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RECENT TURBULENT DRAG REDUCTION RESEARCH AT LANGLEY RESEARCH CENTER

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SUMMARY

This paper represents a report on a portion of the fuselage viscous drag reduction research at NASA Langley Research Center. The paper discusses three areas: oscillatory longitudinal curvature, large eddy breakup devices and small longitudinal surface striations. The first two concepts produce sizable local turbulent skin friction reductions, but further research is required to optimize the effect, reduce parasitic device drag, and thus provide a net increase in vehicle performance. The surface striations, due to large wetted area increases for a given planform, have not yet yielded a planform-averaged skin friction reduction. However, heat transfer data indicate such surfaces may have useful application in heat exchangers.

INTRODUCTION

One of the major goals of aerodynamic research is increased aircraft performance. Reducing drag is an obvious method of increasing performance and at the same time reducing fuel usage. Long haul aircraft drag is mainly drag due to lift and turbulent skin friction. Recent advances in technology (supercritical wings, winglets) provide sizable reductions in drag due to lift. However, while skin friction drag reduction research is currently enjoying somewhat of a renaissance, there is no generally applicable technique yet available which gives a net reduction in turbulent skin friction other than driving the flow all the way to the laminar condition (Laminar Flow Control). This forced laminar option is under active study at NASA Langley Research Center for wing application, but other metnods should be examined for the fuselage, which is responsible for approximately one half of the aircraft skin friction drag. Turbulent drag reduction techniques are reviewed in reference 1 and this paper presents a progress report on research for several approaches not yet identified when reference 1 was prepared. The approaches include oscillatory longitudinal curvature (ref. 2), large eddy breakup devices (ref. 3) and small longitudinal surface striations (ref. 4 - paper accepted for presentation).

A chronology of the Langley viscous drag reduction research program is shown on figure 1. This research is based primarily on concepts derived from consideration of the coherent structures recently identified in turbulent boundary layers (fig. 2). The turbulent layer is assumed to consist of the usual outer region with large scale motion, a wall region where turbulent production occurs, and a communication process from outer to inner layers which causes the inner layer to erupt. Obvious possibilities for turbulent drag reduction include breakup of the outer eddy structure, (thereby altering the outer-to-wall communication and perhaps decreasing the bursting activity) and stabilization of the near wall layer. However, care must be taken to consider and perhaps modify "secondary influences" of candidate drag reduction techniques to ensure that the overall effect is the net drag reduction. There are many techniques which reduce turbulence production, but actually increase overall drag, simple examples being small to moderate wall suction and favorable pressure gradients. Therefore, for each of the three candidate drag reduction techniques which will now be discussed, the effect on overall drag will be addressed, not just the influence on turbulent skin friction.

Oscillatory Longitudinal Curvature

Early results from this study are available in reference 2. The basic concept is to use transverse surface waviness in an attempt to produce periodic partial relaminarization and thus a lower average skin friction. The essence of the approach is the extreme sensitivity of turbulent flows to longitudinal curvature effects (ref. 5). Transverse wall waves produce periodic variations in two boundary conditions which strongly influence turbulent boundary layers, alternating favorable and adverse pressure gradients and concave and convex curvature. The pressure variations are phase-shifted approximately 90° from the curvature variations, but there is a region, upstream of the wave crest, where the boundary layer is subjected simultaneously to the combined influence of convex curvature and favorable pressure gradient, both of which are known to stabilize the turbulent flow. Sufficiently large and long lasting convex curvature and favorable pressure gradient effects are known to cause relaminarization of the turbulent boundary layer.

From research performed thus far, one of the keys to obtaining an average C_f reduction is the use of small wave lengths (order of the boundary layer thickness) to cause large curvature effects (small radius of curvature, proportional to wave length squared). Usual guidelines (e.g. ref. 5) indicate that δ/R values greater than 0.005 to 0.01 cause large changes in turbulence structure. In the transverse wavy wall case relatively innocuous waves, $\frac{a}{\lambda} \approx 0.03$ (but small wave legth, $\lambda \sim \delta$) produce $\delta/R \sim O(1)$ and therefore the boundary layer is subjected to tremendous oscillatory curvature influences. The pressure gradients are also not small, with maximum $\beta\left(\frac{\delta^*}{\tau w}\frac{dP}{dx}\right)$ values of order 10 → 15. If such influences were monatonically applied to the boundary layer, the effects would be ultimately catastrophic, either complete relaminarization or separation, depending upon the sign.

