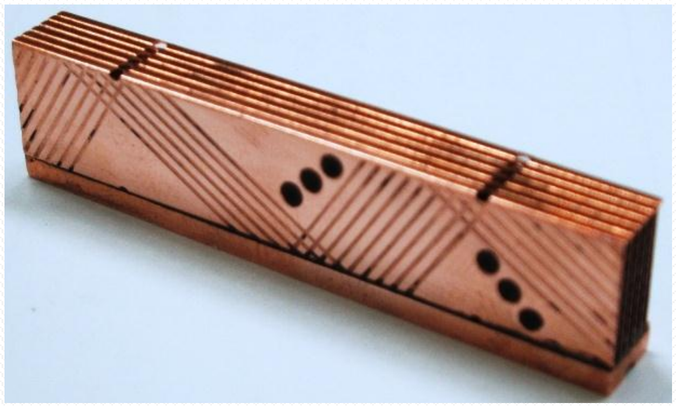
An extra problem for some VG & interrupted surfaces

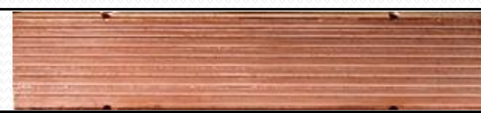


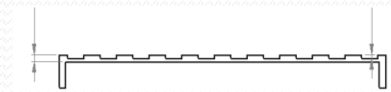
Very small fin spacing also jeopardize the formation of LVG

So, what's next?

- Oblique Dimples with cannelure structure



(plate fin)	(oblique dimple gap 4-12fin)
	
(oblique dimple gap 6-12 fin)	(cannelure fin I)
	
(cannelure fin II)	(oblique dimple gap 4-12 cannelure fin)
	
(oblique dimple gap 6-12 cannelure fin I)	(oblique dimple gap 6-12 cannelure fin II)
	



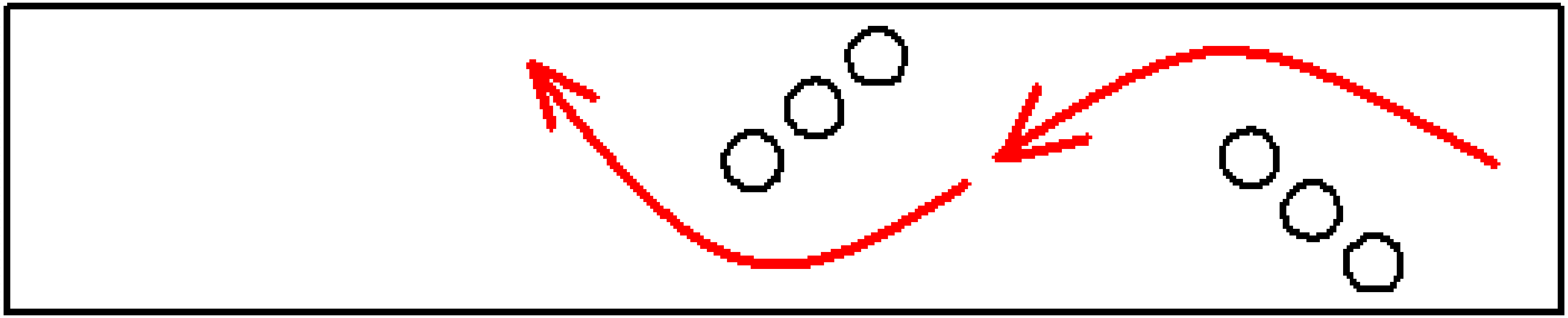
Cannelure channel

Depth: 0.1 mm

Width: 0.4 mm

The original idea for oblique dimple..

- Concavity + Dimple
- Lengthen the flow path
- No need for significant amount dimples
  - Reduce the number of dimples to decrease the pressure drop



The idea of cannelure channels..

