# HEAT TRANSFER MEASUREMENTS AT MACH 8 ON AN AERODYNAMICALLY CONTROLLABLE WINGED RE-ENTRY CONFIGURATION

# PART OF AN INVESTIGATION OF HYPERSONIC FLOW SEPARATION AND CONTROL CHARACTERISTICS

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#### FOREWORD

This report presents the results of one segment of an experimental program for the investigation of hypersonic flow separation and control characteristics being conducted by the Research Department of Grumman Aircraft Engineering Corporation, Bethpage, N. Y. Mr. Donald E. Hoak of the Flight Dynamics Laboratory, Research and Technology Division, located at Wright-Patterson Air Force Base, Ohio, is the Air Force Project Engineer for the program, which is being supported primarily under Contract AF 33(616)-8130, Air Force Task 821902.

The experimental data obtained (pressure distributions, aerodynamic heating rates, and six-component force data) are extensive and must be presented in a series of data reports, of which this is one. These data reports are presented without analysis for the purpose of disseminating all the experimental information as rapidly as possible.

The author wishes to express his appreciation to the staff of the von Karman Facility, ARO Inc., for their helpfulness in conducting the tests and particularly to Messrs. Burchfield and Deitering for providing the machine plotted graphs of the experimental data included in this report. The tabulated data, not included herein, are available to qualified Air Force requestors as an Appendix to this report. These Appendices can be obtained on loan from the Flight Dynamics Laboratory (Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio).

#### ABSTRACT

Heat transfer data were obtained at Mach 3 for a winged re-entry configuration with several types of aerodynamic controls. The basic model consisted of a clipped delta wing with an overslung cone-cylinder body. Most of the tests were conducted with partial span trailing edge flaps. The effects of tip fins, a hemisphere-cylinder body, a full span trailing edge flap, and a full span, plug-type, trailing edge spoiler were also investigated. The partial span flap deflection were varied between  $\pm$  39 degrees in an angle of attack range of  $\pm$  20 degrees. Selected configurations were used to examine the angle of attack ranges of -30 degrees to -50 degrees and  $\pm$  30 degrees to  $\pm$  50 degrees. The major portion of the program was conducted at a unit test section Reynolds number of 3.3 x 10<sup>6</sup>/ft with limited comparative testing being done at a unit test section Reynolds number of 1.1 x 10<sup>6</sup>/ft.

This report has been reviewed and is approved.

C. L. Bryan

W. A. SLOAF, Jr. Colonel, USAF Chief, Flight Control Division AF Flight Dynamics Laboratory

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k)	Nu/ <del>/Rex</del> vs.Y'	8 <sub>2</sub> = 8 <sub>3</sub> = 0	upper surface 94
1)	Nu/ <del>/Re</del> vs. Y'	$b_2 = b_3 = +10$	upper surface
m)	Nu//Rex vs. Y'	$b_2 = b_3 = +20$	upper surface
n)	Nu//Rex vs. Y'	$b_2 = b_3 = +30$	upper surface
0)	Nu//Rex vs. Y'	0 <sub>2</sub> = 0 <sub>3</sub> = +39	upper surface
P)	Nu/ <del>/Re<sub>x</sub> vs.</del> X'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = 0	upper surface 95
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r)	Nu//Rex vs. X'	8 <sub>2</sub> = 8 <sub>3</sub> = +20	upper surface
3)	Nu//Rex vs. X'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +30	upper surface
t)	Nu//Rax vs. X'	<sup>8</sup> <sub>2</sub> = <sup>8</sup> <sub>3</sub> = +39	upper surface
Configur	ation I, $\alpha = +20$		
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g)	Nu//Rex vs. Y'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = -39	lower surface 99
h)	Nu//Rex vs. X'		lower surface
1)	Nu//Rex vs. Y'	<sup>8</sup> 2 = <sup>8</sup> 3 ≈ -10	upper surface 100
52	Nu/ Re vs. Y'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = -20	upper surface
k)	Nu//Kex vs. X'	$5_2 = 5_3 = -10$	upper surface
1)	Nu//Rex vs. X'	<sup>6</sup> 2 = <sup>6</sup> 3 = -20	upper surface
m)	Nu/VKex vs. Y'	<sup>8</sup> <sub>2</sub> = <sup>8</sup> <sub>3</sub> = -30	upper surface 101
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h)	Nu//Rex vs. X'		lower surface 112

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Configuration I,  $b_2 = b_3 = 0$  (Cont'd) i) Nu//Re vs. Y' a = +50 lower surface..... 113 j) Nu//Rev vs. X' lower surface..... 114 k) Nu/<del>/Re,</del> vs. Y'  $\alpha = +30$ upper surface..... 115 1) Nu/ Re vs. Y' α = +35 upper surface m) Nu//Re vs. Y' a = +49 upper surface n) Nu/<sub>V</sub>Rev vs. Y'  $\alpha = +45$ upper surface o) Nu//Re vs. Y'  $\alpha = +50$ upper surface p) Nu/VRay vs. X'  $\alpha = +30$ upper surface ..... 116 q) Nu/ Re vs. X' α = +35 upper surface r) Nu/VRe vs. X'  $\alpha = +40$ upper surface s) Nu/<sub>V</sub>/Re<sub>x</sub> vs. X<sup>1</sup> a = +45 upper surface t) Nu/(/Re\_ vs. X' α = +50 upper surface Configuration I,  $\alpha = -10$ a) Nu/(/Re, vs. Y' 8<sub>2</sub> = 8<sub>3</sub> = 0 lower surface ..... 117 b) Nu//Re vs. X' lower surface c) Nu//Re vs. Y' upper surface ..... 118 d) Nu//Re vs. X' upper surface ..... 119 e) Nu//Re\_ vs. Y'  $b_2 = b_3 = +10$ lower surface ..... 120 f) Nu/VRe vs. X' lower surface g) Nu//Re\_ vs. Y' upper surface ..... 121 h) Nu/vRe vs. X' upper surface ..... 122 1) Nu//Rev vs. Y' 52 = 53 = +20 lower surface ..... 123 j) Nu/VRe vs. X' lower surface ..... 124 k) Nu/ Re vs. Y' upper surface ..... 125 1) Nu/(/Re, vs. X' upper surface ..... 126 m) Nu/ Re vs. Y' 5<sub>2</sub> = 5<sub>3</sub> = +30 lower surface ..... 127 n) Nu/VRev vs. X' lower surface ..... 128 o) Nu/ Re vs. Y' upper surface ..... 129 p) Nu/ Rex vs. X' upper surface ..... 130

q)  $Nu/\sqrt{Re_x} vs. Y'$ r)  $Nu/\sqrt{Re_x} vs. X'$ s)  $Nu/\sqrt{Re_x} vs. Y'$ t)  $Nu/\sqrt{Re_x} vs. X'$ 

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Configuration I, $\alpha = -10$		
a) Nu/Rex vs. Y'	$b_2 = b_3 = -10$	lower surface 135
b) Nu/ <del>Rex</del> vs.Y'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = -20	lower surface
c) Nu/ <sub>/</sub> /Re <sub>x</sub> vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = -30	lower surface

lower surface ..... 131

lower surface ..... 132

upper surface ..... 133

upper surface ..... 134

5<sub>2</sub> = 5<sub>3</sub> = +39

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Configuration I,  $\alpha = -10$  (Cont'd)

	, , , , , , , , , , , , , , , , , , , ,		
d)	Nu//Rex vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = -39	lower surface 135
e)	Nu//Rex vs. X'	$b_2 = b_3 = -10$	lower surface 136
f)	Nu/ <del>/Rex</del> vs.X'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = -20	lower surface
g)	Nu//Rex vs. X'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = -30	lower surface
h)	Nu//Rex vs. X'	<sup>5</sup> 2 <b>*</b> <sup>5</sup> 3 <b>=</b> -39	lower surface
1)	Nu//Rex vs. Y'	$b_2 = b_3 = -10$	upper surface 137
j)	Nu//Rex vs. X'		upper surface 138
k)	Nu//Rex vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = -20	upper surface 139
1)	Nu//Rex vs. X'		upper surface 140
m)	Nu//Rex vs. Y'	$b_2 = b_3 = -30$	upper surface 141
n)	Nu//Rex vs. X'		upper surface
0)	Nu//Rex vs. Y'	<sup>6</sup> <sub>2</sub> = <sup>6</sup> <sub>3</sub> = -39	upper surfsce 142
(q	Nu//Rex vs. X'		upper surface
Configur	ation I, $\alpha = -20$	<b>.</b>	t a constante a
a)	Nu//Rex vs. Y'	5 <sub>2</sub> - 5 <sub>3</sub> = 0	lower surface
b)	Nu//Rex vs. Y'	<sup>6</sup> 2 • <sup>6</sup> 3 = +10	lower surface
c)	Nu//Rex vs. Y'	<sup>6</sup> <sub>2</sub> = <sup>6</sup> <sub>3</sub> = +20	lower surface
d)	Nu//Rex vs. X'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = 0	lower surface 144
e)	Nu// <del>Re</del> vs. X'	<sup>5</sup> 2 <sup>• 5</sup> 3 <sup>•</sup> +10	lower surface
f)	Nu// <del>Re</del> x vs. X'	8 <sub>2</sub> = 8 <sub>3</sub> = +20	lower surface
g)	Nu/ <del>/Rex</del> vs.Y'	8 <sub>2</sub> = 8 <sub>3</sub> = 0	upper surface 145
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1)	Nu/ <del>/Rex</del> vs, Y'	$b_2 = b_3 = +10$	upper surface 147
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m)	Nu//Rex vs. Y'	$5_2 = 5_3 = +30$	lower surface 151
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0)	Nu//Re vs. Y'		upper surface 153
p)	Nu// <del>Re</del> x vs. X'		upper surface 154
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b)	Nu//Rex vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = -20	lower surface

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Configuration I, $\alpha = -20$ (	(Cont'd)	
c) Nu//Rex vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = -30	lower surface
d) Nu/ <sub>V</sub> Rex vs. Y'	$\delta_2 = \delta_3 = -39$	lower surface
e) Nu/ <del>/Rex</del> vs.X'	$b_2 = 5_3 = -10$	lower surface
f) Nu/ <del>/Rex</del> vs.X'	$b_2 = b_3 = -20$	lower surface
g) Nu/ <del>/Re<sub>x</sub> vs. X'</del>	$\delta_2 = \delta_3 = -30$	lower surface
h) Nu/ <del>/Rex</del> vs.X'	5 <sub>2</sub> = 5 <sub>3</sub> = -39	lower surface
i) Nu/VRev vs. Y'	$5_2 = 5_2 = -10$	UDDer surface
j) Nu/ <del>/Re_</del> vs, X'	2 3	upper surface
k) Nu/√ <u>Re</u> vs,Y'	$5_{0} = 5_{0} = -20^{2}$	upper surface 162
1) $Nu/\sqrt{Re_{u}}$ vs. X'	<b>3 3 4 1</b>	upper surface 163
m) Nu//Re vs. Y'	5. <b>F</b> 5. <b>F</b> -30	upper Burrace
n) Nu $\sqrt{Re}$ vs. X <sup>1</sup>	° <sub>2</sub> ° ° <sub>3</sub> – °50	upper surrace 164
$\frac{1}{2} \frac{1}{2} \frac{1}$	• - • ••	upper surface
$\frac{1}{2} \frac{1}{2} \frac{1}$	$6_2 = 6_3 = -39$	upper surface 165
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e) Nu/ <del>/Re</del> vs.X'	$\alpha = -40$	lower surface
f) Nu//Rex vs. X'	a = • 50	lower surface
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k) Nu//Rex vs. Y'	α = -50	upper surface
1) Nu//Re_ vs. X'		UDDEr surface

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C

k) Nu//Rex vs. Y'

1) Nu//Rex vs. X'

m) Nu/

n) Nu//Rex vs. X'

o) Nu/VRex vs. Y'

p) Nu//Rex vs. X'

Configuration IV, $\alpha = 0$		
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f) $Nu/\sqrt{Re_x}$ vs. X <sup>1</sup>		lower surface
g) Nu//Rex vs. Y'		upper surface
h) Nu//Rex vs. X'		upper surface
1) Nu//Re vs. Y'	$\delta_2 = \delta_3 = +20$	lower surface
j) Nu//Rex vs. X'	. ,	lower surface
k) Nu/VRex vs. Y'		upper surface
1) Nu/VRex vs. X'		upper surface
m) Nu/VRex vs. Y'	$\delta_2 = \delta_3 = +30$	lower surface
n) Nu//Re vs. X'	<b>•</b> J	lower surface
o) Nu/VRe vs. Y'		upper surface
p) Nu//Re vs. X'		upper surface. 187
q) Nu//Re vs. Y'	5, = 5, = +39	lower surface
r) Nu//Re_ vs. X'	2 3	lower surface
s) Nu//Re vs. Y'		upper surface 190
t) Nu//Re_ vs. X'		upper surface
onfiguration IV, $\alpha = 0$		
a) Nu//Re vs. Y'	$\delta_{2} = \delta_{2} = -10$	lower surface
b) Nu//Re_ vs. Y'	$\delta_{2} = \delta_{2} = -20$	lower surface
c) Nu/ <del>/Re_</del> vs. Y'	$\delta_{2} = \delta_{2} = -30$	lower surface
d) Nu/VRe_vs.Y'	$z_{3}$	lower surface
e) Nu//Re_ vs. X'	$5_{2} = 5_{2} = -10$	lower surface
f) Nu/VRe vs. X'	$5_2 = 5_2 = -20$	lower surface
g) Nu/ <del>Re_</del> vs. X'	$5_2 = 5_2 = -30$	lower surface
h) Nu//Re vs. X'	$5_2 = 5_3 = -39$	lower surface
1) Nu//Re vs. Y'	5. <b>5 5 -</b> -10	Nower surface
1) Nu/ Re vs. X'	2 3 2 10	upper surface 193
x		upper surface 194