The mitigating influence which keeps the turbulent flow relatively well behaved is the oscillatory nature of these influences. The turbulence is kept in a highly nonequilibrium state; as soon as the flow begins to adjust to the local gradients the spatially periodic surface condition alters them. In fact, this nonequilibrium effect may not allow the usual Görtler vortices to form in the concave region, and delayed formation of these vortices (made probable by small λ) may be necessary for wavy walls to reduce average skin friction. If the vortices formed they would probably continue on into the area where partial relaminarization could occur and perhaps seriously disrupt the relaminarization process.

Reference 2 documents a calculation technique developed for wave-shaped walls of small wave length with first order nonequilibrium effects included via rate equations for the wall damping, wall layer and curvature modeling "constants". The method was developed and calibrated to reproduce wall shear (fig.3) and velocity profiles measured in small λ wavy wall experiments. Note that the average skin friction for figure 2 is approximately 20 percent lower than for a flat plate. This apparent reduction in average surface skin friction is not yet a net drag reduction, as the oscillatory (nonequilibrium) δ^* variation over the wall causes a phase shift in the pressure field induced by the wavy surface and therefore a form or pressure drag occurs which is larger than the C_f reduction. The calculation procedure just discussed can predict this oscillatory δ^* variation and the current Langley Research Center research is aimed at testing models of "skewed" wavy walls where the surface wave is "corrected" for this oscillatory δ^*. On paper, such optimized surfaces can produce a reasonable (10 → 20 percent) net drag reduction; even when the small additional surface area associated with the wave is included.

Large Eddy Breakup Devices

The original research on this concept is documented in reference 3. The initial basic approach was to insert across the boundary layer (but not across the entire flow) a screen or other device to break up the outer eddies (fig. 4). The usual relaxation distance for the outer flow is 60 to 100 δ, and in this region the outer eddies convalesce, heal and grow back to their usual scale. During this healing or relaxation process the outer-to-wall communication might be disrupted, resulting in less bursts and a lower C_f. The screen experiments of reference 3 show a large C_f reduction (up to 50 percent) with a monatonic relaxation to the "undisturbed level" in the order of 50 → 100 δ. The device (screen) drag in reference 3 is probably larger than the area integrated C_f reduction and therefore further research is required to determine whether the device drag can be reduced below the C_f reduction so a net drag reduction can be obtained.

As shown on figure 4, in unpublished tests at Langley by J. N. Hefner, we have used honeycombs rather than screens. These honeycombs have approximately an order of magnitude less drag than the screen of reference 3. Preliminary direct drag (balance) measurements indicate C_f reductions the order of those observed in reference 3 (0 - 50 percent), but the device drag is still larger (by a factor of 2 to 3) than the skin friction reduction. The current Langley Research Center research in this area attempts to determine whether a device such as shown on the right of figure 4 (having a smaller number of horizontal and vertical elements) can also produce large C_f reductions downstream. If so, a net drag reduction may be obtainable. The basic question of what effect various device geometries have upon suppressing the outer structures in turbulent boundary layers is essentially an entirely new line of inquiry. Most previous work focused upon the opposite problem of using "vortex generators" or roughness to excite the turbulent boundary and keep the flow attached in adverse pressure gradient regions, or for enhanced heat transfer. Estimates based upon the form drag of four horizontal elements with an aspect ratio of 10 indicate a net drag reduction of 10 to 20 percent, if such a device produces large C_f reductions. The research on "large eddy breakup devices " is obviously in an early stage.

Small Longitudinal Surface Striations

The basic concept is described in reference 4. Early work by Eckert and Irvine (ref. 6) indicate that the apex region of isosoles triangle ducts (with small apex angle) could have laminar flow locally, although the major portion of the duct flow was turbulent. An obvious possible origin for this behavior is the local dimunition in transverse scale associated with the apex region, i.e., locally the flow is highly viscous. With this experience in mind, and considering the wall scales associated with the bursting process, several walls were machined with triangular (and rectangular) shaped "riblets" having dimensions Δy^{+}, $\Delta z^{+} \sim 0(50)$. These longitudinal striations are considerably smaller than any used in previous research.