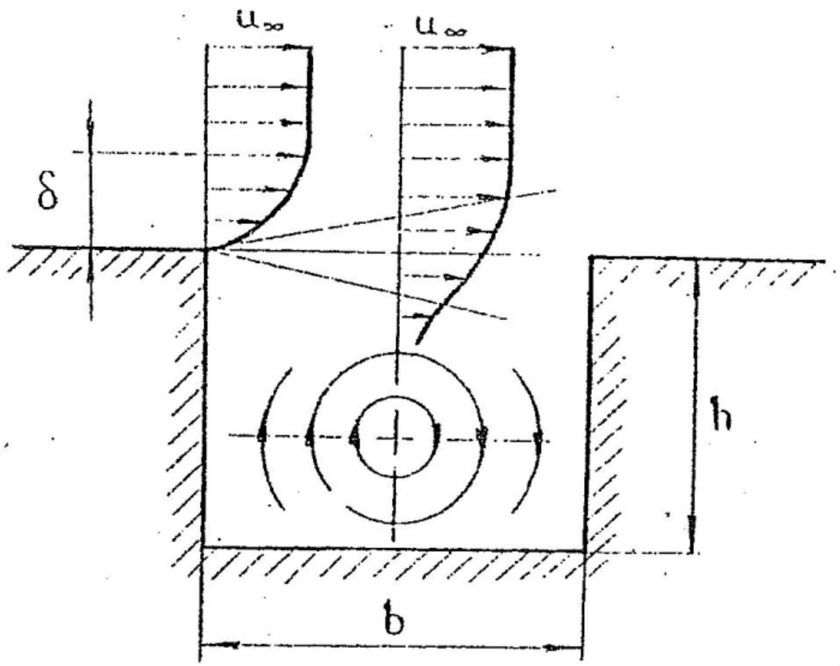


Fig. 1. Model of flow in an isolated rectangular pit [2] in a wall.

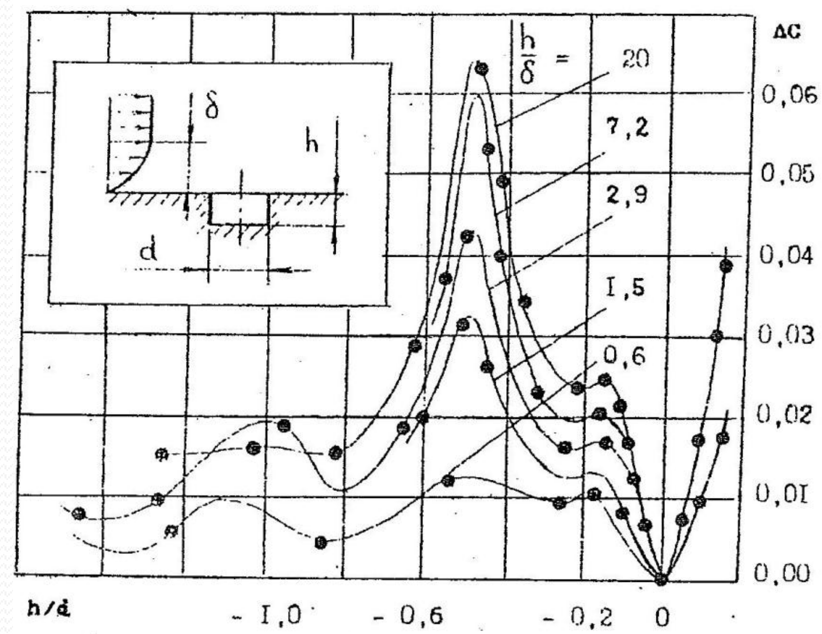


Fig. 2. Increment of the drag coefficient as a function of the dimensionless depth of the pit [4].

