necessary in the final section of Ref 2 Incidentally, theoretical models for LP of some substances should differ considerably from either of those discussed in this note The evaporation process might not be confined to a layer several molecules thick, which is implicit in the models considered Also, the pyrolysis might even be time-dependent, as exemplified by the chuffing pyrolysis of ammonium perchlorate discussed by Andersen It is hoped that the present note will aid future LP workers in properly matching experimental conditions and theoretical models

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Comment on "Effects of Controlled Roughness on Boundary-Layer Transition at a Mach Number of 6 0"

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Nomenclature

- k = height of roughness element
- Re_{t0} = Reynolds number of transition with no roughness applied
- R_k = value of Reynolds number sufficient to cause $x_t \approx x_k$, based on k and computed flow conditions at height of roughness element in undisturbed laminar boundary layer
- T_w = wall temperature
- T_{aw} = adiabatic (insulated) wall temperature
- x_t = station of transition
- x_k = station where roughness is located
- δ = boundary layer thickness at location where roughness is applied, computed for undisturbed laminar flow
- ω = exponent in relation between viscosity and temperature

SUBJECT note[1] reports additional evidence that neither k/δ nor R_k are adequate parameters for assessing the influence of surface roughness on transition of boundary layers Conclusive demonstrations of this result have been published previously [2–4] The conclusion in Ref 1 relative to influence of increasing Mach number on values of k/δ required to effect transition with constant T_w/T_{aw} also supports earlier published work [2 4]

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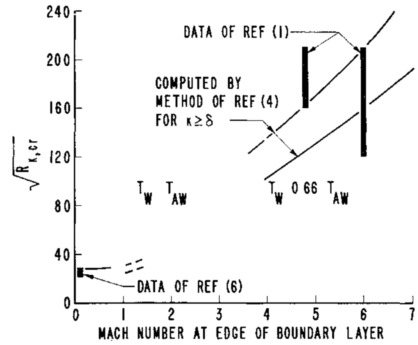

Fig 1 Effective roughness required to cause transition at the roughness

The purpose of this comment is to direct attention to relevant earlier work, possibly overlooked by the authors of Ref 1 Using the method proposed in Ref 4, both the influence of Mach number and wall temperature are predicted in relatively good agreement with published experimental data, considering that significantly varying test conditions are represented in the experiments compared

Because of the inconsistency in values of Re_{t0} given in Figs 1 and 2 of Ref 1, no attempt is made to estimate x_t when $x_t > x_k$ by the method of Ref 4, which requires knowledge of Re_{t0} for that purpose If, as implied in Ref 1, entire leading-edge sections were interchanged and all were supposed to have nominal thicknesses of 0 002 in, at least a partial explanation of the apparent inconsistency may be suggested For example, if a dimensional tolerance of $\pm 0\ 0005$ in is assumed, on the order of $\pm 10\%$ variation in Re_{t0} is estimated from Refs 2 or 4

The conditions necessary for three-dimensional roughness elements to cause transition from laminar to turbulent flow near the roughness have been calculated according to Ref 4, thereby yielding $(R_k\ )^{1/2}$ as used in Ref 1 (The result is dependent on ω, and $\omega = 0\ 88$ has been selected in view of the temperatures of concern in Ref 1) In accord with the conditions of Ref 1, $k \geq \delta$ has been assumed This often is the situation at higher Mach numbers but is not generally the case at lower Mach numbers (The possible side effects of using such large roughness are apparent) Thus, the computed curves in Fig 1 are shown as broken lines in the region of lower supersonic Mach numbers The method of Ref 4 permits estimates for $k < \delta$ as well, but present purposes are served by the examples shown here

Figure 1 shows that the rapid increase with Mach number of relative roughness size required to establish transition at or near the roughness has been predicted A large amount of data confirming the computed curves to the extent reasonable to expect for transition data may be found in Refs 2 and 4 The data of Ref 5 (Ref 2 in Ref 1, Fig 3) are not shown in Fig 1 because it is the present authors' understanding that they refer to the roughness just adequate to initiate movement of transition, rather than the roughness needed to move transition forward to very near the location of roughness To confirm the subsonic portion of Fig 1, the experimental data of Ref 6 are shown When Mach number approaches zero, the curves representing Ref 4 are not affected by k/δ

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Reply by Authors to J L Potter and J D Whitfield

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Nomenclature

k = vertical height of roughness above plate, ft
$\dot{q}$ = heat flow rate along the centerline of the model
R_0 = freestream unit Reynolds number per ft
R_k = Reynolds number based on fluid conditions at top of the roughness elements and the height of the roughness
R_k = roughness Reynolds number for which a further increase in roughness height causes no appreciable forward movement of the beginning of fully developed turbulent flow
x = distance from the leading edge
x_k = distance from the leading edge to the roughness position