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upper surface..... 195

upper surface..... 196

upper surface..... 197

upper surface..... 198

upper surface..... 199

upper surface

<sup>5</sup><sub>2</sub> - <sup>5</sup><sub>3</sub> - -20

<sup>5</sup><sub>2</sub> = <sup>5</sup><sub>3</sub> = -30

<sup>5</sup><sub>2</sub> = <sup>5</sup><sub>3</sub> = -39

17 Configuration IV,  $\alpha = +10$ a) Nu//Re vs. Y' 52 - 53 - 0 lower surface..... 200 b) Nu//Re vs. X' lower surface..... 201 c) Nu//Re vs. Y' 52 = 53 = +10 lower surface..... 202 d) Nu/VRe vs. X' lower surface ..... 203 e) Nu//Re\_ vs. Y' 52 = 53 = +20 lower surface..... 204 f) Nu/<sub></sub>/Re\_ vs. X' lower surface ..... 205 g) Nu//Re\_ vs. Y' 52 = 53 = +30 lower surface ..... 206 h) Nu//Re\_ vs. X' lower surface 1) Nu/VRe vs. Y' 52 = 53 = +39 lower surface ..... 207 j) Nu//Ke vs. X' lower surface ..... 208 k) Nu//Re vs. Y' 52 = 53 = 0 upper surface ..... 209 1) Nu/Ne\_vs. X' upper surface m) Nu//Re\_ vs. Y'  $b_2 = b_3 = +10$ upper surface ..... 210 n) Nu/VRe vs. Y' 52 = 53 = +20 upper surface o) Nu//Re vs. Y' δ<sub>2</sub> = δ<sub>3</sub> = +30 upper surface p) Nu/VRe vs. Y' 52 = 53 = +39 upper surface q) Nu/ Re vs. X'  $5_2 = 5_3 = +10$ upper surface ..... 211 r) Nu/VRe vs. X' 5<sub>2</sub> = 5<sub>3</sub> = +20 upper surface s) Nu/ARe vs. X'  $b_2 = b_3 = +30$ upper surface t) Nu/VRe vs. X'  $b_2 = b_3 = +39$ upper surface 18 Configuration IV,  $\alpha = +10$ a) Nu//Re vs. Y' 52 = 53 = -10 lower surface ..... 212 b) Nu//Re vs. X' lower surface ..... 213 c) Nu//Re vs. Y' upper surface ..... 214 d) Nu/VRe vs. X' upper surface ..... 215 e) Nu//Re vs. Y' 52 = 53 = -20 lower surface ..... 216 f) Nu//Re\_ vs. X' lower surface g) Nu//Re\_ vs. Y' uppet surface ..... 217 h) Nu/\Re\_ vs. X' upper surface ..... 218 1) Nu//Re\_ vs. Y' 52 = 53 = -30 lower surface ..... 219 j) Nu/Ne vs. X' lower surface k) Nu//Re vs. Y' upper surface ..... 220 1) Nu//Re vs. X' upper surface ..... 221 m) Nu//Re vs. Y' 52 = 53 = -39 lower surface ..... 222 n) Nu/<del>/Re</del> vs. X' lower surface o) Nu/AR vs. Y' upper surface ..... 223 p) Nu/Ae vs. X' upper surface ..... 224

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19 Configuration IV,  $\alpha = +20$ 

a) Nu//Rex vs. Y'	5 <sub>2</sub> - 5 <sub>3</sub> - 0	lower surface 229
b) Nu//Rex vs. X'		lower surface 226
c) Nu//Rex vs. Y'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +10	lower surface 227
d) Nu//Rex vs. X'		lower surface 228
e) Nu//Rex vs. Y'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +20	lower surface 229
f) Nu//Kex vs. X'		lower surface
g) Nu//Rex vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = +30	lower surface 230
h) Nu//Rex vs. X'		lower surface 231
1) Nu//Rex vs. Y'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +39	lower surface 232
j) Nu//Rex vs. X'		lower surface 233
k) Nu//Rex vs. Y'	<sup>5</sup> <sub>2</sub> - <sup>5</sup> <sub>3</sub> - 0	upper surface 234
1) Nu//Rex va. Y'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +10	upper surface
m) Nu//Rex vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = +20	upper surface
n) Nu//Rex vs. X'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = 0	upper surface 235
o) Nu//Rex vs. X'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +10	upper surface
p) Nu//Rex vs. X'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +20	upper surface
q) Nu//Rex vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = +30	upper surface 236
r) Nu/ <del>/Re<sub>x</sub></del> vs. X'		upper surface
s) Nu/ <sub>v</sub> Re <sub>x</sub> vs. Y	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +39	upper surface 237
t) Nu/VRex vs. X'		upper surface
Configuration IV, $\alpha = +20$		
a) Nu/ <del>/Re</del> x vs. Y'	$b_2 = b_3 = -10$	lower surface, 238
b) Nu/ <del>Rex</del> vs. X'	•	lower surface 239
c) Nu/ <del>/Rex</del> vs. Y'		upper surface 240
d) Nu//Rex vs. X'		upper surface
e) Nu/ <sub>√</sub> Re <sub>x</sub> vs. Y'	<sup>5</sup> <sub>2</sub> - <sup>5</sup> <sub>3</sub> 20	lower surface 241
f) Nu/ <del>/Re<sub>x</sub></del> vs. X'		lower surface
g) Nu/ <del>/Re<sub>x</sub></del> vs.Y'		upper surface 242
h) Nu/ <del>/Re<sub>x</sub></del> vs. X'		upper surface
i) Nu/ <sub>v</sub> Re <sub>x</sub> vs. Y'	<sup>5</sup> <sub>2</sub> - <sup>5</sup> <sub>3</sub> 30	lower surface 243
j) Nu//Rex vs. X'		lower surface
k) Nu//Rex vs. Y'		upper surface 244
1) Nu/ <sub>v</sub> Re <sub>x</sub> vs. X'		upper surface 245
m) Nu//Rex vs. Y'	<sup>6</sup> <sub>2</sub> - <sup>6</sup> <sub>3</sub> 39	lower surface 246
n) Nu/VRex vs. X'		lower surface
o) Nu//Rex vs. Y'		upper surface 247
p) Nu//Rex vs. X'		upper surface 248

21 Configuration IV,  $\delta_2 = \delta_3 = 0$ a) Nu//Re\_ vs. Y'  $\alpha = +35$ lower surface..... 249 b) Nu//Re vs. X' lower surface..... 250 c) Nu/ Re vs. Y' a = +40lower surface..... 251 d) Nu//Re vs. X' lower surface..... 252 e) Nu//Re vs. Y' a = +35 upper surface..... 253 f) Nu//Re vs. Y' a = +40 upper surface g) Nu/ Re vs. X' a = +35 upper surface h) Nu//Re vs. X' a = +40 upper surface i) Nu/VRe vs. Y' a = +45 lower surface..... 254 j) Nu/ Re vs. X' lower surface..... 255 k) Nu//Re vs. Y' upper surface ..... 256 1) Nu/ Re vs. X' upper surface m) Nu//Re vs. Y' a = +50 lower surface..... 257 n) Nu/ Re vs. X' lower surface ..... 258 o) Nu//Rex vs. Y' upper surface ..... 259 p) Nu//Re vs. X' upper surface ..... 260 22 Configuration IV,  $\alpha = -10$ a) Nu//Re vs. Y' 52 = 53 = 0 lower surface ..... 261 b) Nu//Re vs. X' lower surface c) Nu/Ne vs. Y' upper surface ..... 262 d) Nu//Re vs. X' upper surface ..... 263 e) Nu/ Re vs. Y'  $5_2 = 5_3 = +10$ lower surface ..... 264 f) Nu/ Re vs. X' lower surface ...... 265 g) Nu/ Re vs. Y' upper surface ..... 266 h) Nu/VRe vs. X' upper surface ..... 267 i) Nu//Re vs. Y' 5<sub>2</sub> = 5<sub>3</sub> = +20 lower surface ..... 268 j) Nu/ Re vs. X' lower surface ..... 269 k) Nu//Re vs. Y' upper surface ..... 270 1) Nu//Re\_ vs. X' upper surface ..... 271 m) Nu//Re vs. Y' 52 = 53 = +30 lower surface ..... 272 n) Nu/ Re vs. X' lower surface ..... 273 o) Nu/ Re vs. Y' upper surface ..... 274 p) Nu/Ne vs. X' upper surface ..... 275 q) Nu/ Re vs. Y' 52 = 53 = +39 lower surface ..... 276 r) Nu/<sub>\/Re</sub> vs. X' lower surface ..... 277 s) Nu//Re vs. Y' upper surface ..... 278 t) Nu//Re vs. X' upper surface ..... 279

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23	Configuration IV, $\alpha = -10$		
	a) Nu//Rex vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = -10	lower surface 280
	b) Nu//Rex vs. Y'	δ <sub>2</sub> = δ <sub>3</sub> = -20	lower surface
	c) Nu/VRex vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = -30	lower surface
	d) Nu/ <del>Rex</del> vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = -39	lower surface
	e) Nu//Rex vs. X'	5 <sub>2</sub> - 5 <sub>3</sub> 10	lower surface 281
	f) Nu//Rex vs. X'	<sup>5</sup> 2 • <sup>5</sup> 3 • -20	lower surface
	g) Nu//Rex vs. X'	$b_2 = b_3 = -30$	lower surface
	h) Nu//Rex vs. X'	δ <sub>2</sub> = δ <sub>3</sub> = -39	lower surface
	1) Nu//Rex vs. Y'	$b_2 = b_3 = -10$	upper surface 282
	j) Nu//Rex vs. X'		upper surface 283
	k) Nu/ <del>/Re<sub>x</sub></del> vs. Y'	<sup>5</sup> 2 - <sup>5</sup> 320	upper surface 284
	1) Nu//Rex vs. X'		upper surface
	m) Nu//Re vs. Y'	<sup>5</sup> <sub>2</sub> - <sup>5</sup> <sub>3</sub> 30	upper surface 285
	n) Nu//Rex vs. X'		upper surface
	o) Nu//Rex vs. Y'	5 <sub>2</sub> - 5 <sub>3</sub> 39	upper surface 286
	p) Nu//Re vs. X'		upper surface
24	Configuration IV, $\alpha = -20$		
	a) Nu/ <sub>V</sub> Re <sub>x</sub> vs. Y'	<sup>5</sup> <sub>2</sub> - <sup>5</sup> <sub>3</sub> - 0	lower surface 287
	b) Nu//Rex vs. Y'	<sup>5</sup> <sub>2</sub> - <sup>5</sup> <sub>3</sub> - +10	lower surface
	c) Nu//Rex vs. X'	ō <sub>2</sub> - ō <sub>3</sub> - 0	lower surface
	d) Nu//Rex vs. X'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +10	lower surface
	e) Nu//Rex vs. Y'	<sup>5</sup> <sub>2</sub> - <sup>5</sup> <sub>3</sub> - 0	upper surface 288
	f) Nu//Rex vs. X'		upper surface 289
	g) Nu/ <sub>v</sub> Re <sub>x</sub> vs. Y'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +10	upper surface 290
	h) Nu//Rex vs. X'		upper surface 291
	i) Nu/ <sub>v</sub> Re <sub>x</sub> vs. Y'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +20	lower surface 292
	j) Nu/ <del>/Re</del> x vs. X <sup>1</sup>		lower surface 293
	k) Nu/ <del>/Rex</del> vs. Y'		upper surface 294
	1) Nu/\/Rex vs. X'		upper surface 295
	m) Nu/ <del>/Re</del> x vs. Y'	δ <sub>2</sub> = δ <sub>3</sub> = +30	lower surface 296
	n) Nu/ <sub>v</sub> Re <sub>x</sub> vs. X'		lower surface 297
	o) Nu/ <del>/Rex</del> vs. Y'		upper surface 298
	p) Nu//Rex vs. X'		upper surface 299
	q) Nu/ <del>/Re<sub>x</sub></del> vs. Y'	<sup>5</sup> <sub>2</sub> = <sup>5</sup> <sub>3</sub> = +39	lower surface 300
	r) Nu/ <del>/Rex</del> vs. X <sup>*</sup>		lower surface 301
	s) Nu/ <del>/Re<sub>x</sub></del> vs. Y'		upper surface 302
	t) Nul Re va. X'		upper surface 303