Heat Transfer Research 25(1), 1993, 22-56

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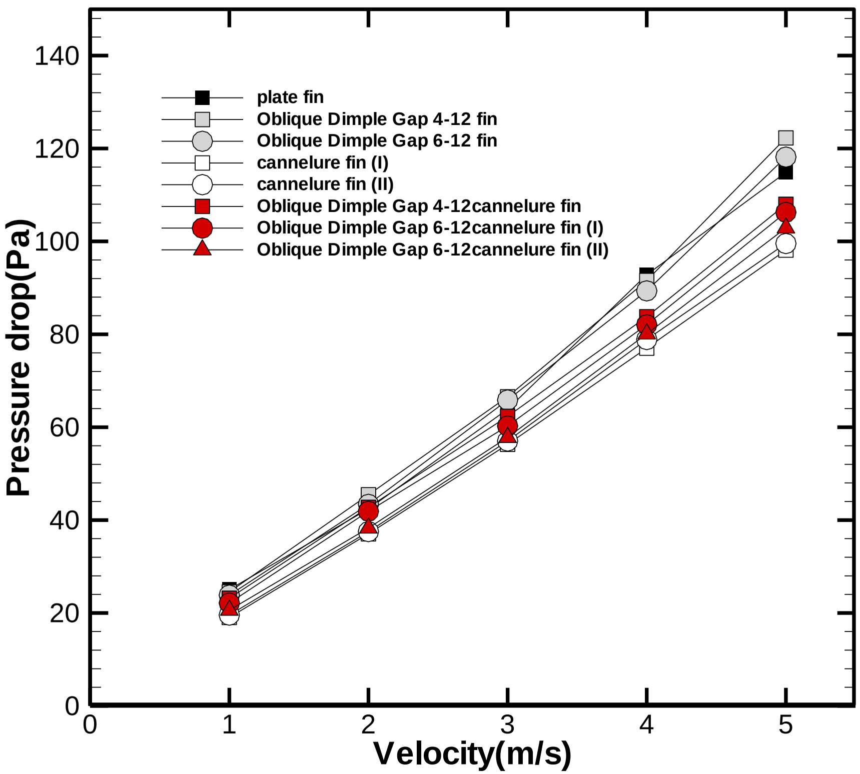
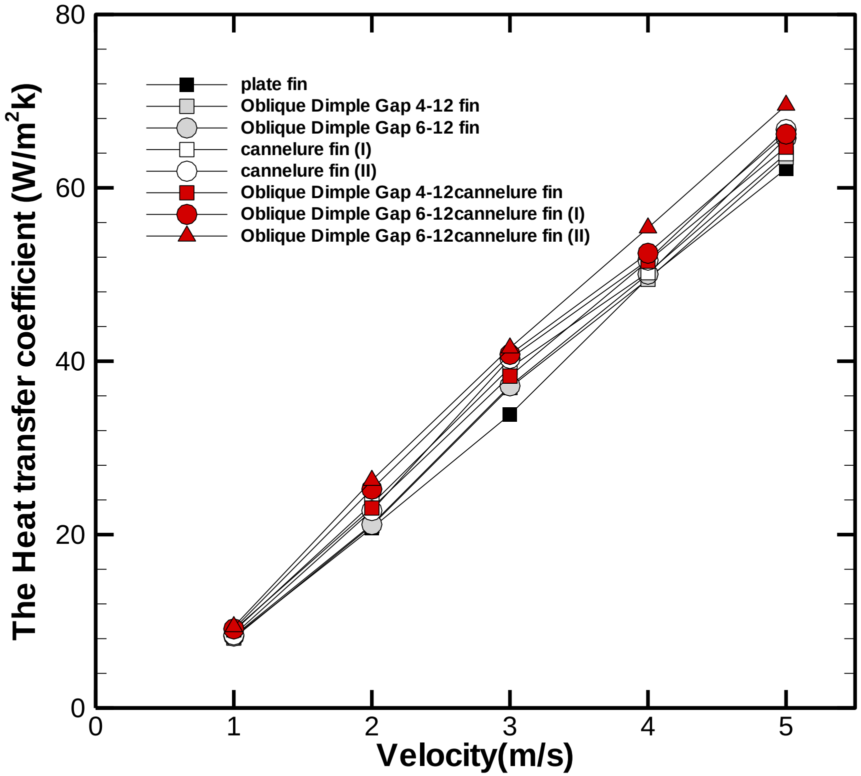
Results:
More than 20% increase HTC & 20% reduction in pressure drop