Direct drag measurements indicate small drag increases (5 → 10 percent) when compared to a flat or smooth surface of the same planform. However, the actual surface (wetted) area associated with the riblets was as much as 300 percent greater than the smooth surface. Therefore, on a wetted area basis the drag was reduced considerably (but not on a planform basis, which is the only important consideration for aircraft drag reduction). Work is continuing to determine if a net drag reduction can be achieved. It should be noted that because the striations are longitudinal, there is no local pressure of form drag associated with such surfaces.

Having evidently altered the wetted surface average C_f considerably, we next checked the heat transfer behavior of these riblets. Results shown on figure 5 indicate a sizable increase in Reynolds analogy factor compared to the flat plate case. This observation may be of considerable interest for heat exchanger applications, as these small riblets evidently increase heat transfer more than they increase pumping power for non-pressure gradient (external type) surfaces. Most devices which increase heating do so at the expense of much greater pumping power compared to the heat transfer increase.

CONCLUDING REMARKS

This progress report is on a portion of the fuselage viscous drag reduction research at NASA Langley Research Center. Paper discusses three areas: oscillatory longitudinal curvature, large eddy breakup devices, and small longitudinal surface striations. The first two concepts produce sizable local turbulent skin friction reductions, but farther research is required to optimize the effect, reduce parasitic device drag and thus provide a net increase in vehicle performance. The surface striations, due to large wetter areas increases for a given planform, have not yet yielded a planform-averaged skin friction reduction. However, heat-transfer data indicate such surfaces may have useful application in heat exchangers.

REFERENCES

1. Hefner, J. N.; and Bushnell, D. M.: An Overview of Concepts for Aircraft Drag Reduction. AGARD R-654 "Concepts for Drag Reduction," 1977.

2. Balasubramanian, R.; Cary, A. M., Jr.; Bushnell, D. M.; and Ash, R. L.: Influence of Transverse Surface Waves on Turbulent Boundary Layers. Presented at 5th Biennial Symposium on Turbulence at University of Missouri, Rolla, Oct. 1977.

3. Yajnik, K. S.; and Acharya, M.: Non-Equilibrium Effects in a Turbulent Boundary Layer due to the Destruction of Large Eddies. Symposium on Turbulence at Technische Universitat Berlin, Aug. 1977.

4. Walsh, M. J.; and Weinstein: Drag and Heat Transfer on Surfaces with Small Longitudinal Fins. AIAA 11th Fluid and Plasma Dynamics Conference, Seattle, Washington, July 10-12, 1978.

5. Bradshaw, P.: Effects of Streamline Curvature on Turbulent Flow. AGARDograph 169, 1973.

6. Eckert, E. R. G.; and Irvine, T. F., Jr.: Flow in Corners of Passages with Non-Circular Cross Sections. Transactions of the ASME, May 1956, pp. 709-718.