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25 Configuration IV, α= -20

contraction it, a to		
a) Nu//Re vs. Y'	$b_2 = b_3 = -10$	lower surface 304
b) Nu//Rex vs. Y'	5 <sub>2</sub> = 5 <sub>3</sub> = -20	lower surface
c) Nu/ARex vs. Y'	<sup>6</sup> 2 - <sup>6</sup> 330	lower surface
d) Nu//Rex vs. Y'	$\delta_2 = \delta_3 = -39$	lower surface
e) Nu//Rex vs. X'	$b_2 = b_3 = -10$	lower surface 305
f) Nu//Rex vs. X'	δ <sub>2</sub> - δ <sub>3</sub> 20	lower surface
g) Nu//Rex vs. X'	<sup>5</sup> <sub>2</sub> - <sup>5</sup> <sub>3</sub> 30	lower surface
h) Nu//Re <sub>x</sub> vs. X'	<sup>5</sup> 2 - <sup>5</sup> 339	lower surface
1) Nu//Rex vs. Y'	δ <sub>2</sub> - δ <sub>3</sub> 10	upper surface 306
j) Nu//Re <sub>x</sub> vs. X'		upper surface
k) Nu//Rex vs. Y'	δ <sub>2</sub> = δ <sub>3</sub> = -20	upper surface 307
1) Nu//Rex vs. X'		upper surface
m) Nu//Rex vs. Y'	$\delta_2 = \delta_3 = -30$	upper surface 308
n) Nu/ <sub>v</sub> Re <sub>x</sub> vs. X'		upper surface
o) Nu/VRex vs. Y'	δ <sub>2</sub> • δ <sub>3</sub> • -39	upper surface 309
p) Nu//Rex vs. X'		upper surface 310
Configuration IV, $\alpha$ = -30		
a) Nu//Re <sub>x</sub> vs. Y'	δ <sub>2</sub> - δ <sub>3</sub> - 0	lower surface 311
b) Nu//Rex vs. Y'	δ <sub>2</sub> = δ <sub>3</sub> = +39	lower surface
c) Nu/ <del>/Re</del> x vs. X'	δ <sub>2</sub> - δ <sub>3</sub> - 0	lower surface
d) Nu/ <sub>v</sub> Re <sub>x</sub> vs. X'	δ <sub>2</sub> = δ <sub>3</sub> = +39	lower surface
e) Nu/ <del>/Rex</del> vs. Y'	δ <sub>2</sub> - δ <sub>3</sub> - 0	upper surface 312
f) Nu/ <del>/Rex</del> vs. X'		upper surface 313
g) Nu/ <sub>v</sub> Re <sub>x</sub> vs. Y'	δ <sub>2</sub> = δ <sub>3</sub> = +39	upper surface 314
h) Nu/ <sub>v</sub> Re <sub>x</sub> vs. X'		upper surface 315
Configuration IV, $\alpha = -40$		
a) Nu/ <sub>v</sub> Re <sub>x</sub> vs. Y'	δ <sub>2</sub> = δ <sub>3</sub> = 0	lower surface 316
b) Nu//Rex vs. Y'	δ <sub>2</sub> = δ <sub>3</sub> = +39	lower surface
c) Nu/ <del>Rex</del> vs. X'	δ <sub>2</sub> = δ <sub>3</sub> = 0	lower surface
d) Nu//Rex vs. X'	<sup>δ</sup> <sub>2</sub> = δ <sub>3</sub> = +39	lower surface
e) Nu/ <sub>V</sub> Re <sub>x</sub> vs. Y'	<sup>δ</sup> <sub>2</sub> = δ <sub>3</sub> = 0	upper surface 317
f) Nu/ <del>/Rex</del> vs.X'		upper surface 318
g) Nu/ <del>/Re</del> x vs.Y'	δ <sub>2</sub> = δ <sub>3</sub> = +39	upper surface 319
h) Nu//Rex vs. X'		upper surface 320
Configuration IV, $\alpha = -50$		
a) Nu/VRex vs. Y'	δ <sub>2</sub> - δ <sub>3</sub> - 0	lower surface 321
b) Nu/VRe vs. Y'		upper surface

28 Configuration IV,  $\alpha = -50$  (Cont'd) c) Nu/Ne vs. X' 52 - 53 - 0 lower surface ..... 322 d) Nu//Re\_ vs. X' upper surface 29 Configuration VII, Spoiler On a) Nu//Re vs. Y'  $\alpha = 0$ , Re /ft x  $10^{-6}$  3.3. lower surface ..... 323 b) Nu//Re vs. X' lower surface ..... 324 c) Nu//Re, vs. Y' upper surface ..... 325 d) Nu//Re, vs. X' upper surface e) Nu/Ne vs. Y!  $\alpha = 0$ , Re /ft x 10<sup>-6</sup> = 1.1 lower surface ..... 326 f) Nu/Re vs. X' lower surface ..... 327 g) Nu//Re vs. Y' upper surface ..... 328 h) Nu/ Re vs. X' upper surface i) Nu/ $\sqrt{Re_v}$  vs. Y'  $\alpha = -10$ , Re\_/ft x 10<sup>-6</sup>= 3.3 lower surface ..... 329 j) Nu/ Re, vs. X' lower surface k) Nu/<sub>/Re</sub> vs. Y' upper surface ..... 330 1) Nu//Re, vs. X' upper surface ..... 331 m) Nu/ $\sqrt{Re_v}$  vs. Y'  $\alpha = -20$ , Re\_/ft x 10<sup>-6</sup> = 3.3 lower surface ..... 332 n) Nu//Re vs. X' lower surface o) Nu//Re, vs. Y' upper surface ..... 333 p) Nu/ Re vs. X' upper surface ..... 334 Configuration VIII,  $\alpha = 0$ , Spoiler On, Fins On 30  $Re_{ft} \times 10^{-6} = 3.3$ a) Nu/Ne vs. Y' lower surface ..... 335 b) Nu/VRe vs. X' lower surface ..... 336 c) Nu/ Re vs. Y' upper surface ..... 337 d) Nu//Re vs. X' upper surface ..... 338 Configuration IX,  $\alpha = 0$  Re/ft x  $10^{-6} = 3.3$ 31 a) Nu/Ne vs. Y' 52 = 53 = +20 lower surface ..... 339 b) Nu//Re vs. X' lower surface ..... 340 c) Nu/Ne vs. Y' upper surface ..... 341 d) inu/ Re vs. X' upper surface ..... 342 e) Nu/Ne vs. Y' 52 = 53 = +39 lower surface ..... 343 f) Nu/<sub>\(Re, vs. X'</sub> lower surface g) Nu/ Re vs. Y' upper surface ...... 344 h) Nu/Re vs. X' upper surface Configuration IX,  $\alpha = 0$  Re /ft x 10<sup>-6</sup> = 3.3 32 a) Nu/ Re vs. Y' 52 = 53 = -20 lower surface ..... 345 b) Nu//Re, vs. X' lower surface c) Nu/VKe vs. Y' upper surface ..... 346 d) Nu//Re vs. X' upper surface ..... 347

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32	Configuration IX. $\alpha = 0$ (Co	mt'd)	
	e) Nu//Re vs. Y'	5 - 5 <b>3</b> 9	lower surface
	f) $\frac{Nu}{Re}$ vs. Y	2 3	upper surface
	R) Nu/Re vs. X'		lower surface
	b) Nu/Re ve X'		Noner surface
33	Configuration IX $a = \pm 10$	$Re / ft = 10^{-6} = 3.3$	apper surrace
	a) Nul/Ma us VI		lover ourface 34
	b) $\frac{1}{\sqrt{2}}$ vs. 1	<sup>0</sup> <sub>2</sub> <sup>- 0</sup> <sub>3</sub> <sup>- 0</sup>	lower surface
	c) $\frac{Nu}{\sqrt{Re}}$ vs. X		upper surface 35
	d) $\frac{Nu}{\sqrt{R_{T}}} = \frac{V^{2}}{V^{2}}$		upper surface
	a) $\frac{Nu}{\sqrt{Re_x}} = \frac{V^{\dagger}}{V}$	5 = 5 = ±20	lover surface
	$\frac{1}{X} = \frac{1}{X} = \frac{1}$	° <sub>2</sub> = ° <sub>3</sub> = +20	lower surface
	$\frac{1}{X} = \frac{1}{X} = \frac{1}$		lower surface
	$\frac{1}{x} = \frac{1}{x} = \frac{1}{x}$		upper surface
	$\frac{1}{X} = \frac{1}{X} = \frac{1}$		upper surface 35
	$\frac{1}{1} \frac{1}{1} \frac{1}$	$b_2 = b_3 = +39$	lower surface 35
	$\frac{1}{2} \frac{1}{2} \frac{1}$		lower surface 35
	$\frac{1}{x} = \frac{1}{x} = \frac{1}{x}$		upper surface 35
21	$\frac{1}{x} = \frac{1}{x} = \frac{1}{x}$	Ro / 60 - 10 <sup>-6</sup> - 2.2	upper surface 36
24	$configuration ix, \alpha = +10$	Re <sub>w</sub> /11 x 10 = 3.5	
	a) $\frac{1}{\sqrt{Re}}$ vs. $\frac{1}{x}$	$b_2 = b_3 = -20$	lower surface 36.
	b) $\frac{Nu}{\sqrt{Re_x}} \sqrt{s}$ , $x^2$		lower surface
	c) $Nu/\sqrt{Re_x}$ vs. Y		upper surface 36
	d) $NU/\sqrt{Re_x}vs. X'$		upper surface 36.
	e) $NU/\sqrt{Ke_x} vs. X'$	$5_2 - 5_339$	lower surface 364
	I) NU/VRe vs. Y		lower surface
	g) $Nu/\sqrt{Ke_x}$ vs. Y		upper surface 36
25	h) $Nu/\sqrt{Re_x vs. X'}$		upper surface 360
35	Configuration IX, $\alpha = +20$	$\operatorname{Re}_{\infty}/\operatorname{ft} \times 10^{-1} = 3.3$	
	a) Nu//Re vs. Y'	$b_2 = b_3 = 0$	lower surface 36
	b) Nu/ <sub>v</sub> Re vs. X'		lower surface 368
	c) $Nu/\sqrt{Re} vs. Y'$		upper surface 369
	d) Nu//Re vs. X'		upper surface 370
	e) Nu//Re vs. Y'	$b_2 = b_3 = +20$	lower surface 371
	f) Nu//Re vs. X'		lower surface
	g) Nu//Rex vs. Y'		upper surface 372
	h) Nu//Rex vs. X'		upper surface 37:
	1) Nu//Rex vs. Y'	<sup>6</sup> 2 <sup>- 6</sup> 3 <sup>- +39</sup>	lower surface 374
	1) Nul Re ve Y'		lower surface 37

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Configuration IX,  $\alpha = +20$  (Cont'd) k) Nu/Ne vs. Y' 8, = 8, = +39 upper surface ..... 376 1) Nu//Re vs. X' upper surface ..... 377 Configuration IX,  $\alpha = +20$  Re /ft x 10<sup>-6</sup> = 3.3 a) Nu//Re\_ vs. Y' 82 - 83 - -20 lower surface ..... 378 b) Nu/ Re vs. X' lower surface ..... 379 c) Nu//Re vs. Y' upper surface ..... 380 d) Nu//Re vs. X' upper surface ..... 381 e) Nu/ Re vs. Y' 82 = 83 = -39 lower surface ..... 382 f) Nu//Re vs. X' lower surface ..... 383 g) Nu/Ne vs. Y' upper surface ..... 384 h) Nu//Re vs. X' upper surface ..... 385  $Re / ft \times 10^{-6} = 1.1$ Configuration IX,  $\alpha = 0$ <sup>8</sup><sub>2</sub> - <sup>8</sup><sub>3</sub> - 0 a) Nu/ Re vs. Y' lower surface ..... 386 b) Nu//Re vs. Y' 82 - 83 - -20 lower surface c) Nu//Re\_ vs. Y' 82 - 83 - -39 lower surface d) Nu//Re\_ vs. X' 82 - 83 - 0 lower surface e) Nu//Re vs. X' 82 - 83 - -20 lower surface f) Nu/VRe vs. X' 82 = 83 = -39 lower surface g) Nu/ Re vs. Y' 82 - 82 - 0 upper surface ..... 387 h) Nu//Re vs. X' uper surface ..... 388 i) Nu//Re vs. Y' 82 - 83 - -20 upper surface ..... 389 j) Nu//Te vs. X' upper surface k) Nu//Re\_ vs. Y' 82 - 83 - -39 upper surface ..... 390 1) Nu//Re vs. X' upper surface m) Nu//Re vs. Y' 82 = 83 = +20 lower surface ..... 391 n) Nu/VRe vs. X' lower surface o) Nu//Re vs. Y' upper surface ..... 392 p) Nu//Re vs. X' upper surface ..... 393 q) Nu//Re vs. Y' 82 - 83 - +39 lower surface ..... 394 r) Nu//Re- vs. X' lower surface ..... 395 s) Nu//Re vs. Y' upper surface ..... 396 t) Nu//Re\_ vs. X' upper surface ..... 397 Configuration X,  $\delta_1 = \delta_2 = \delta_3 = +20$  $\alpha = 0$ , Re<sub>m</sub>/ft x 10<sup>-6</sup> = 3.3 a) Nu//Re, vs. Y' lower surface ..... 398 b) Nu//Ke, vs. X' lower surface ..... 399 c) Nu/Ne\_ vs. Y' upper surface ..... 400

d) Nu//Re\_ vs. X'

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upper surface ..... 401

38 Configuration X,  $\delta_1 = \delta_2 = \delta_3 = +20$  (Cont'd)

e)	Nu//Re vs. Y'	$\alpha = 0$ , Re <sub>10</sub> /ft x 10 <sup>-6</sup> = 1.1	lower surfsce 402
f)	Nu/ <del>/Re</del> x vs. X'		lower surfsce 403
g)	Nu//Re vs. Y'		upper surface 404
h)	Nu//Rex vs. X'		upper surface 405
i)	Nu//Rex vs. Y'	$\alpha = +10$ , $\text{Re}_{\infty}/\text{ft} \times 10^{-6} = 3.3$	lower surface 405
j)	Nu//Rex vs. X'		lower surfsce 407
k)	Nu//Rex vs. Y'		upper surface 408
1)	Nu/ <del>/Re</del> x vs. X'		upper surface 409
m)	Nu/ Rex vs. Y'	$\alpha = +20$ , $\text{Re}_{\infty}/\text{ft} \times 10^{-6} = 3.3$	lower surfsce 410
n)	Nu/ARex vs. X'		lower surfsce 411
0)	Nu/Ae vs. Y'		upper surface 412
p)	Nu/ Rex vs. X'		upper surface 413