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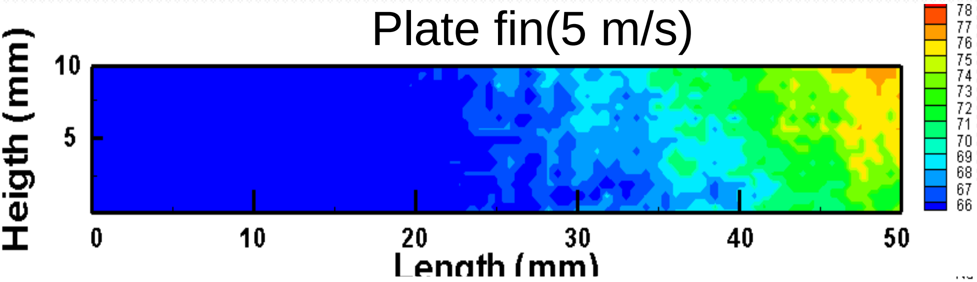
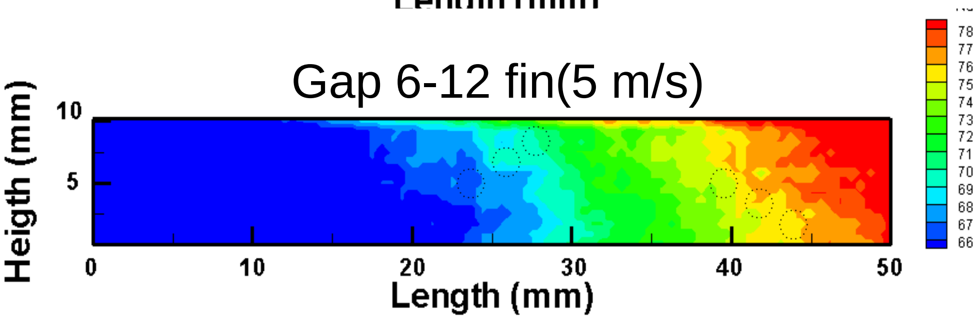
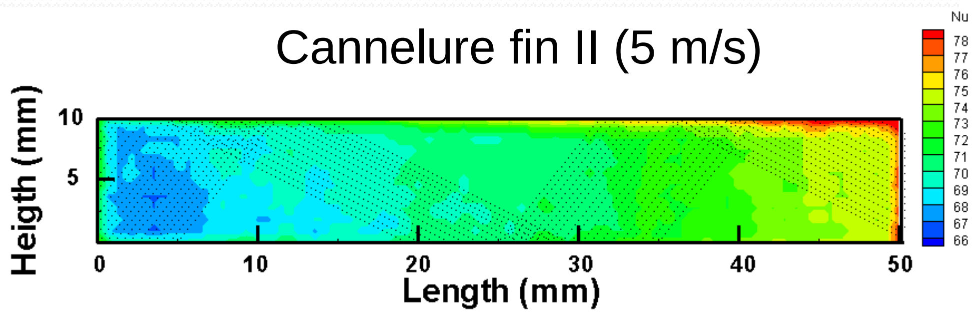
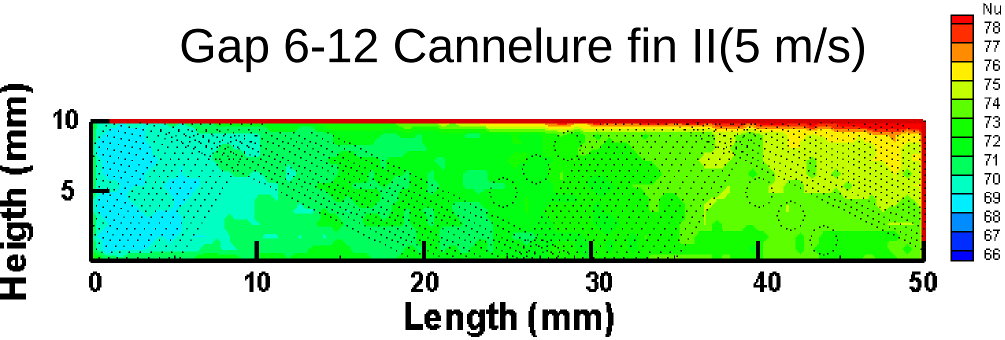
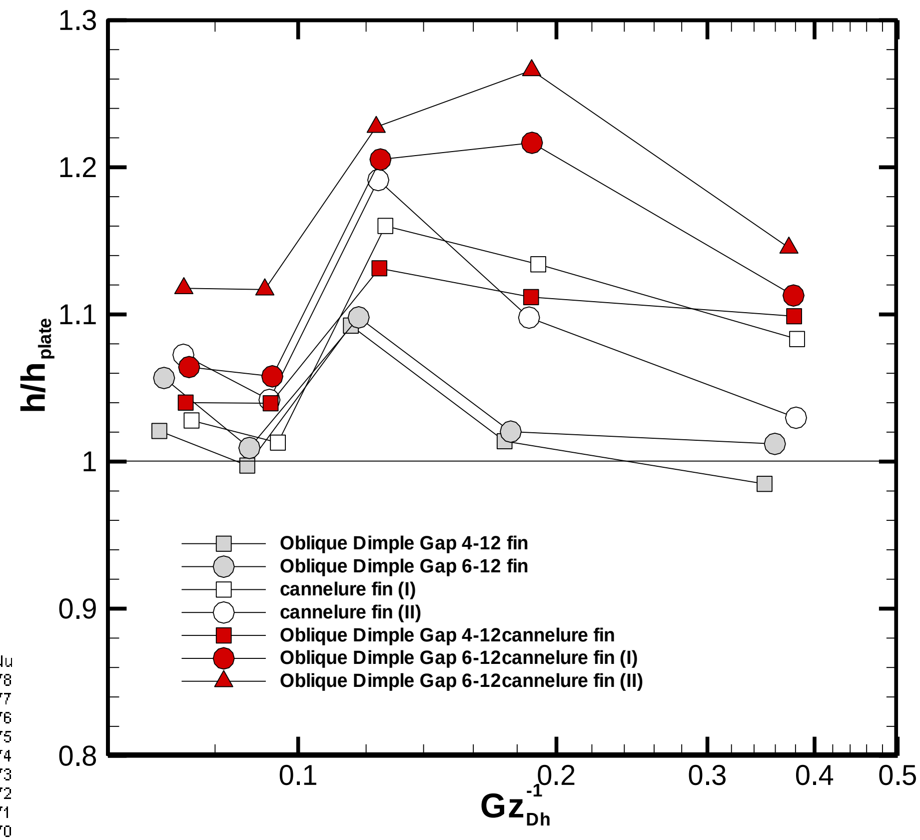
Performance & IR image





