Single- and Multiple-Crater Induced Nosetip Transition

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Nomenclature

k = crater depth
l = crater length
M = Mach number
$\dot{Q}$ = heat-transfer rate
R_N = nose radius
Re_∞/m = unit Reynolds number based on freestream conditions
Re_k = local Reynolds number based on crater depth
Re_θ = local Reynolds number based on momentum thickness
S = surface distance
T = temperature
T'/T_e = $1+0.9\,[(T_w/T_s)-1]+0.28[(T_r/T_e)-1]$
θ = momentum thickness
ξ = $(k/\theta)(T_e/T_w)[1+B(k/R_N)]^{-1}$

Subscripts

e = edge condition
r = recovery condition
s = stagnation condition
T = transition
w = wall condition
∞ = freestream condition

Abstract

EXPERIMENTS were conducted at a Mach number of 5 to assess the effect of simulated weather impact craters on nosetip boundary-layer transition. The program treated single craters and patterns of multiple elliptical craters of various depth, ellipticity, and azimuth angle. Test results confirm predictions that craters of the order of from 0.05 to 0.64 mm (2 to 25 mil) depth induce nosetip boundary-layer transition. Results obtained from backface thermocouple measurements show the influence of crater parameters on local transition Reynolds numbers. Re_k and Re_θ transition criteria for craters are compared to criteria for protuberance roughness.

Contents

Introduction

The experiments were designed to obtain ground test data needed to develop criteria for predicting nosetip boundary-layer transition due to weather impact craters. Single- and multiple-crater experiments were conducted to assess the effect of crater location, size, geometry, and number required to promote transition.[1,2]

The tests were conducted in the Naval Surface Weapons Center Tunnel 8 Facility at a freestream Mach number of 5 and a freestream Reynolds number range of 0.328 to 9.84×10^7/m (1.0 to 30×10^6/ft). The nominal wall-to-stagnation temperature ratio was 0.3. The test models were spherical nosetips with nose radii of 63.5 and 25.4 mm (2.5 and 1.0 in.). Transition was indicated from heat-transfer data obtained with backface thermocouples. Criteria for determining nosetip boundary-layer transition due to weather impact craters were developed.[1,2]

Details of the test conduct, including test conditions, model geometries, instrumentation, and test procedures are given in Ref. 1. The crater size and geometry simulation rationale is treated in Ref. 2.

Results

Heat flux distributions downstream of the craters were categorized as either laminar, transitional/relaminarized (defined as the condition corresponding to onset of crater-induced transition), transitional, or fully turbulent. Analysis was performed using a nonsimilar laminar boundary-layer code to evaluate boundary-layer variables where the various craters induced transition.[2] Several formats used in correlating boundary-layer tripping data behind protuberance roughness were assessed for correlating the present crater transition data.[1,2] It should also be noted that heating augmentation was typically observed just downstream of the craters regardless of whether the boundary layer was tripped or not. Figure 1 presents a representative transition/relaminarized heating distribution on a meridian having three craters in-line at the 10-, 20-, and 40-deg azimuth locations. Apparently the third crater, i.e., the crater at the 40-deg azimuth location, was primarily responsible for tripping the boundary layer even though some heating augmentation is indicated by the upstream thermocouples.

To correlate the crater data, the Van Driest formulation[3] was examined. A linear least-squares fit of the single- and two- and three-crater data was used to obtain values of B and C, as defined in Fig. 2, which presents the data in this modified Van Driest format. The data are correlated with B and C equal to 1050 and 460, respectively. The constant multiplier B, is about a factor of 1.75 larger than that obtained by Van Driest for protuberance-type roughness. All the single-crater, particle, and two- and three-crater data are correlated with a constant $C=460$, but the distributed crater "patches" yield values of C about a factor of 2 lower with $B=1050$.

Figure 3 presents the data in momentum Reynolds number coordinates. The disturbance parameter has been modified to include longitudinal curvature using $B=1050$ (determined previously in the least-squares fit). In these coordinates, all the single-crater, particle, and two- and three-crater data are well correlated with a slope of -1 for "simulated" cases where crater ellipticity is increasing with azimuth (i.e., the crater tripping effectiveness is increasing). However, if constant ellipticity data are used, larger Re_θ's exhibiting steeper decay slopes on the order of -1.5 to -2 are obtained. Thus there exists a family of Re_θ vs ξ correlations, having crater ellipticity as an additional parameter.