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# LIST OF SYMBOLS

a	density of skin material $\sim 1 \text{bm/ft}^3$
Ъ	wing semi-span ~ inches
c	specific heat of skin material ~ BTU/1bm
C <sub>Root</sub>	virtual root chord of wing ~ inches
h	heat transfer coefficient (h = $\frac{\dot{q}_w}{T_o - T_w}$ ~ BTU/ft <sup>2</sup> sec <sup>o</sup> R
k	free stream thermal conductivity of air ~ BTU/ft <sup>2</sup> sec <sup>0</sup> R/ft
M <sub>∞</sub>	free stream Mach number
Nu	Nusselt Number Nu $\equiv (\frac{hx}{k_{\infty}})$
P	free stream static pressure ~ psia
₫ <sub>₩</sub>	aerodynamic heating rate ~ BTU/ft <sup>2</sup> sec
$\mathbf{q}^{\infty}$	free stream dynamic pressure = $\frac{\gamma}{2} P_{\infty} M_{\infty}^2$
Rex	Reynolds number based on planform distance from virtual apex = $\frac{\rho_{\infty} V_{\infty} x}{\mu_{\infty}}$
${\tt Re}_{\infty}/{\tt ft}$	free stream unit Reynolds number = $\frac{\rho_{\infty} V_{\infty}}{\mu_{\infty}}$
t	time ~ seconds
т	stagnation temperature $\sim R$
Τ <sub>w</sub>	wall temperature ~ <sup>O</sup> R
V <sub>∞</sub>	free stream velocity ~ ft/sec
x	planform chordwise coordinate (measured from virtual apex) ~ ft
у	planform spanwise coordinate (measured from model center plane) ~ ft
X'	non-dimensional chordwise coordinate = x/c <sub>Root</sub> (Virtual)

Y'	non-dimensional spanwise coordinate = v/b
α	angle of attack ~ degrees
γ	ratio of specific heats = 1.4
<sup>5</sup> 1	center flap deflection angle $\sim$ degrees
<sup>5</sup> 2	left outboard flap deflection angle ~ degrees
δ <sub>3</sub>	right outboard flap deflection angle $\sim$ degrees
۳°	free stream viscosity $\sim \frac{slugs}{ft sec}$
ρ <sub>∞</sub>	free stream density $\sim \frac{slugs}{ft^3}$
τ	skin thickness $\sim$ ft
ζ	honeycomb correction factor (=1.00 for t = 1.00 seconds)

#### INTRODUCTION

The Fluid Mechanics Section of the Grumman Research Department is currently engaged in a research program directed at determining flow separation effects and the effectiveness of aerodynamic controls on hypersonic flight vehicles. The program consists of theoretical and experimental research on "basic" configurations (flat plates with flap and wedge type separators) and representative hypersonic glide configurations (a clipped delta wing-body combination and a pyramidal body). The configurations to be investigated in the over-all program are shown in Fig. 1a.

This report presents the results of one segment of the experimental program. It treats a winged hypersonic glider configuration consisting, in basic form, of a clipped delta wing with an overslung cone-cylinder body. This configuration was used for obtaining pressure and heat transfer data on various aerodynamic controls at hypersonic Mach numbers. The heat transfer data are presented herein, and the pressure data are presented in another report (Ref. 1). The controls investigated were partial span trailing edge flaps, with a deflection range of -39° to +39°; a full span flap with a deflection of +20°; a full span, plug-type, trailing edge spoiler and tip fins. An overslung hemispherecylinder body was also tested.

The experimental work was done at the AEDC 50-inch Mach 8 Hypersonic Wind Tunnel during July and August of 1963. Descriptions of these test facilities can be found in Ref. 2. Heat transfer data were obtained at a unit Reynolds number of  $3.3 \times 10^6$ with selected points at a Reynolds number of  $1.1 \times 10^6$ . This same model was also used to obtain pressure data in the AEDC 40 x 40inch Supersonic Tunnel at  $M_{\infty} = 5.0$ , and in the AEDC 50-inch Hypersonic Tunnel at  $M_{\infty} = 8.0$ . A geometrically similar model, instrumented to obtain force and moment data, was tested in this facility at an earlier date. Another geometrically similar model, with limited pressure instrumentation, was tested in AEDC Hotshot 2 Hypervelocity Tunnel. The results of the last four investigations are presented in Refs. 1, 3, 4, and 5.

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#### DESCRIPTION OF MODELS

#### General

Six test configurations were built up from a basic model that consisted of a clipped delta wing with an overslung body. The clipped delta wing had a spherically blunted apex, cylindrically blunted leading edges, and a blunt base. Of the control surfaces to be tested, three partial span trailing edge flaps were built into the wing, and attachments were provided for mounting a full span spoiler. The two outboard flaps were of the aileron type, deflectable in the positive and negative direction, while the central flap was of the split flap variety, deflectable only in the positive direction. When all three flaps are deflected in the same direction, and to the same angle, they form a full span flap. The flap-type control surfaces were remotely actuated from outside the tunnel. Three-view drawings of the test configurations are presented in Figs. 1b through 1g. The dimensions of the basic configurations are shown in Fig. 1b and are the same for all other configurations. The other configuration drawings show dimensions only for the components added to the basic configuration. A summary of the geometric properties of the various model components is presented in Table 1.

Two of the heat transfer models tested in this program are geometrically similar to force models which were previously reported (Ref. 4). Four additional models are reported on herein for which force data are not available; they were developed by changing the forebody shape from a half-cone to a half-hemisphere. Pressure data are available for five of the six test configurations (Ref. 3).

# Controls and Sign Conventions

Each flap-type control was driven by a 28-volt dc, gear reduced, electrical motor through a 1/2 inch-10 acme thread drive screw which was connected to the flap bell cranks by push-pull rods. Control deflection measurements were obtained through calibrated linear potentiometers. The three motors with their attendant potentiometers and drive screws were located in a water cooled housing immediately behind the model. The drive screws were connected to the flap bell cranks by push-pull rods that passed through the front of the actuator housing and into the base of the model. This actuation system produced a deflection rate of 1 degree/sec and permitted the independent operation of each control surface. The control surfaces were calibrated cold, that is, when the model was installed in the tunnel, and checked frequently. The calibrating was done with pre-cut templates varying from 0 degrees to 40 degrees in 5-degree increments. A specially cut template was used to calibrate the 39-degree deflection angle. The potentiometer outputs, used in setting flap angles during the test, were recorded visually from Leeds and Northrup Midget Model D indicators. This calibration was also recorded into the digital computing equipment at AEDC for use of the computer during print-out. We were thus capable of testing asymmetric, as well as symmetric, control configurations.

The sign convention for denoting the angle of attack and the control deflection angle can be obtained from the basic model, a flat plate, clipped delta wing with an overslung body. The definition fixes the flat plate surface of the wing as the lower surface. Thus, the angle of attack is positive when the flat plate surface is the windward surface of the model. The control deflection angles are also defined with respect to the lower (flat plate) surface of the model. If we consider our model at zero angle of attack (flow parallel to the lower flat plate surface), then the positive trailing edge flap deflections are obtained by deflecting the trailing edge down. The outboard, partial span, trailing edge flaps, designed to operate independently of each other, had a maximum travel angle of  $\pm$  39 degrees, and could be calibrated to yield any deflection angle in this range. The central flap section, which operated independently of the other flaps, had a maximum travel of 0 to +20 degrees.

#### Model Designation

All the test configurations consisted basically of a clipped delta wing with an overslung body. The instrumented portion of the overslung body consisted of a half-cylindrical after section and a half-hemispherical foresection. An uninstrumented conical fairing was attached over the foresection of the body to provide a body shape that was geometrically similar to the body shape used in the force tests described in Ref. 4. This wing body combination was one of two major configurations of this test program and is referred to as Configuration I. The second major configuration was obtained by adding a set of tip fins to Configuration I and is referred to as Configuration IV. These tip fins were clipped deltas in elevation and were attached in such a way as not to alter the aspect ratio (of the configuration). Configurations I and IV provided the heat transfer data corresponding to the pressure and force data previously obtained (Refs. 1 and 4).

In the force test phase of the program, each of these major configurations was expanded into three additional control models, yielding eight test configurations. It was not feasible to attempt heat transfer testing on such a large scale, due to the operational problems and time limitations. Therefore, the heat transfer tests were limited to the two major configurations previously mentioned and to four additional configurations that would provide useful data on: 1) the effects of a strong shock generator, and 2) trailing edge controls that would induce strong separation effects. The strong shock generator was a blunt forebody section on the overslung body, and the separation inducing trailing edge controls were a full span flap and a full span, plug-type spoiler.

As with the force tests, described in Ref. 4, an adequate comparison point between the partial span flaps and the other trailing edge controls (full span spoiler and flap) would be at a flap deflection angle of +20 degrees. The height of the full span, plug-type, trailing edge spoiler was designed to be equal to the vertical displacement of the trailing edge flaps when they are deflected +20 degrees. This spoiler was attached to the lower, flat plate surface at the trailing edge. The full span flap was developed by building into the model a third, partial span, split flap to fit between the outboard, aileron type flaps. When all three flaps were deflected +20 degrees, they formed a full span flap.

The overslung body was built in two sections. The first was a single, instrumented body consisting of a half-hemispherical forebody and a half-cylindrical afterbody. The second section was an uninstrumented conical fairing that could be attached over the blunt, half-hemispherical, forebody of the first section and simulate, on a smaller scale, the conical forebody used in the force tests.

Working on the assumption that the effects of the blunt body, spoiler, and full span flap would be uncoupled if the body and

spoiler, or flap, were placed on opposite surfaces of the wing, we developed four configurations. The first model consisted of a wing-body combination with a full span, plug-type, spoiler attached at the trailing edge of the lower surface and an overslung body composed of a half-hemispherical forebody and a halfcylindrical afterbody. The blunt forebody was obtained by removing the conical forebody fairing. This configuration was called Configuration VII. The second model, Configuration VIII, was obtained by adding tip fins to Configuration VII. The third model, a wing-body combination without the spoiler, but with the half-hemispherical forebody was denoted as Configuration IX. Configuration X was obtained from Configuration IX by deflecting all three partial span flaps to +20 degrees. A complete definition of the models is presented in Table 2. The model designation system maintains continuity with the previous experimental work reported in Refs. 1 and 4.

## Model Construction and Instrumentation

The wing for these configurations was fabricated of an internal stainless steel frame, which served as the basic load supporting structure, and instrumented surface panels, which served as the data gathering units. The flaps were also fabricated the same way; i.e., an internal frame with attached instrumented panels. The flaps were connected to the wing structure by hinges and actuated from the actuator housing by a system of bell cranks and push-pull rods. All internal frame work was made of 416 stainless steel, and the surface panels were pressure relieved, silver braised, honeycomb cections; the face sheets, core, and frame were of 321 stainless steel. Where a thermocouple was to be spot-welded to the inner surface of the honeycomb face sheet, the back sheet was drilled away and the cell cleansed of solder by washing with concentrated nitric acid. This left a clean, solder-free surface upon which to spot-weld the thermocouple. The body and the conical fairing were fabricated of 321 stainless steel sheet, while fins and spoiler were made of solid 321 stainless steel. The actuator housing, which served as the connection between the model and the sting, as well as the housing for the actuation motors, was made of 17-4PH stainless steel.

The model was instrumented with 38 thermocouples distributed on the upper and lower surface of the wing and on the halfhemisphere cylinder body. The thermocouples were made of 30 gage chromel-alumel wire and were spot-welded to the inner surface of the outside honeycomb face sheet (face sheet exposed to the flow). The location of each thermocouple, the skin thickness at the thermocouple station, and the distance from the virtual apex of the model to each thermocouple are listed in Table 3 and shown in Figure 1h. When the conical forebody fairing was installed, five thermocouples (669-673) were covered; and when the spoiler was installed, four thermocouples (528, 538, 548, 588) were covered. Installation of the fins did not inactivate any instrumentation.

#### EXPERIMENTAL DATA

## Description of Wind Tunnels and Test Conditions

This segment of the experimental program was conducted in the 50-inch Mach 8 Hypersonic Wind Tunnel located at the von Karman Facility of the Arnold Engineering Development Center. A complete description of the wind tunnels and their associated measuring, recording, and tabulating equipment is given in Ref. 2. The tests were conducted at a nominal test section Mach number of 8.0 and test section unit Reynolds numbers of  $3.3 \times 10^6$  per foot and 1.1  $\times 10^6$  per foot. (Most of the program was conducted at a Reynolds number of 3.3  $\times 10^6$  per foot and 1.1  $\times 10^6$  per foot. (Most of the program was conducted at a Reynolds number of 3.3  $\times 10^6$  per foot. The test were used for comparative purposes only.) Due to the tunnel operating conditions, the actual test Mach number was 8.09. The variation in each Reynolds number was less than 1.5 per cent.

The two main configurations (I and IV) were tested most extensively, while experiments with the other configurations were restricted and were used only to provide comparison data with the main configurations. Configurations I and IV were tested through an angle of attack range of -20 to +20 degrees, for symmetric, partial span, flap deflections of -39 to +39 degrees. For zero flap deflection angles, data were gathered through an angle of attack range of -50 to +50 degrees. Configurations VII and VIII yielded data on the effect of a full span, plug-type, trailing edge spoiler; and information on the effect of a strong shock generator on the aerodynamic heating characteristics of deflected, partial span, trailing edge flaps was obtained with Configuration IX. The effect of a full span trailing edge flap was determined using Configuration X. These Configurations (VII-X) also provided the information on the effect of a strong shock generator on the aerodynamic heating characteristics of a flat plate wing panel.

A complete tabulation of the experimental program showing the angle of attack range, control deflection, and flow conditions is presented in Table 4. The angle of attack range was obtained by using two different pre-bend angles on the water-cooled split sting that is standard tunnel equipment. The two pre-bend angles used were 12 degrees and 39 degrees, which provided an angle of attack range of 0 to +50 degrees. The negative angles of attack were obtained by inverting the model.

Cooling shoes were installed in the Mach 8 Tunnel in order to obtain aerodynamic heating rates by the thin wall, transient temperature technique. Tunnel conditions were stabilized for the desired free stream Reynolds number; the remotely controlled flaps were set at the desired angles, and the model was pitched to the required angle of attack while inside the cooling shoes. The cooling shoes were then rapidly retracted (full retraction from the tunnel centerline to walls within 0.8 second), and temperature of each thermocouple was recorded for 4 seconds at intervals of 0.05 second. The shoes were then closed, the model cooled to approximately 520°R, the flap angles set, and the model pitched to the next desired angle of attack where the process was repeated. In this manner, all of the heat transfer data were obtained for a given configuration and Re /ft through the angle of attack range, while limiting the amount of heat absorbed by the model. The experimental data are presented graphically, in the form of Nu//Re\_'.