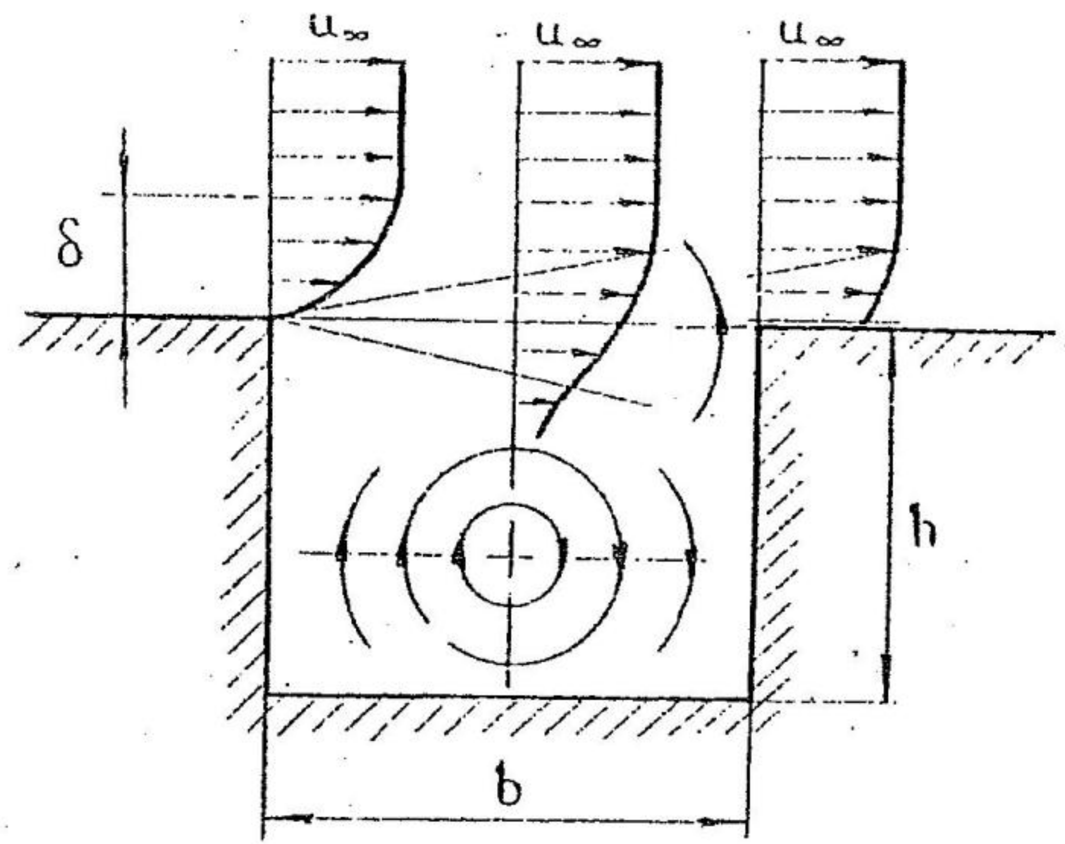






Why cannelure structure is working? – One possible reason

- Reduce the BL thickness to improve the heat transfer performance for fully developed region.
- It acts like a “suction” device.



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Evidence from previous data

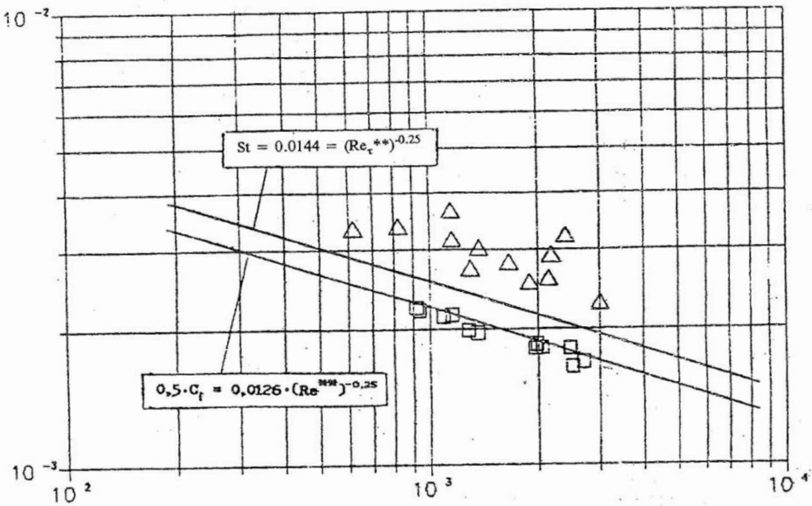


Fig. 13. Friction and heat transfer on indented walls.
□ - the dynamic (velocity) boundary layer; Δ - the thermal boundary layer.