Summary

The most significant results of these experiments follow:

1) Small craters ($8\times10^{-4}<k/R_N<2.5\times10^{-2}$) induce nosetip boundary-layer transition. Transition Re_k's, for a single spherical protuberance and a single crater having the same value of k, located at the same azimuth angle, show good agreement.

Presented as Paper 81-1087 at the AIAA 16th Thermophysics Conference, Palo Alto, Calif., June 23-25, 1981; submitted June 22, 1982; synoptic received Oct. 15, 1982. Full paper available from AIAA Library, 555 W. 57th St., New York, N.Y. 10019. Price: Microfiche, $4.00; hard copy, $8.00. **Remittance must accompany order.**

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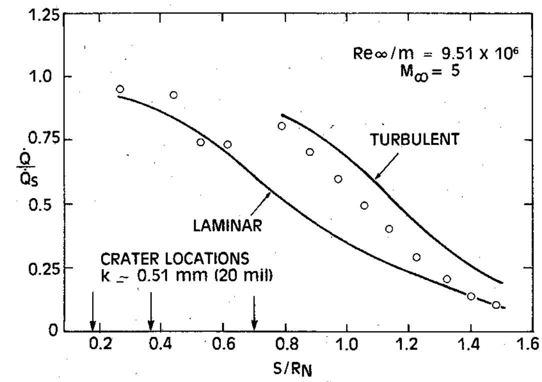

Fig. 1 Normalized heat flux distribution—transition/relaminarized.

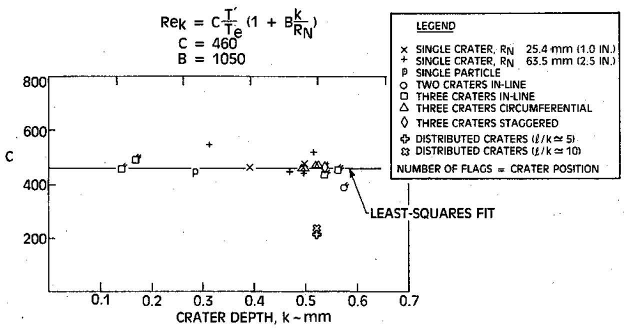

Fig. 2 Modified Van Driest constant—transition/relaminarized.

2) For craters with *fixed* ellipticity and depth, an order of magnitude increase in transition Re_k is produced when the crater azimuthal location varies from 5 to 60 deg.

3) For fixed crater depth, transition Re_k's decrease as crater ellipticity increases.

4) Multiple craters are not more effective than single craters for crater spacings as small as from 5 to 10 deg in azimuth angle. Patches of craters are about twice as effective as single craters in promoting transition.

5) The experiments verified the longitudinal curvature effect on roughness induced nosetip transition. This effect is three times larger for craters than for protuberances.

6) In momentum Reynolds number coordinates, a -1 slope correlates the data for the particular crater ellipticity variations with azimuth that was used. A steeper slope pertains for fixed crater ellipticity.

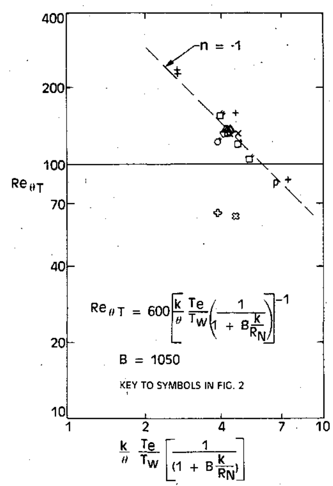

Fig. 3 Transition/relaminarized Reynolds number.

7) For virtually all the flows in which transition was first observed behind craters, the boundary layer subsequently relaminarized in the shoulder region. Correlations were also developed for conditions where the boundary layer remains transitional over the shoulder.[1,2]

Acknowledgments

This work was performed under Air Force Contract F04701-78-C-0144; Major Sikra, Project Officer, Advanced Ballistic Reentry Systems. The authors acknowledge the contributions of Gary Newman, Frank Baltakis, and the Naval Surface Weapons Center test crew.

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[2] Todisco, A., Reeves, B., Siegelman, D., and Mascola, R., "Boundary Layer Transition on Blunt Axisymmetric Nosetips Induced by Single and Multiple Craters," BMO-TR-81,79, AVCO Systems Division, Wilmington, Mass., July 1981.

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