#### Data Reduction and Accuracy

Thin wall approximations were used to obtain the transient aerodynamic heating rates from the recorded temperature-time histories. The equation used for calculating the heating rates was  $\dot{q}_w = \zeta_{a\tau c} \frac{dt_w}{dt}$ , and the temperature derivative was obtained

by fitting a polynomial through any 11 consecutive points of the temperature time curve and differentiating the polynomial at the mid-point interval. The very thin wall and the absence of heat sinks at each thermocouple installation (see table), which was made possible by the use of honeycomb sandwich construction of the test panels, allowed a very rapid response to the aerodynamic heat input. This made it possible to reduce the data at t = 1.00 second after the start of cooling shoe retraction. At this time interval, the honeycomb correction factor  $\zeta$  was equal to 1.00. Representative thermocouples were monitored during the heat transfer tests and indicated that all starting effects caused by the opening of the cooling shoes were dissipated prior to the time at which the data were reduced. The aerodynamic heating rates were then nondimensionalized in the form:

$$\frac{\underline{Nu}}{\sqrt{Re_{x}}} = \frac{\frac{\dot{q}_{w}}{T_{o}-T_{w}}}{\sqrt{\frac{\rho_{w}V_{w}}{r_{o}}}}$$

The values of x, as well as the skin thickness and nondimensionalized location of each thermocouple, are tabulated and presented in Table 3. Due to the strict time schedule, it was not possible to provide check-runs to determine the error limits in the measured heating rates and assess the inaccuracies in the calculated values of  $Nu/\sqrt{Re_x}$ . The discrepancy in the plotted data due to the use of automatic plotting machines should not exceed  $\pm$  0.20 per cent of the maximum scale. Each graph has been inspected and questionable points have been checked with the tabulated data.

### RESULTS AND DISCUSSION

This program was designed to provide the heat transfer data needed to complement the controls information previously obtained on a basic type of hypersonic flight vehicle; namely, a clipped delta wing-body combination. Data are presented at positive and negative angles of attack for the case of an overslung body.

This configuration was tested with tip fins on and off, with partial span and full span trailing edge flaps, with a full span trailing edge spoiler, and with a blunt instrumented body as well as the conical body used in the force tests. The experiments were conducted at Mach numbers of 8.08 and 8.09 and with limited Reynolds number comparisons. Due to the tight test schedule, only the symmetric flap deflection cases were tested, whereas the force data of Ref. 4 presents both symmetric and asymmetric cases.

The basic wing-body combination was designed to provide heat transfer data for configurations having either overslung or underslung bodies. For convenience we have chosen the overslung body configuration as our reference, and defined the coordinate system and control deflection angles with reference to this basic configuration. Thus, the positive angle of attack regime for the overslung body provides the data for the underslung body at negative angles of attack. The sign of the flap deflection angles for the underslung body case must be reversed in order that both cases be viewed in the same reference system.

The data are presented in the form of Nu/ $\sqrt{Re_x}$  plotted as functions of nondimensionalized chordwise (streamwise), and spanwise, coordinates (X' and Y'). The chordwise coordinate is measured from the virtual apex of the model, and the spanwise coordinate is measured from the vertical centerplane of the model. The data obtained on the upper and lower surfaces of the test configuration are presented separately for each set. Thus, for each test configuration, all the data are presented in four graphs (two graphs for the chordwise plots and two graphs for the spanwise plots).

The data for Configuration I are presented in Figs. 3 through 14; for Configuration IV in Figs. 15 through 28; for Configuration VII in Fig. 29; for Configuration VIII in Fig. 30;
for Configuration IX in Figs. 31 through 37; and for Configuration X in Fig. 38. The complete test program is tabulated in Table 4 and the specific conditions presented in each figure are noted in the list of illustrations in the front matter.

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- 4. Meckler, Lawrence, <u>Static Aerodynamic Characteristics at Mach</u> <u>5 and 8 of an Aerodynamically Controllable Winged Re-entry</u> <u>Configuration</u>, FDL-TDR-64-10.
- 5. Hartofilis, Stavros A., <u>Pressure Measurements at Mach 19 for a</u> Winged Re-entry Configuration, ASD-TDR-63-319, March 1963.

#### TABLE 1

#### GEOMETRIC CHARACTERISTICS

### Wing:

Clipped Delta Wing with Blunt Apex, Leading Edges, and Base		
Root Chord	12.350 13.00	inches actual inches virtual
Tip Chord	2.608	inches
Span	12.00	inches
Apex Radius	0.650	inch
Leading Edge Sweep	60	degrees
Leading Edge Radius	0.650	inch
Wing Thickness (Constant)	1.30	inches
Planform Area	93.3 97.6	inches <sup>2</sup> actual, inches <sup>2</sup> virtual
Aspect Ratio	1.542	
Taper Ratio	0.211	
Thickness Ratio (Root)	0.1052	2
Control Area - Outboard Partial Span Flaps	12.75	inches <sup>2</sup>

#### Body:

Half Cone - Cylinder (Base Mounted Flush with Wing Trailing Edge)		
Cone Angle	13	degrees
Cone Length	5.49	inches
Cone Radius (Maximum at Tangency Point)	1.269	inches
Cylinder Length	4.415	inches
Cylinder Radius	1.30	inches
Fairing (Cone to Cylinder)		
Length	0.292	inch
Radius	1.30	inches
Included Angle	13	degrees
Total Body Length (Half-Cone Cylinder)	10.20	inches
Planform Area (Half-Cone Cylinder)	17.81	inches <sup>2</sup>
Hemisphere Radius	1.30	inches
Total Body Length (Half-Hemisphere Cylinder)	5.715	inches
Planform Area (Half-Hemisphere Cylinder)	14.145	inches <sup>2</sup>

## Tip Fin:

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P

Clipped Delta Wing with Blunt Leading Edge		
Root Chord	3.275	inches
Tip Chord	0.990	inch
Span	4.160	inches
Leading Edge Sweep	50	degrees
Leading Edge Radius	0.325	inch
Thickness (Constant)	0.650	inch
Area	9.27	inches <sup>2</sup>
Aspect Ratio	1.862	
Taper Ratio	0.302	5
Thickness Ratio (Fin Root-Wing Center Plane)	0.199	

## TABLE 1 (Cont'd)

### GEOMETRIC CHARACTERISTICS

### Spoiler:

Full Span, Plug Type with Cylindrical Lower Edge		
Chord (Constant)	0.650	inch
Span	10.70	inches
Height	0.611	inch
Planform Area	6.96	inches
Bottom Cylinder Radiua	0.325	inch

## Central Flap:

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Split Flap - Central Section of Full Span Trailing Edge Flap		
Chord	2.220	inches
Span	2.600	inches
Planform Area	5.772	inches <sup>2</sup>

TABLE 2

DESCRIPTION OF TEST CONFIGURATIONS

Configuration	Description
I	Basic configuration (wing - body)
	Wing - clipped delta wing, spherically blunted apex, cylindrically blunted leading edges, blunt base
	+Body - overslung, half-conical forebody and half-cylindrical afterbody
IV	Basic + Tip Fins (I)
IIA	Wing - clipped delta wing, spherically blunted apex, cylindrically blunted leading edges, blunt base
	+Body - overslung, half-hemispherical forebody and half-cylindrical afterbody
	+Spoiler - plug type, trailing edge spoiler
IIIA	VII + Tip Fins
IX	Wing - clipped delta wing, spherically blunted apex, cylindrically blunted leading edges, blunt base
	+Body - overslung, half-hemispherical forebody and half-cylindrical afterbody
X	IX + Full Span, lower surface flap ( $\delta_1 = \delta_2 = \delta_3 = +20^\circ$ )

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e TABLE THERMOCOUPLE LOCATION & SKIN THICKNESS