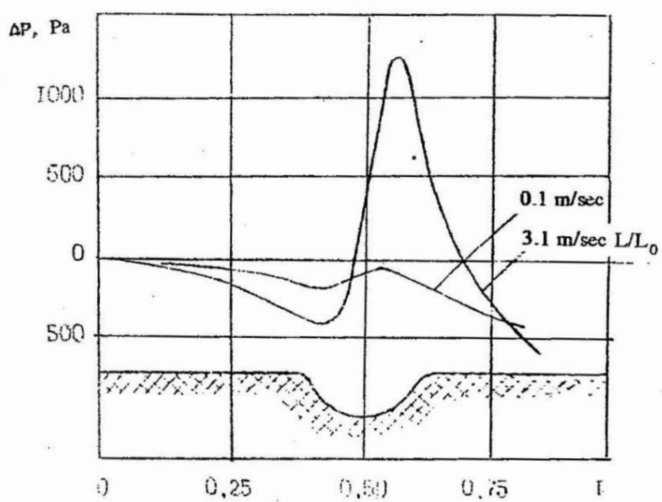
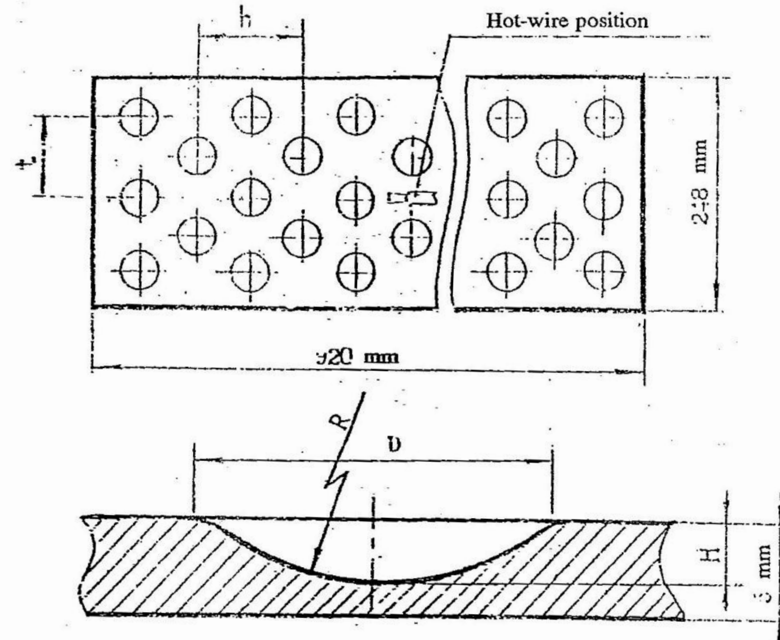


Fig. 10. Distribution of the pressure drop along the axis of a duct with an isolated hemispherical pit in the wall [15].



No.	D, mm	H, mm	R, mm	t, mm	h, mm	f, %
1	7.5	0.5	13.32	13.3	11.5	25
2	6.0	0.4	10.20	10.6	9.1	25
3	4.5	0.3	7.65	8.0	7.5	25
4	7.5	0.5	13.32	9.4	8.1	50
5	6.0	0.4	10.20	7.5	6.5	50
6	4.5	0.3	7.65	5.6	4.9	50
7	7.5	0.5	13.32	8.4	7.3	70
8	6.0	0.4	10.20	6.4	5.5	70
9	4.5	0.3	7.65	4.8	4.2	70

Fig. 12. Geometric parameters of the walls studied.

Conclusions

- The test fin patterns can be classified into four categories, namely the base plain fin heat sink (Type I), interrupted fin geometry (Type II), dense vortex generator (Type III), loose vortex generator (Type IV) and their combinations.
- It is found that the heat transfer performance is strongly related to the developing/fully developed flow characteristics. The result from the present experiment suggests that the asymmetric combination using loose vortex generator arrangement (Type IV) can be quite effective.
- The triangular attack VG is regarded as the optimum enhancement design for it could reduce 12~15% surface area at a frontal velocity of 3 m/s~5 m/s. The asymmetric design is still applicable even when the fin spacing is reduced to 0.8 mm.

Conclusions

- Combined Con-cavity and dimple is quite effective in heat transfer and pressure drop reduction, provided the numbers are low.
- Cannelure structure may reduce the boundary layer thickness to further reduce pressure drop.
- The cannelure structure is especially effective at fully developed region.
- In the best condition, more than 20% increase in HTC and 20% reduction of pressure drop is achieved.