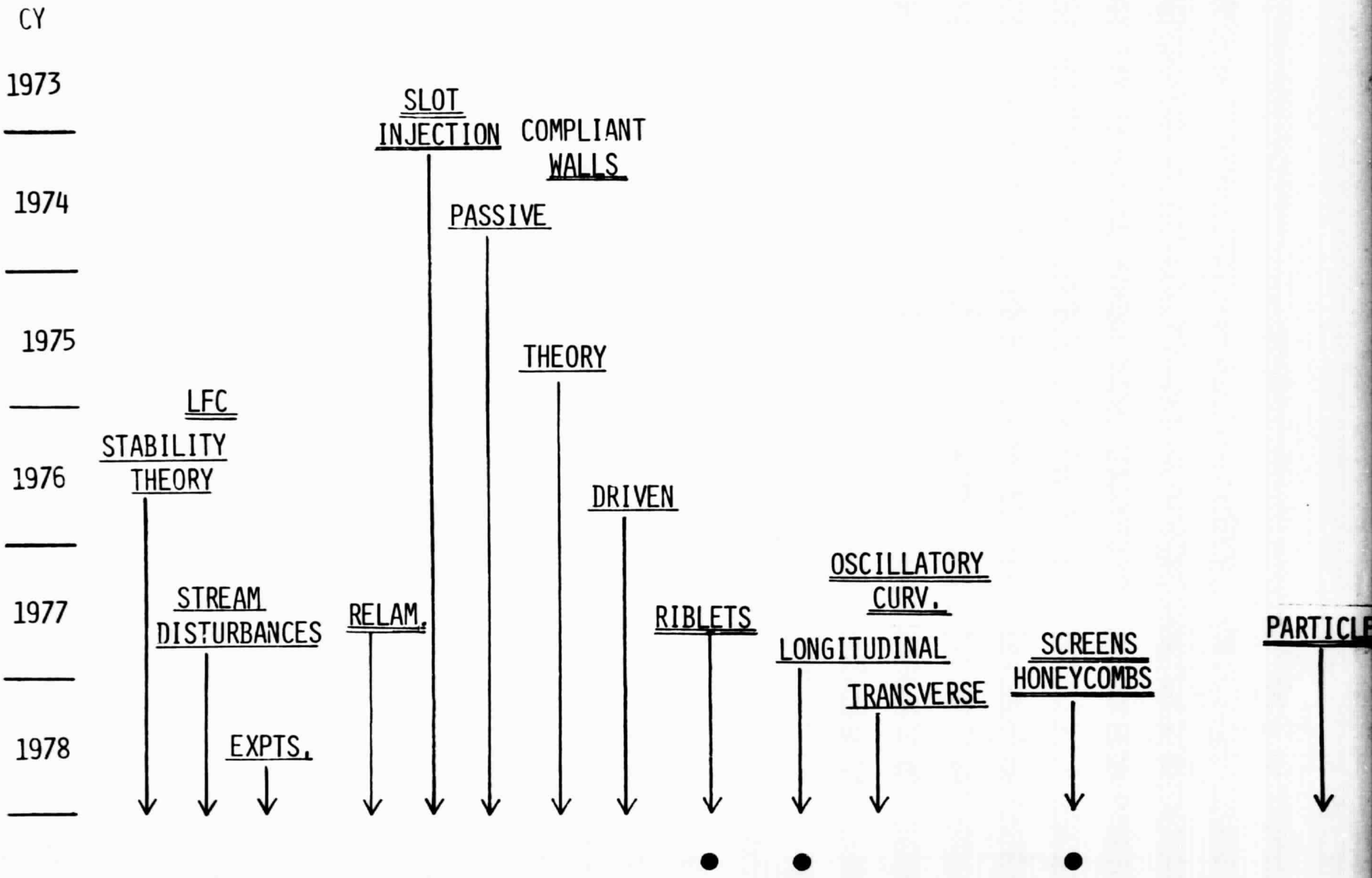


FIGURE 1.- LANGLEY DRAG REDUCTION CHRONOLOGY

OBVIOUS POSSIBILITIES

OSCILLATORY CURVATURE, SCREENS
- o REDUCE SEVERITY (AMPLITUDE, TIME SCALE) OF OUTER TO INNER COMMUNICATION BY FRAGMENTATION OF OUTER STRUCTURES