Tower Surface

Curfor \$ IIa

Thermo- couple Number	۲	'Y	Skin Thickness ft	x ft		Thermo- couple Number	۰x	ıÅ	Skin Thickness ft	x ft	the second s
580	0.2308	0	0.00148	0.2500		699	0.2308	0	0.00148	0.2500	
583	0.6058	0	0.00150	0.6563		670	0.3750	0	0.00148	0.4063	
586	0.7846	0	0.00150	0.8500		671	0.5192	0	0.00150	0.5625	-
587	0.9173	0.0313	0.00147	0.9937		672	0.5735	0	0.00222	0.6213	
588	0.9750	0.0313	0.00146	1.0563		673	0.6058	0	0.00219	0.6563	
543	0.6058	0.3125	0.00149	0.6563		666	0.7846	0.1083	0.00188	0.8500	
546	0.7846	0.3125	0.00150	0.8500		667	0.9173	0.1083	0.00163	0.9937	
547	0.9173	0.3125	0.00147	0.9937		654	0.6923	0.1877	0.00185	0.7500	_
548	0.9750	0.3125	0.00147	1.0563		656	0.7846	0.1877	0.00190	0.8500	
533	0.6058	0.5625	0.00150	0.6533		657	0.9173	0.1877	0.00165	0.9937	
536	0.7846	0.5625	0.00148	0.8500		643	0.6058	0.3125	0.00148	0.6563	
537	0.9173	0.5625	0.00149	0.9937		646	0.7846	0.3125	0.00147	0.8500	-
538	0.9750	0.5625	0.00148	1.0563		647	0.9173	0.3125	0.00147	0.9937	-
526	0.7846	0.8020	0.00148	0.8500		648	0.9750	0.3125	0.00146	1.0563	
527	0.9173	0.8020	0.00147	0.9937		633	0.6058	0.5625	0.00149	0.6563	
528	0.9750	0.8020	0.00148	1.0563		634	0.6923	0.5625	0.00150	0.7500	_
NOTE:	All therm	ocouples ar	e located	with resper	Ļ	636	0.7846	0.5625	0.00146	0.8500	_
to the	virtual at	pex. and th	ne vertical	center pla	aut	637	0.9173	0.5625	0.00147	0.9937	
of the	model. Th	hermocouple	ss 626 - 67	3 are on rh	9	638	0.9750	0.5625	0.00146	1.0563	
upper s	urface and	d thermocou	mles 526 -	588 are or		626	0.7846	0.8020	0.00147	0.8500	
the low	ver (flat-	plate) surf	ace of the	model.		627	0.9173	0.8020	0.00146	0.9937	
Thermoc	ouples 65	7. 666 Inop	erative fo	r entire te	sst	628	0.9750	0.8020	0.00146	1.0563	
program high an I and I	a. Thermoxigle of att	couples 533 tack condit	3, 543 inop itons for C	erative in onfiguratic	suc						
	Thermo- couple Number 580 583 586 583 586 586 586 586 586 547 588 547 588 548 548 548 548 548 548 548 548 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td=""><td>Thermo-         X'         Y'         Skin         Thermo-           Couple         X'         Y'         Thickness         x           S80         0.2308         0         0.00150         0.8563         669           580         0.5058         0.00150         0.8563         670         671           581         0.9750         0.00149         0.2500         6666         671           583         0.9750         0.00149         0.6563         671         673           588         0.9750         0.00149         0.6563         671         671           588         0.9750         0.00149         0.6563         673         673           546         0.7846         0.3125         0.00147         0.9937         673           547         0.9173         0.0147         0.9937         674         673           546         0.7846         0.3125         0.00147         0.9937         674           547         0.9173         0.9123         0.9149         0.9563         674           533         0.7846         0.7846         0.7846         0.7846         675           533         0.9173         0.914</td><td>Thermo-Thermo-Thermo-Thermo-Thermo-X'fThicknessxSeoupleX'FtftftNumber0.001500.001500.056630.23085830.0038800.001500.056636690.23085840.97500.03130.001470.99376710.51925880.97500.31250.001470.99376770.91735840.97500.31250.001470.99376670.91735450.97500.31250.001470.99376670.91735460.78460.31250.001470.99376560.91735470.91730.31250.001470.99376560.91735480.78460.78460.78460.78460.78465470.91730.91230.001470.99376560.91735480.78460.78460.78460.78460.78465330.97500.91730.99376560.91735260.91730.901480.85000.99376560.91735270.91730.56250.001481.05636560.78465280.97500.91730.69130.69230.69235280.97500.91730.80200.001480.99375280.97500.91730.80200.001480.99375280.97500.91730.99370.6923&lt;</td><td>Thermo- Thermo-X'Y'Skin ftThermo- ftX'Y'Y'CoupleX'Y'Thicknessx'Y'Y'S800.230800.001480.25006690.230805830.50580.31250.001430.25006690.230805830.91730.03130.001440.99306660.375005830.97500.31250.001461.05636710.519205830.97500.31250.001471.05636720.519205830.97500.31250.001471.05636720.519205430.97500.31250.001471.05636670.91730.18775460.78460.31250.001471.05636540.91730.18775470.91730.91730.001471.05636540.91730.18775480.97500.31250.001471.05636540.91730.18775330.97500.31250.001481.05636540.91730.18775340.97500.91730.001481.05636540.91730.18775350.97500.901481.05630.601480.95230.91730.91735380.97500.901481.05630.91730.91730.91235290.97500.901481.05630.91730.91730.9123</td><td>Thermo-X'Y'SkinxThermo-x'Y'SkincoupleX'Y'ThicknessxY'ThicknessskinsounderX'Y'Thicknessx'Y'Thicknesssounder0.23080.23080.001480.25630.55630.001480.00148sounder0.001500.85000.65630.55120.001460.001460.00150sounder0.01130.001461.05630.55120.001460.00125sounder0.01130.001461.05630.5710.519200.00125sounder0.01130.001470.99376570.5730.60580.00125sounder0.01130.001470.99376560.78460.001250.00147sounder0.01130.001470.99376560.18870.00125sounder0.01130.001470.99376560.18870.00147sounder0.01440.55250.001470.99376560.18770.00147sounder0.78460.56250.001480.56250.001470.901566570.01147sounder0.78460.56250.001480.56250.001480.56250.00147sounder0.78460.56250.001480.56250.001460.56250.00147sounder0.78460.56250.001480.56250.001460.56250.00147sounder</td><td>Thermo- 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td=""><td>Thermo-         X'         Y'         Skin         Thermo-           Couple         X'         Y'         Thickness         x           S80         0.2308         0         0.00150         0.8563         669           580         0.5058         0.00150         0.8563         670         671           581         0.9750         0.00149         0.2500         6666         671           583         0.9750         0.00149         0.6563         671         673           588         0.9750         0.00149         0.6563         671         671           588         0.9750         0.00149         0.6563         673         673           546         0.7846         0.3125         0.00147         0.9937         673           547         0.9173         0.0147         0.9937         674         673           546         0.7846         0.3125         0.00147         0.9937         674           547         0.9173         0.9123         0.9149         0.9563         674           533         0.7846         0.7846         0.7846         0.7846         675           533         0.9173         0.914</td><td>Thermo-Thermo-Thermo-Thermo-Thermo-X'fThicknessxSeoupleX'FtftftNumber0.001500.001500.056630.23085830.0038800.001500.056636690.23085840.97500.03130.001470.99376710.51925880.97500.31250.001470.99376770.91735840.97500.31250.001470.99376670.91735450.97500.31250.001470.99376670.91735460.78460.31250.001470.99376560.91735470.91730.31250.001470.99376560.91735480.78460.78460.78460.78460.78465470.91730.91230.001470.99376560.91735480.78460.78460.78460.78460.78465330.97500.91730.99376560.91735260.91730.901480.85000.99376560.91735270.91730.56250.001481.05636560.78465280.97500.91730.69130.69230.69235280.97500.91730.80200.001480.99375280.97500.91730.80200.001480.99375280.97500.91730.99370.6923&lt;</td><td>Thermo- Thermo-X'Y'Skin ftThermo- ftX'Y'Y'CoupleX'Y'Thicknessx'Y'Y'S800.230800.001480.25006690.230805830.50580.31250.001430.25006690.230805830.91730.03130.001440.99306660.375005830.97500.31250.001461.05636710.519205830.97500.31250.001471.05636720.519205830.97500.31250.001471.05636720.519205430.97500.31250.001471.05636670.91730.18775460.78460.31250.001471.05636540.91730.18775470.91730.91730.001471.05636540.91730.18775480.97500.31250.001471.05636540.91730.18775330.97500.31250.001481.05636540.91730.18775340.97500.91730.001481.05636540.91730.18775350.97500.901481.05630.601480.95230.91730.91735380.97500.901481.05630.91730.91730.91235290.97500.901481.05630.91730.91730.9123</td><td>Thermo-X'Y'SkinxThermo-x'Y'SkincoupleX'Y'ThicknessxY'ThicknessskinsounderX'Y'Thicknessx'Y'Thicknesssounder0.23080.23080.001480.25630.55630.001480.00148sounder0.001500.85000.65630.55120.001460.001460.00150sounder0.01130.001461.05630.55120.001460.00125sounder0.01130.001461.05630.5710.519200.00125sounder0.01130.001470.99376570.5730.60580.00125sounder0.01130.001470.99376560.78460.001250.00147sounder0.01130.001470.99376560.18870.00125sounder0.01130.001470.99376560.18870.00147sounder0.01440.55250.001470.99376560.18770.00147sounder0.78460.56250.001480.56250.001470.901566570.01147sounder0.78460.56250.001480.56250.001480.56250.00147sounder0.78460.56250.001480.56250.001460.56250.00147sounder0.78460.56250.001480.56250.001460.56250.00147sounder</td><td>Thermo- 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<td< td=""><td>Thermo-         X'         Y'         Skin         Thermo-           Couple         X'         Y'         Thickness         x           S80         0.2308         0         0.00150         0.8563         669           580         0.5058         0.00150         0.8563         670         671           581         0.9750         0.00149         0.2500         6666         671           583         0.9750         0.00149         0.6563         671         673           588         0.9750         0.00149         0.6563         671         671           588         0.9750         0.00149         0.6563         673         673           546         0.7846         0.3125         0.00147         0.9937         673           547         0.9173         0.0147         0.9937         674         673           546         0.7846         0.3125         0.00147         0.9937         674           547         0.9173         0.9123         0.9149         0.9563         674           533         0.7846         0.7846         0.7846         0.7846         675           533         0.9173         0.914</td><td>Thermo-Thermo-Thermo-Thermo-Thermo-X'fThicknessxSeoupleX'FtftftNumber0.001500.001500.056630.23085830.0038800.001500.056636690.23085840.97500.03130.001470.99376710.51925880.97500.31250.001470.99376770.91735840.97500.31250.001470.99376670.91735450.97500.31250.001470.99376670.91735460.78460.31250.001470.99376560.91735470.91730.31250.001470.99376560.91735480.78460.78460.78460.78460.78465470.91730.91230.001470.99376560.91735480.78460.78460.78460.78460.78465330.97500.91730.99376560.91735260.91730.901480.85000.99376560.91735270.91730.56250.001481.05636560.78465280.97500.91730.69130.69230.69235280.97500.91730.80200.001480.99375280.97500.91730.80200.001480.99375280.97500.91730.99370.6923&lt;</td><td>Thermo- Thermo-X'Y'Skin ftThermo- 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        671           581         0.9750         0.00149         0.2500         6666         671           583         0.9750         0.00149         0.6563         671         673           588         0.9750         0.00149         0.6563         671         671           588         0.9750         0.00149         0.6563         673         673           546         0.7846         0.3125         0.00147         0.9937         673           547         0.9173         0.0147         0.9937         674         673           546         0.7846         0.3125         0.00147         0.9937         674           547         0.9173         0.9123         0.9149         0.9563         674           533         0.7846         0.7846         0.7846         0.7846         675           533         0.9173         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### TABLE 4

## TEST SCHEDULE FOR THE 50-INCH HYPERSONIC WIND TUNNEL AT MACH 8.08

Configuration	Tr	cailing H Control	ldge	a Range	$Re_{r}/ft \times 10^6$
	F	Partial S Flaps	Span		
	δ1	δ2	δ3		
I Spoiler off Conical forebody Fins off	0 0 0 0 0 0 0	0 +10 +20 +30 +39 -10 -20 -30 -39	0 +10 +20 +30 +39 -10 -20 -30 -39	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	3.3
IV Spoiler off Conical forebody Fins on		0 +10 +20 +30 +39 -10 -20 -30 -39	0 +10 +20 +30 +39 -10 -20 -30 -39	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	3.3
VII Spoiler on Blunt forebody Fins off	0	0	0	0 -20 0	3.3 1.1
VIII Spoiler on Blunt forebody Fins on	0	0	0	0	3.3
IX Spoiler off Blunt forebody Fins off	0 0 0 0 0 0 0 0 0	0 +20 +20 +40 +40 -20 -20 -40 -40	0 +20 +20 +40 +40 -20 -20 -40 -40	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	3.3 1.1 3.3 1.1 3.3 1.1 3.3 1.1 3.3 1.1 3.3 1.1
X Spoiler off Blunt forebody Fins off Full span flap	+20 +20	+20 +20	+20 +20	0 +20 0	3.3 1.1

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Separated Flows ahead of a Ramp Fore and aft flaps, end plates 3 separate models:

- Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8
- 2) Controlled wall temperature, pressure, AEDC Tunnel B, M = 8
- 3) Pressure and heat transfer, Grumman Shock Tunnel, M  $\simeq 13$  & 19

Wedge - Plate Interaction Small and large fins with sharp and blunt leading edges 2 separate models:

- Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8
- 2) Pressure and heat transfer, Grumman Shock Tunnel,  $M \approx 13 \ \& \ 19$
- Clipped Delta, Blunt L.E. Center body, T.E. flaps, drooped nose, spoiler, tip fins 3 separate models:
- Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8
- 2) Pressure, AEDC Hotshot 2, M 5 19
- 3) Six component force, AEDC Tunnels A & B, M = 5 & 8



- Delta, Blunt L.E. Dihedral T.E. flaps. canard, ventral fin 3 separate models:
- Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8
- 2) Pressure and heat transfer, Grumman Shock Tunnel, M  $\gtrsim 19$
- 3) Six component force, AEDC Tunnels A & B, M = 5 & 8

Fig. la General Outline of Models and Remarks for Over-all Program



Fig. 1b Configuration I - Basic Wing-Body





Fig. 1d Configuration VII - Wing-Blunt Body + Full Span Plug Spoiler (for dimensions see Fig. 1b)





1

Fig. le Configuration VIII - Wing-Blunt Body + Full Span Plug Spoiler + Tip Fins (for dimensions see Figs. 1b, lc, ld)



Fig. 1f Configuration IX - Wing-Blunt Body (for dimensions see Figs.1b, 1d)





Fig. 1h Thermocouple Location and Model Coordinate System

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Fig. 1j Bottom View Photograph - Configuration I



Tressource mach & Wind Tunnel



Fig. 1% Rear View Photograph - Configuration IV, Mounted on Actuator Housing in the 50" Hypersonic Mach 8 Wind Tunnel

















Fig. 3 Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = 0$ a) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface b) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface







(NONDIMENSIONAL STREAMWIBE DISTANCE FROM VIRTUAL APEX)

Fig. 3 Configuration I, α = 0, δ<sub>2</sub> = δ<sub>3</sub> = 0
c) Nu//Re<sub>x</sub> vs. X' lower surface
d) Nu//Re<sub>x</sub> vs. X' upper surface







Fig. 3f Configuration I,  $\alpha = 0$ ,  $b_2 = b_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 3g Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = \pm 10$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface











Fig. 3j Configuration I,  $\alpha = 0$ ,  $n_2 = n_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 3k Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 31 Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 3m Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 3n Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 30 Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +30$ Nu $^{7}\sqrt{Re_x}$  vs. Y' upper surface



Fig. 3p Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{\text{Rex}}$  vs. X' upper surface


Fig. 3q Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 3r Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 3s Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 3t Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface







Nu Nu



Fig. 4c Configuration I,  $\alpha = 0$ ,  $b_2 = b_3 = -20$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



 $Nu/\sqrt{Re_x}$  vs. X' upper surface



Fig. 4e Configuration I,  $\alpha = 0$ ,  $b_2 = b_3 = -30$ Nu/ $\sqrt{Re_x}$  vs. Y<sup>1</sup> upper surface



Fig. 4f Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = -30$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



$$Nu/\sqrt{Re_x}$$
 vs. Y' upper surface



Fig. 4h Configuration I,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface





m)  $\delta_2 = \delta_3 = -10$ n)  $\delta_2 = \delta_3 = -20$ o)  $\delta_2 = \delta_3 = -30$ p)  $\delta_2 = \delta_3 = -39$ 







Fig. 5 Configuration I, 
$$\alpha = +10$$
,  $\delta_2 = \delta_3 = 0$   
a) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface  
b) Nu/ $\sqrt{Re_y}$  vs. Y' lower surface



c)  $Nu/\sqrt{Re_x}$  vs. X' upper surface d)  $Nu/\sqrt{Re_x}$  vs. X' lower surface



Fig. 5e Configuration I,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = +10$ 

Nu/ Rex vs. Y' lower surface



Fig. 5f Configuration I,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = \pm 10$ Nu//Rex vs. X' lower surface





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Fig. 5 Configuration I,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = \pm 10$ g) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface h) Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Nu Re<sub>x</sub>

1

2.

Fig. 51 Configuration I,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 5j Configuration I,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = +20$ 

Nu/<sub>1</sub>/Re<sub>x</sub> vs. X' lower surface







Fig. 5*t* Configuration I,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = \pm 30$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 5 Configuration I,  $\alpha = +10$ , Nu/ $\sqrt{Re_x}$  vs. Y', upper surface

o)  $\delta_2 = \delta_3 = +20$ p)  $\delta_2 = \delta_3 = +30$ q)  $\delta_2 = \delta_3 = +39$ 



Fig. 5 Configuration I,  $\alpha$  = +10, Nu/ $\sqrt{Re_{\chi}}$  vs. X', upper surface

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r)  $\delta_2 = \delta_3 = +20$ s)  $\delta_2 = \delta_3 = +30$ t)  $\delta_2 = \delta_3 = +39$ 



a)  $Nu / Re_{x} vs. Y'$  lower surface b)  $Nu / Re_{x} vs. X'$  lower surface





Fig. 6 Configuration I, 
$$\alpha = +10$$
,  $\delta_2 = \delta_3 = -10$ 

c) Nu/<del>/Re<sub>x</sub></del>vs.Y' upper surface d) Nu/<del>/Re<sub>x</sub></del>vs.X' upper surface





Fig. 6g Configuration I,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = -20$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 6h Confir ration I,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = -20$ N:  $x = \frac{1}{x} vs$ , X' upper surface



.