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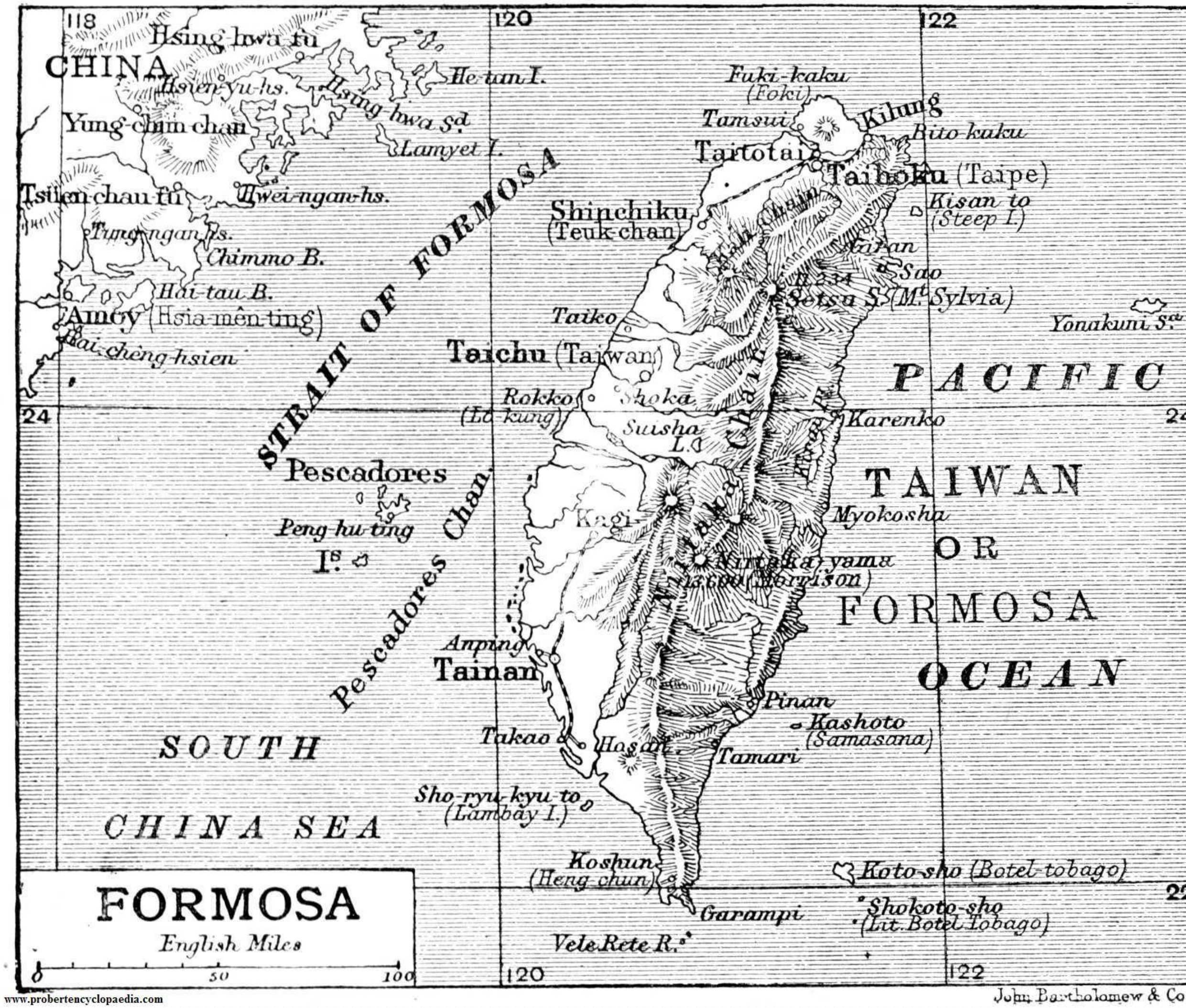

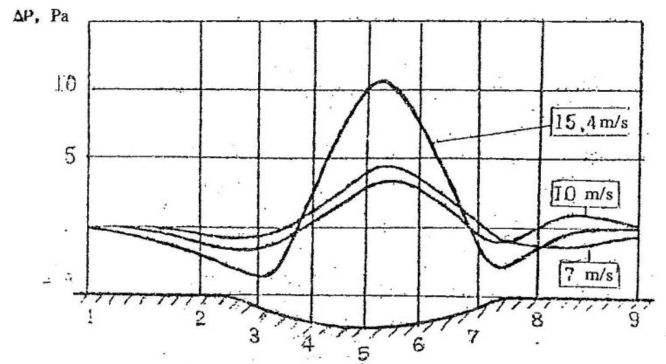

Fig. 18. Pressure distribution along a section through an isolated cylindrical groove in the case of nonseparated cross flow (boundary layer adhering to the wall.)