THE salient points mentioned in the preceding comments were not discussed in Ref 1 because of a desire to make that manuscript as brief as possible However, these matters (including references of the preceding comment) are discussed in a more detailed report,[2] which was under preparation at the time the original manuscript was submitted The authors certainly feel that any full length paper on transition should include a reference to the work of Potter and Whitfield

The discrepancy between the Reynolds numbers for natural transition in Figs 1 and 2 of Ref 1 is thought to result not only from small variations in the leading-edge thickness, but also from a small angle-of-attack variation between the two assemblies However, the angle of attack for each series of roughness tests was invariant The interchangeable leading-edge section method of varying the roughness elements has some inherent disadvantages since leading-edge thickness is a factor in determining the location of transition However, this method was chosen as a practical means of reducing the required time for a model change

Since this early work indicated that small roughness heights may delay transition, further research on this phenomenon is being conducted (This work has been further stimulated by the comments of Potter and Whitfield) Some new data now available have indicated that whereas some of the variation in the location of transition reported in Ref 1 was due to variation of the leading-edge thickness, under certain conditions transition is apparently slightly delayed when the surface roughness is less than the boundary layer thickness Figure 1 presents the heat flow rate distribution for the model with various height roughness elements at a unit Reynolds number of approximately 8×10^6/ft and a Mach number of 6 Test conditions are similar to those given in Ref 1 A schematic of the model shown in the figure illustrates the new

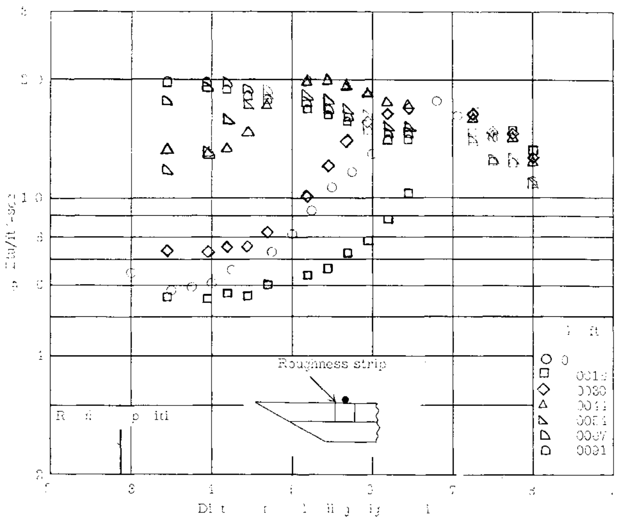

Fig 1 Heating rate distribution along flat plate with various size roughness, $R_0 = 8\ 3 \times 10^6$

mounting technique with the same leading edge (thickness diameter of 0 0025 in) being used for all tests and the small roughness strips being interchangeable This figure illustrates both the delay in transition obtained with the smallest roughness elements and the critical roughness height required for these freestream conditions (critical height is taken as 0 0091 in the figure) Figure 2 shows the variation of the critical roughness Reynolds number with freestream unit Reynolds number Included in this figure are the data from Fig 3 of Ref 1 and new data taken with one leading edge with roughness elements mounted on an interchangeable strip Although the new and old data do not coincide, which may be due in part to a different location (x_k) of the roughness elements, these data do not change the conclusions given in Ref 1 A study of the effect of small roughness heights on transition is being continued

The definition and determination of the critical roughness Reynolds number varies considerably in the literature Difficulties arising from this were recognized, and as a result the roughness data were also compared in Ref 2 to other transition roughness data detected by a method sensitive to permanent changes in the boundary layer This comparison did not change the conclusions given in Ref 1

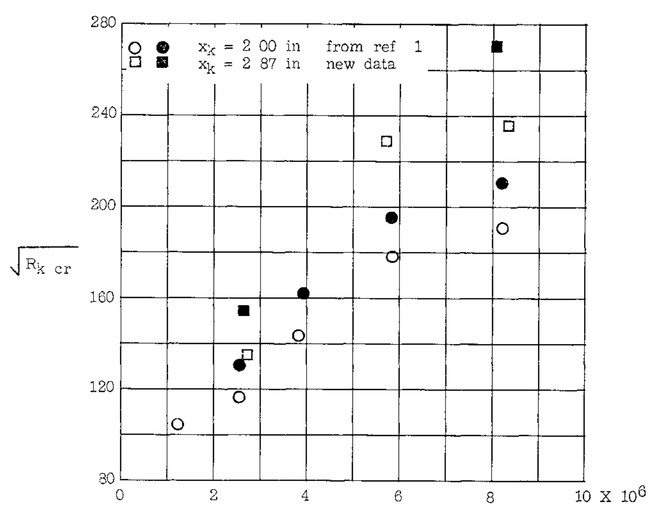

Fig 2 Variation of critical roughness Reynolds number with freestream Reynolds number Open symbols indicate that the roughness height is slightly less than the critical value, and solid symbols indicate that the roughness height is slightly greater than the critical value

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