Fig. 6 Configuration I,  $\alpha = \pm 10$ ,  $b_2 = b_3 = -30$ i) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface j) Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 6k Configuration I,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = -30$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 6*l* Configuration I,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = -30$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface







Fig. 6 Configuration I,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = -39$ m)  $Nu/\sqrt{Re_x}$  vs. Y' lower surface n)  $Nu/\sqrt{Re_x}$  vs. X' lower surface



Fig. 60 Configuration I,  $\alpha = \pm 10$ ,  $b_2 = b_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 6p Configuration I,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface


Fig. 7a Configuration I,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface







Fig. 7c Configuration I,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 7d Configuration I,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



e)  $Nu/\sqrt{Re_x}$  vs. Y' lower surface f)  $Nu/\sqrt{Re_x}$  vs. X' lower surface



 $\checkmark$ 

Fig. 7g Configuration I,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 7h Configuration I,  $\alpha = +20$ ,  $b_2 = b_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. X<sup>1</sup> lower surface



Fig. 71 Configuration I,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 7j Configuration I,  $\alpha = +20$ ,  $b_2 = b_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



JE

7

J







Fig. 8 Configuration I,  $\alpha = +20$ ,  $b_2 = b_3 = -20$ c) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface





Fig. 8 Configuration I,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -30$ e) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 8 Configuration I,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -39$ g) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



(NONDIMENSIONAL SEMISPAN DISTANCE)



(NONDIMENSIONAL SEMISPAN DISTANCE)



(NONDIMENSIONAL STREAMWISE DISTANCE FROM VIRTUAL APEX)





Fig. 8 Configuration I,  $\alpha = +20$ , upper surface

i)  $Nu/\sqrt{Re_x}$  vs. Y'  $\delta_2 = \delta_3 = -10$ j)  $Nu/\sqrt{Re_x}$  vs. Y'  $\delta_2 = \delta_3 = -20$ k)  $Nu/\sqrt{Re_x}$  vs. X'  $\delta_2 = \delta_3 = -10$ l)  $Nu/\sqrt{Re_x}$  vs. X'  $\delta_2 = \delta_3 = -20$ 100



Fig. 8m Configuration I,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -30$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface

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Fig. 8n Configuration I,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -30$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface





 $Nu/\sqrt{Re_x}$  vs. Y' upper surface

ar a . . .



Fig. 8p Configuration I,  $\alpha = +20$ ,  $\beta_2 = \beta_3 = -39$ Nu//Re vs. X' upper surface







Fig. 9b Configuration I,  $\alpha = +30$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 9c Configuration I,  $\alpha = +35$ ,  $\delta_2 = \delta_3 = 0$ Nu $\sqrt{Re_x}$  vs. Y' lower surface

P





Fig. 9d Configuration I,  $\alpha = +35$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface







.











Fig. 9h Configuration I,  $\alpha = +45$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface









Fig. 9j Configuration I,  $\alpha = +50$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface













Fig. 10 Configuration I,  $\alpha = -10$ ,  $b_2 = b_3 = 0$ a) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface b) Nu/ $\sqrt{Re_x}$  vs. X' lower surface









Fig. 10d Configuration I, 
$$\alpha = -10$$
,  $\delta_2 = \delta_3 = 0$   
Nu/ $\sqrt{Re_v}$  vs. X' upper surface









Fig. 10 Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +10$ e) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface f) Nu/ $\sqrt{Re_x}$  vs. X' lower surface


Fig. 10g Configuration I,  $\alpha = -10$ ,  $b_2 = b_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 10h Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 101 Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +20$ NuL/Re vs. Y' lower surface



Nu//Re vs. X' lower surface



Fig. 10k Configuration I,  $\alpha = -10$ ,  $b_2 = b_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 10/ Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{2}$  vs. X' upper surface



Fig. 10m Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Nu/ Rex vs. X' lower surface



Fig. 100 Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. Y<sup>4</sup> upper surface



Fig. 10p Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 10q Configuration I,  $\alpha = -10$ ,  $b_2 = b_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 10r Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 10s Configuration I,  $\alpha = -10$ ,  $b_2 = b_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 10t Configuration I,  $\alpha = -10$ ,  $b_2 = b_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface

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Fig. 111 Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = -10$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 11j Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = -10$ Nu/ $\sqrt{Re_x}$  vs. X° upper surface



Fig. 11k Configuration I,  $\alpha = -10$ ,  $b_2 = b_3 = -20$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 11/ Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = -20$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface









Fig. 11 Configuration I,  $\alpha = -10$ ,  $b_2 = b_3 = -30$ m) Nu $/\sqrt{Re_x}$  vs. Y' upper surface n) Nu $/\sqrt{Re_x}$  vs. X' upper surface



Fig. 11 Configuration I,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = -39$ o) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface p) Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 12 Configuration I,  $\alpha$  = -20, Nu/ $\sqrt{Re_{_X}}$  vs. Y', lower surface

a)  $b_2 = b_3 = 0$ b)  $b_2 = b_3 = +10$ c)  $b_2 = b_3 = +20$ 



d) 
$$b_2 = b_3 = 0$$
  
e)  $b_2 = b_3 = +10$   
f)  $b_2 = b_3 = +20$ 



Fig. 12g Configuration I,  $\alpha = -20$ ,  $b_2 = b_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



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Fig. 12h Configuration I,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re}$  J. X' upper surface



Fig. 12i Configuration I,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +10$ Nu $/\sqrt{Re_x}$  vs. Y' upper surface



Fig. 12j Configuration I,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 12k Configuration I,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +20$ Nu $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 12/ Configuration I,  $\alpha = -20$ ,  $b_2 = b_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface







Fig. 12n Configuration I,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface

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Fig. 120 Configuration I,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +30$ Nu/,  $\overline{\text{Re}_x}$  vs. Y' upper surface



Fig. 12p Configuration I,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface










Fig. 12s Configuration I,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y<sup>1</sup> upper surface



Fig. 12t Configuration I,  $\alpha = -20$ ,  $b_2 = b_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface V







Fig. 131 Configuration I,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = -10$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface

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Fig. 13j Configuration I,  $\alpha = -20$ ,  $b_2 = b_3 = -10$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface













Fig. 130 Configuration I,  $\alpha = -20$ ,  $b_2 = b_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 13p Configuration I,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface





Fig. 14g Configuration I,  $\alpha = -30$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 14h Configuration I,  $\alpha = -30$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



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Fig. 141 Configuration I,  $\alpha = -40$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 14j Configuration I,  $\alpha = -40$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 14k Configuration I,  $\alpha = -50$ ,  $\delta_2 = \delta_3 = 0$  $\frac{\kappa_u}{\sqrt{Re_x}}$  vs. Y' upper surface





Fig. 14*t* Configuration I,  $\alpha = -50$ ,  $\delta_2 = \delta_3 = 0$ Nu $\sqrt{Re_x}$  vs. X' upper surface



Fig. 15 Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = 0$ a) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface b) Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 15 Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = 0$ c) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface d) Nu/ $\sqrt{Re_x}$  vs. X' upper surface









Fig. 15f Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +10$ Nu/VRex vs. X' lower surface



Nu VRe<sub>x</sub>

Nu/VRex vs. Y' upper surface



Fig. 15h Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = \pm 10$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface







Fig. 15j Configuration IV,  $\alpha = 0$ ,  $b_2 = b_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. X<sup>1</sup> lower surface



Fig. 15k Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 15% Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface







Fig. 15n Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{\text{Re}_x}$  vs. X' lower surface



Nu VRe<sub>x</sub>



Fig. 15p Configuration IV, 
$$\alpha = 0$$
,  $\delta_2 = \delta_3 = +30$   
Nu/ $\sqrt{Re}$  vs. X' upper surface

Nu Re<sub>x</sub>



(NONDIMENSIONAL SEMISPAN DISTANCE)



Fig. 15 Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +39$ q) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface r) Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 15s Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +39$ 





Fig. 15t Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +39$  $\frac{3}{\sqrt{Re_x}}$  vs. X' upper surface

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d)  $b_2 = b_3 = -39$ 



 $\checkmark$


Fig. 161 Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = -10$ Nu $/\sqrt{Re_x}$  vs. Y' upper surface

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Fig. 16j Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = -10$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 16k Configuration IV,  $\alpha = 0$ ,  $b_2 = b_3 = -20$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface





Fig. 16m Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = -30$ Nu $/\sqrt{Re_x}$  vs. Y' upper surface



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Fig. 16n Configuration IV,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = -30$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface







Fig. 17b Configuration IV,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 17c Configuration IV,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 17d Configuration IV,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface











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Fig. 171 Configuration IV,  $\alpha = +10$ ,  $b_2 = b_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 17j Configuration IV,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = \pm 39$ Nu/ $\sqrt{Re_x}$  vs. X<sup>1</sup> lower surface



- k) Nu $\sqrt{Re_x}$  vs. Y' upper surface
- 1) Nu/ $\sqrt{Re_x}$  vs. X' upper surface











Fig. 18b Configuration IV,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = -10$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Nu Re<sub>x</sub>

Fig. 18c Configuration IV,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = -10$ Nu/ $\sqrt{Rr}$  /s. Y' upper surface



Fig. 18d Configuration IV,  $\alpha$  = +10,  $\delta_2$  =  $\delta_3$  = -10

 $Nu/\sqrt{Re_x}$  vs. X' upper surface



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Fig. 18 Configuration IV,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = -20$ e) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface f) Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 18g Configuration IV,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = -20$ Nu $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 18h Configuration IV,  $\alpha = +10$ ,  $b_2 = b_3 = -20$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 18 Configuration IV,  $\alpha = \pm 10$ ,  $5_2 = 5_3 = -30$ 

i)  $Nu/\sqrt{Re_x}$  vs. Y' lower surface

j)  $Nu/\sqrt{Re_x}$  vs. X' lower surface







Fig. 18*l* Configuration IV,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = -30$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 18 Configuration IV,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = -39$ m) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface n) Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 180 Configuration IV,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 18p Configuration IV,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface







 $\sqrt{\frac{Nu}{Re_{x}}}$ 

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Fig. 19c Configuration IV,  $\alpha = +20$ ,  $b_2 = b_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 19d Configuration IV,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = +10$  $Nu/\sqrt{Re_x}$  vs. X' lower surface


Fig. 19 Configuration IV,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = +20$ e) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface f) Nu/ $\sqrt{Re_x}$  vs. X' lower surface



√Nu √Re<sub>x</sub>

Fig. 19g Configuration IV,  $\alpha = +20$ ,  $b_2 = b_3 \approx +30$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 19h Configuration IV,  $\alpha = +20$ ,  $b_2 = b_3 = +30$ Nu/ $\overline{Re_x}$  vs. X' lower surface

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Fig. 19j Configuration IV,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = +39$ Nu<sub>i</sub> $\sqrt{Re_x}$  vs. X' lower surface







Fig. 19 Configuration IV, α = +20, Nu/√Re<sub>x</sub> vs. Y', upper surface
k) δ<sub>2</sub> = δ<sub>3</sub> = 0
1) δ<sub>2</sub> = δ<sub>3</sub> = +10
m) δ<sub>2</sub> = δ<sub>3</sub> = +20



Fig. 19 Configuration IV,  $\alpha = +20$ , Nu/ $\sqrt{Re_x}$  vs. X<sup>+</sup>, upper surface

- n)  $\delta_2 = \delta_3 = 0$ o)  $\delta_2 = \delta_3 = +10$
- p)  $b_2 = b_3 = +20$





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(NONDIMENSIONAL STREAMWISE DISTANCE FROM VIRTUAL APEX)

Fig. 19 Configuration IV,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = +30$ q) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface r) Nu/ $\sqrt{Re_x}$  vs. X' upper surface









Fig. 20b Configuration IV,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -10$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



(NONDIMENSIONAL SEMISPAN DISTANCE)





Fig. 20 Configuration IV,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -10$ c) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface d) Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 20 Configuration IV,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -20$ e) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface

f)  $Nu/\sqrt{Re_x}$  vs. X' lower surface



Fig. 20 Configuration IV,  $\alpha = +20$ ,  $\beta_2 = \beta_3 = -20$ g) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface h) Nu/ $\sqrt{Re_x}$  vs. X' upper surface



L) 
$$Nu/\sqrt{Re_x}$$
 vs. Y' lower surface



Fig. 20k Configuration IV,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -30$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 20*l* Configuration IV,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -30$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Nu Re,



Fig. 200 Configuration IV,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface







Fig. 21a Configuration IV,  $\alpha = +35$ ,  $\delta_2 = \delta_3 = 0$ Nu $\sqrt{Re_x}$  vs. Y' lower surface







Fig. 21e Configuration IV,  $\alpha = +40$ ,  $b_2 = b_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 21d Configuration IV,  $\alpha = +40$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



f) 
$$Nu/\sqrt{Re_x}$$
 vs. Y',  $\alpha = +40$   
g)  $Nu/\sqrt{Re_x}$  vs. X',  $\alpha = +35$   
h)  $Nu/\sqrt{Re_x}$  vs. X',  $\alpha = +40$ 

g) h)







Fig. 21j Configuration IV,  $\alpha = +45$ ,  $b_2 = b_3 = 0$ Nu $\sqrt{Re_x}$  vs. X' lower surface





(NONDIMENSIONAL STREAMWISE DISTANCE FROM VIRTUAL APEX)

Fig. 21 Configuration IV,  $\alpha = +45$ ,  $\delta_2 = \delta_3 = 0$ k) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface 1) Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 21m Configuration IV,  $\alpha = +50$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Nu VRe<sub>x</sub>

Fig. 21n Configuration IV,  $\alpha = +50$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 210 Configuration IV,  $\alpha = +50$ ,  $b_2 = b_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 21p Configuration IV,  $\alpha = +50$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{2\epsilon_x}$  vs. X' upper surface



a)  $Nu/\sqrt{Re_x}$  vs. Y' lower surface b)  $Nu/\sqrt{Re_x}$  vs. X' lower surface







Fig. 22d Configuration IV,  $\alpha = -10$ ,  $b_2 = b_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface




Fig. 22f Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +10$  $Nu/\sqrt{Re_x}$  vs. X' lower surface

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Fig. 22g Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface

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0

Nu Re<sub>x</sub>



Fig. 22h Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +10$ Nu $\sqrt{Re_x}$  vs. X' upper surface

x







Fig. 22j Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 22k Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. Y<sup>1</sup> upper surface



(NONDIMENSIONAL STREAMWISE DISTANCE FROM VIRTUAL APEX)

Fig. 22*l* Configuration IV,  $\alpha = -10$ ,  $b_2 = b_3 = +20$ Nu $/\sqrt{Re_x}$  vs. X' upper surface







Fig. 22n Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. X<sup>\*</sup> lower surface