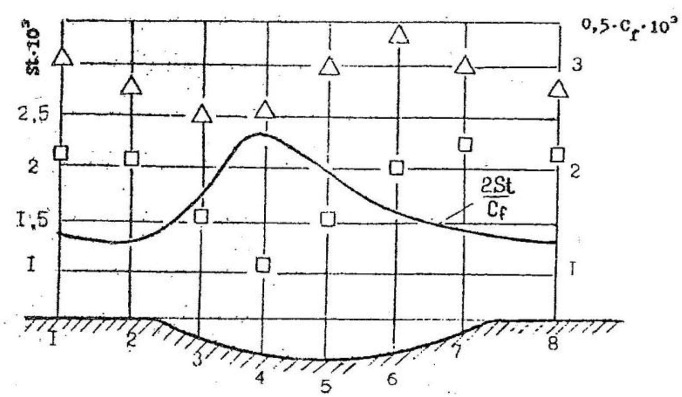

Fig. 19. Friction and heat transfer along the section of a cylindrical trench in the case of nonseparated cross flow.
□, Δ - same as in Fig. 13.

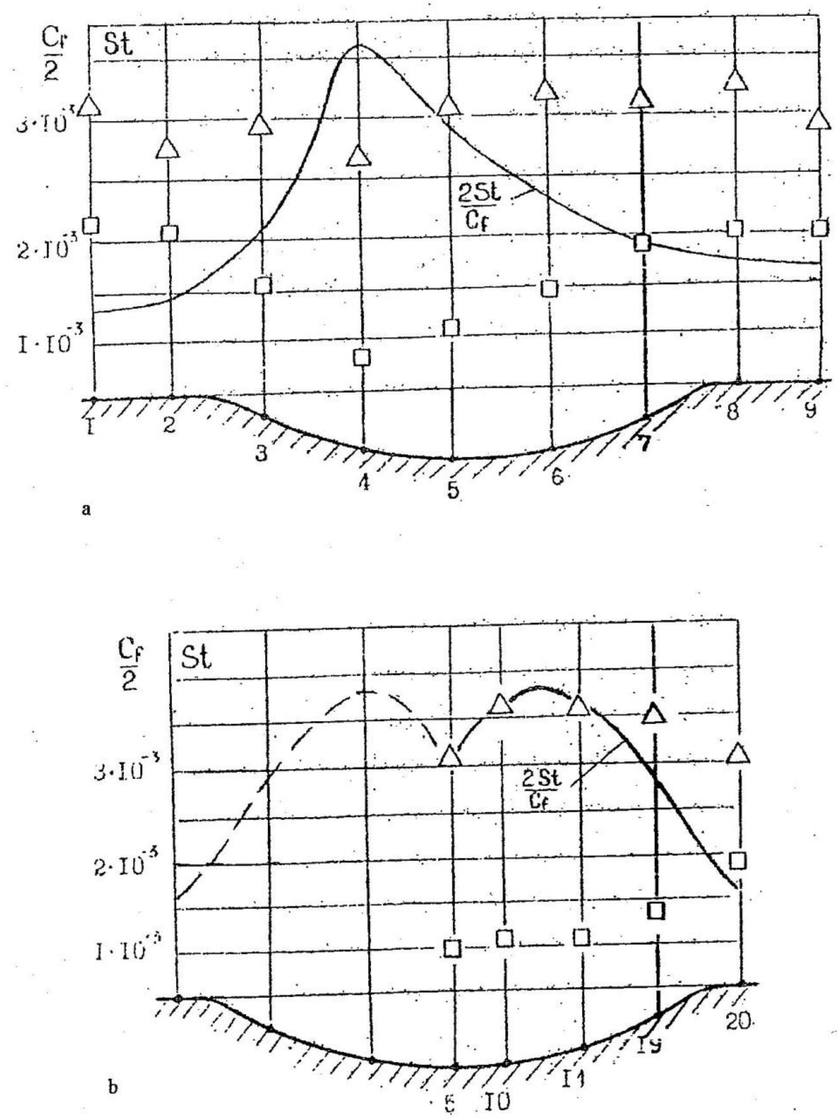

Fig. 15. Distributions of the local friction coefficients and Stanton number on the middle longitudinal (a) and middle cross (b) sections of the pit.
□ - dynamic (velocity) boundary layer; Δ - the thermal boundary layer.