"RIBLETS"
- o INCREASE STABILITY OF WALL FLOW

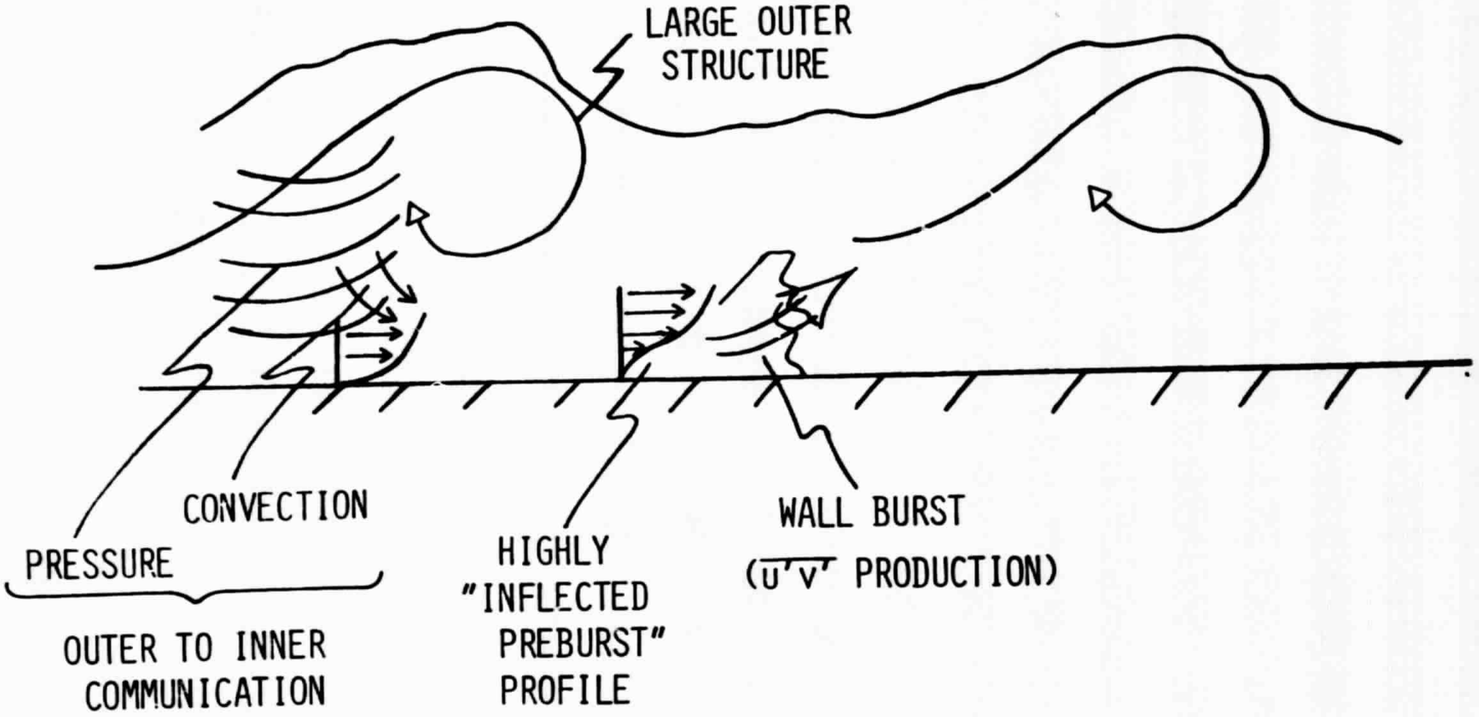


FIGURE 2.- DRAG REDUCTION THROUGH INTERFERENCE WITH TURBULENCE PRODUCTION/FEEDBACK LOOP

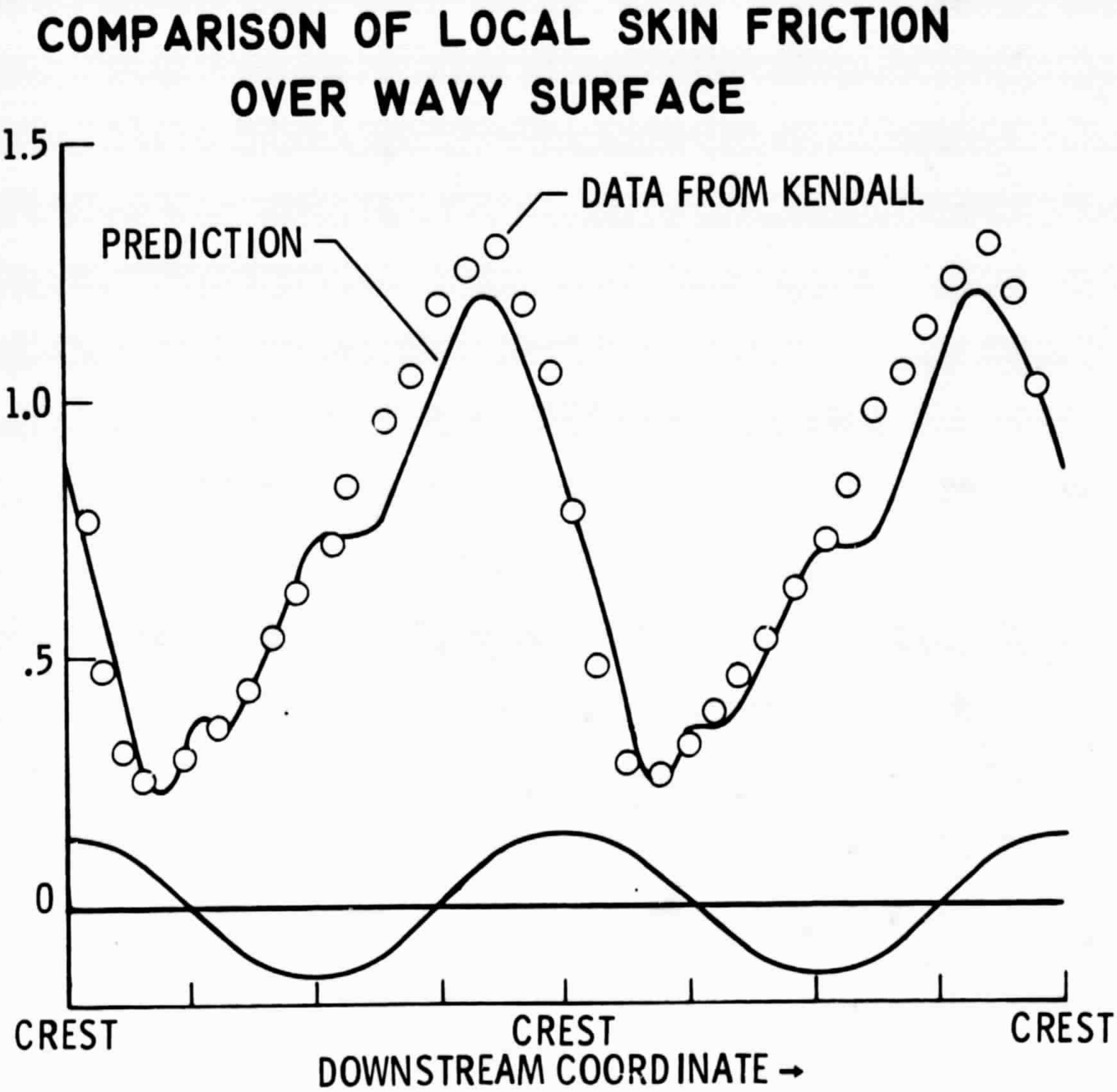
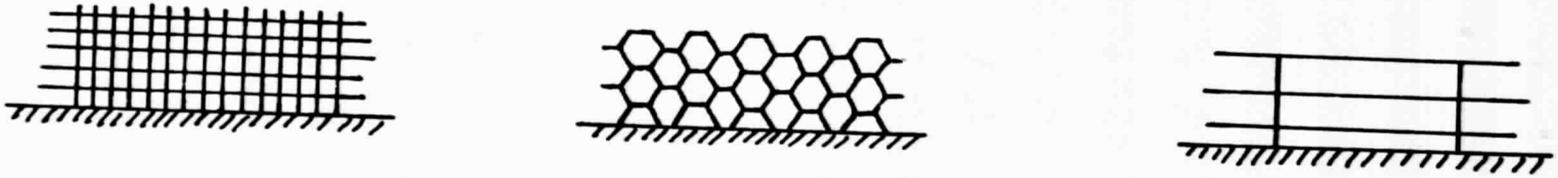


FIGURE 3.- COMPARISON OF LOCAL SKIN FRICTION OVER WAVY SURFACE

HONEYCOMBS/SCREENS FOR TURBULENT VISCOUS DRAG REDUCTION

OBJECTIVE: DEVELOP A TURBULENCE "BREAK-UP" DEVICE WITH A MINIMUM NUMBER OF LOW DRAG VERTICAL/HORIZONTAL MEMBERS SUCH THAT THE DEVICE DRAG PLUS SKIN FRICTION REDUCTION DOWNSTREAM PRODUCES A NET REDUCTION IN VEHICLE DRAG



SCREENS
$C_D \sim O(1)$
(YAJNIK)

HONEYCOMBS
$C_D \sim O(.1)$
(CURRENT LARC)

OPTIMIZED BREAK-UP DEVICE
(PRESENT CONFIGURATION SUGGESTED BY NAGIB)

FIGURE 4.- HONEYCOMBS/SCREENS FOR TURBULENT VISCOUS DRAG REDUCTION

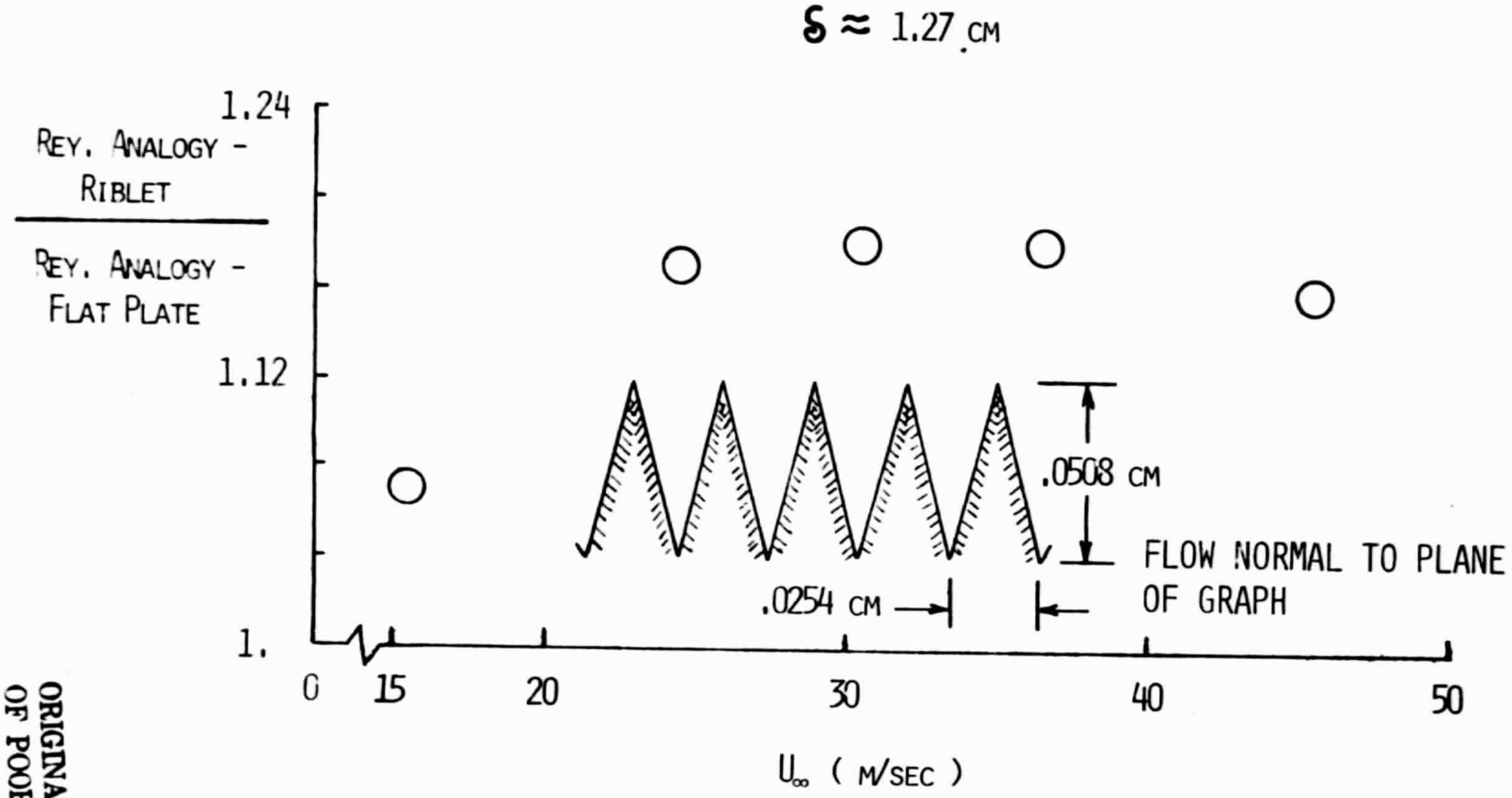


FIGURE 5.- INFLUENCE OF "RIBLETS" ON HEAT TRANSFER

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15. Supplementary Notes

16. Abstract

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