Fig. 220 Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 22p Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 22q Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface



Fig. 22r Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X<sup>1</sup> lower surface







Fig. 22t Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface







Nu Re<sub>x</sub>

Fig. 231 Coeffiguration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = -10$ Nu/ $\sqrt{Re}$  vs. Y' upper surface



Fig. 23j Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = -10$ Nu $\sqrt{Re_x}$  vs. X' upper surface



Fig. 23 Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = -20$ k) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface 1) Nu/ $\sqrt{Re_x}$  vs. X' upper surface

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Fig. 23 Configuration IV,  $\alpha = -10$ ,  $\delta_2 = \delta_3 = -30$ m) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface n) Nu/ $\sqrt{Re_x}$  vs. X' upper surface

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o) Nu/<sub>v</sub>/<del>Re<sub>x</sub></del> vs. Y' upper surface

p) Nu//Re\_vs. X' upper surface



28'



Fig. 24e Configuration IV,  $\alpha = -20$ ,  $b_2 = b_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 24f Configuration IV,  $\alpha = -20$ ,  $b_2 = b_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



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Fig. 24g Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +10$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 24h Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +10$ Nu/,  $Re_x$  vs. X' upper surface







F'g. 24j Configuration IV,  $\alpha = -20$ ,  $b_2 = b_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Fig. 24k Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 24? Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +20$ Nu/,  $Re_{\chi}^{-}$  vs. X' upper surface



VRe<sub>x</sub>





Fig. 24n Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface



Nu Re<sub>x</sub>

Fig. 240 Configuration IV,  $\alpha = -20$ ,  $b_2 = b_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 24p Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +30$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface






Fig. 24r Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface











Fig. 25 Configuration IV,  $\alpha = -20$ , Nu/ $\sqrt{Re_x}$  vs. Y', lower surface

a)  $\delta_2 = \delta_3 = -10$ b)  $\delta_2 = \delta_3 = -20$ c)  $\delta_2 = \delta_3 = -30$ d)  $\delta_2 = \delta_3 = -39$ 



Fig. 25 Configuration IV,  $\alpha = -20$ , Nu/ $\sqrt{Re_x}$  vs. X', lower surface

e)  $\delta_2 = \delta_3 = -10$ f)  $\delta_2 = \delta_3 = -20$ g)  $\delta_2 = \delta_3 = -30$ 

h)  $b_2 = b_3 = -39$ 







(NONDIMENSIONAL STREAMWISE DISTANCE FROM VIRTUAL APEX)

Fig. 25 Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = -10$ i) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface j) Nu/ $\sqrt{Re_x}$  vs. X' upper surface









Fig. 25 Configurat on IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = -20$ k) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface

1) Nu/ $\sqrt{Re_x}$  vs. X' upper surface







(NONDIMENSIONAL STREAMWISE DISTANCE FROM VIRTUAL APEX)

Fig. 25 Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = -30$ m) Nu/ $\sqrt{R_{\pi_X}}$  vs. Y' upper surface n) Nu/ $\sqrt{R_{\pi_X}}$  vs. X' upper surface



Fig. 250 Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 25p Configuration IV,  $\alpha = -20$ ,  $\delta_2 = \delta_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



- b) Nu/ $\sqrt{Re_x}$  vs. Y',  $\delta_2 = \delta_3 = +39$
- c) Nu/ $\sqrt{Re_x}$  vs. X',  $\delta_2 = \delta_3 = 0$
- d) Nu/ $\sqrt{Re_x}$  vs. X',  $\delta_2 = \delta_3 = +39$ 
  - 311



Fig. 26 e Configuration IV,  $\alpha = -30$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Fig. 26f Configuration IV,  $\alpha = -30$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Nu Re<sub>x</sub>





Fig. 26h Configuration IV,  $\alpha = -30$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface





Fig. 27e Configuration IV,  $\alpha = -40$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



Nu Nu Re<sub>x</sub>





'Fig. 27g Configuration IV,  $\alpha = -40$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface







Fig. 28 Configuration IV,  $\alpha = -50$ ,  $\delta_2 = \delta_3 = 0$ a) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface b) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface



<sup>(</sup>NONDIMENSIONAL STREAMWISE DISTANCE FROM VIRTUAL APEX)



Fig. 28 Configuration IV,  $\alpha = -50$ ,  $\delta_2 = \delta_3 = 0$ c) Nu/ $\sqrt{Re_x}$  vs. X' lower surface d) Nu/ $\sqrt{Re_x}$  vs. X' upper surface



Fig. 29a Configuration VII,  $\alpha = 0$ , Spoiler on Nu/ $\sqrt{Re_x}$  vs. Y', lower surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 







d) Nu/ $\sqrt{Re_x}$  vs. X', upper surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 29e Configuration VII,  $\alpha = 0$ , Spoller on  $\frac{10}{\sqrt{Re_x}}$  vs. Y', lower surface,  $\frac{Re}{ft} \times 10^{-6} = 1.1$ 

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g) Nu/ $\sqrt{Re_x}$  vs. Y', upper surface,  $Re_{\infty}/ft \ge 10^{-6} = 1.1$ h) Nu/ $\sqrt{Re_x}$  vs. X', upper surface,  $Re_{\infty}/ft \ge 10^{-6} = 1.1$ 





Fig. 29 Configuration VII,  $\alpha = -10$ , Spoiler on

i) 
$$Nu/\sqrt{Re_x}$$
 vs. Y' lower surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$   
j)  $Nu/\sqrt{Re_x}$  vs. X' lower surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



 $Nu/\sqrt{Re_x}$  vs. Y' upper surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 29/ Configuration VII,  $\alpha = -10$ , Spoiler on Nu/ $\sqrt{Re_x}$  vs. X' upper surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 







Fig. 29 Configuration VII,  $\alpha = -20$ , Spoiler on

m) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ n) Nu/ $\sqrt{Re_x}$  vs. X' lower surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 290 Configuration VII,  $\alpha = -20$ , Spoiler on Nu/ $\sqrt{Re_x}$  vs. Y' upper surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 29p Configuration VII,  $\alpha = -20$ , Spoiler on

 $Nu/\sqrt{Re_x}$  vs. X' upper surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 30a Configuration VIII,  $\alpha = 0$ , Spoiler on, Fins on Nu/ $\sqrt{Re_x}$  vs. Y', lower surface,  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 



Fig. 30b Configuration VIII,  $\alpha = 0$ , Spoiler on, Fins on Nu/ $\sqrt{Re_x}$  vs. X', lower surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$


Fig. 30c Configuration VIII,  $\alpha = 0$ , Spoiler on, Fins on Nu/ $\sqrt{Re_x}$  vs. Y', upper surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 30d Configuration VIII,  $\alpha = 0$ , Spoiler on, Fins on Nu/ $\sqrt{Re_x}$  vs. X', upper surface,  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



ig. 31a Configuration IX, 
$$\alpha = 0$$
,  $\delta_2 = \delta_3 = +20$   
Nu/ $\sqrt{Re_1}$  vs. Y' lower surface Re\_/ft x 10<sup>-6</sup> = 3.3



Fig. 31b Configuration IX,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface  $Re_m/ft \ge 10^{-6} = 3.3$ 

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Fig. 31c Configuration IX,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 31d Configuration IX,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  v... X' upper surface  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



e) Nu/
$$\sqrt{Re_x}$$
 vs. Y' lower surface  
f) Nu/ $\sqrt{Re_x}$  vs. X' lower surface

















Fig. 32 Configuration IX, 
$$\alpha = 0$$
,  $\beta_2 = \beta_3 = -20$ 

a)  $Nu/\sqrt{Re_x}$  vs. Y' lower surface b)  $Nu/\sqrt{Re_x}$  vs. X' lower surface Re<sub>o</sub>/ft x 10<sup>-6</sup> = 3.3







Fig. 32d Configuration IX,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = -20$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 



h)  $Nu/\sqrt{Re_x}$  vs. X' upper surface



Fig. 33a Configuration IX,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 33b Con. (guration IX,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{r}$ , vs. X' lower surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 



Fig. 33c Configuration IX,  $\alpha = \pm 10$ ,  $b_2 = b_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface  $Re_m/ft \times 10^{-6} = 3.3$ 



Fig. 33d Configuration IX, 
$$\alpha = \pm 10$$
,  $\delta_2 = \delta_3 = 0$   
Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_{\omega}/ft \times 10^{-6} = 3.3$ 



Fig. 33e Configuration IX,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = \pm 20$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 



Fig. 33f Configuration IX,  $\alpha = \pm 10$ ,  $\beta_2 = \beta_3 = \pm 20$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 



Fig. 33g Configuration IX,  $x = \pm 10$ ,  $\delta_2 = \delta_3 = \pm 20$ Nu/ $\sqrt{Re_x}$  vs. Y<sup>t</sup> upper surface  $Re_{\omega}/ft \ge 10^{-6} = 3.3$ 







Fig. 331 Configuration IX,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 33j Configuration IX,  $\alpha = +10$ ,  $b_2 = b_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 



Fig. 33k Configuration IX, 
$$\alpha = \pm 10$$
,  $\delta_2 = \delta_3 = \pm 39$   
Nu $\sqrt{Re_2}$  vs. Y<sup>+</sup> upper surface Re\_/ft x 10<sup>-6</sup> = 3.3



Fig. 33*l* Configuration IX,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 34 Configuration IX,  $\alpha = \pm 10$ ,  $b_2 = b_3 = -20$ a) Nu $\sqrt{Re_x}$  vs. Y' lower surface b) Nu $\sqrt{Re_x}$  vs. X' lower surface  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 34c Configuration IX,  $\alpha = +10$ ,  $\delta_2 = \delta_3 = -20$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface  $Re_m/ft \times 10^{-6} = 3.3$ 



Fig. 34d Configuration IX,  $\alpha = \pm 10$ ,  $b_2 = b_3 = \pm 20$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_c/ft \times 10^{-6} = 3.3$ 





Fig. 34g Configuration IX,  $\alpha = \pm 10$ ,  $\delta_2 = \delta_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 



Fig. 34h Configuration IX,  $\alpha = +10$ ,  $\overline{b}_2 = \overline{b}_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 







(NONDIMENSIONAL STREAMWISE DISTANCE FROM VIRTUAL APEX)

Fig. 35b Configuration IX, 
$$\alpha = +20$$
,  $\delta_2 = \delta_3 = 0$   
Nu/ $\sqrt{Re_v}$  vs. X' lower surface Re\_/ft x 10<sup>-5</sup> = 3.3



Fig. 35c Configuration IX,  $\alpha = +20$ ,  $b_2 = b_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 



Fig. 35d Configuration IX,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 









Fig. 3° Configuration IX, 
$$\alpha = +20$$
,  $\delta_2 = \delta_3 = +20$   
e) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface  
f) Nu/ $\sqrt{Re_x}$  vs. X' lower surface



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Fig. 35h Configuration IX,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = +20$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 







Fig. 35j Configuration IX,  $\alpha = +20$  b<sub>2</sub> = b<sub>3</sub> = +39 Nu/ $\sqrt{Re_x}$  vs. X' lower surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 







Fig. 35! Configuration IX,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 



Nu Re<sub>x</sub>





Fig. 36b Configuration IX,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -20$ Nu/ $\sqrt{Re_x}$  vs. X' lower surface  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 

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Fig. 36d Configuration IX,  $\alpha = +20$ ,  $\delta_2 = \delta_3 = -20$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 36e Configuration IX,  $\alpha = +20$ ,  $b_2 = b_3 = -39$ Nu/ $\sqrt{Re_x}$  vs. Y' lower surface  $Re_{\infty}/ft \times 10^{-6} = 3.3$ 



Fig. 36f Configuration IX, 
$$\alpha = +20$$
,  $\delta_2 = \delta_3 = -39$   
Nu $\langle Re_v vs. X'$  lower surface  $Re_v/ft \times 10^{-6} = 3.3$ 







(NONDIMENSIONAL STREAMWISE DISTANCE FROM VIRTUAL APEX)

Fig. 36h Configuration IX, 
$$\alpha = +20$$
,  $b_2 = b_3 = -39$   
Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_{\infty}/ft \ge 10^{-6} = 3.3$ 



Nu Nu Re



(NONDIMENSIONAL SEMISPAN DISTANCE)

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Fig. 37g Configuration IX, 
$$a = 0$$
,  $b_2 = b_3 = 0$   
Nu/ $\sqrt{Re_v}$  vs. Y' upper surface  $Re_v/ft \ge 10^{-6} = 1.1$ 



Fig. 37h Configuration IX,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = 0$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_z/ft \times 10^{-6} = 1.1$ 



1) 
$$Nu/\sqrt{Re}$$
 vs. Y' upper surface

j) 
$$Nu/\sqrt{Re_v}$$
 vs. X' upper surface







Fig. 37 Configuration IX, 
$$\alpha = 0$$
,  $\delta_2 = \delta_3 = -39$   
k) Nu/ $\sqrt{Re_x}$  vs. Y' upper surface  
1) Nu/ $\sqrt{Re_x}$  vs. X' upper surface  
Re\_/ft x 10<sup>-6</sup> = 1.1



Fig. 37 Configuration IX, 
$$\alpha = 0$$
,  $\delta_2 = \delta_3 = +20$   
m) Nu/ $\sqrt{Re_x}$  vs. Y' lower surface  
n) Nu/ $\sqrt{Re_y}$  vs. X' lower surface  
Re<sub>w</sub>/ft x 10<sup>-6</sup> = 1.1











Nu VRc<sub>x</sub>





(NONDIMENSIONAL STREAMWISE DISTANCE FROM VIRTUAL APEX)

Fig. 37r Configuration IX, r = 0,  $r_2 = r_3 = +39$ Nu/ $Re_x$  vs. X' lower surface Re /ft x 10<sup>-6</sup> = 1.1



Fig. 37s Configuration IX,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. Y' upper surface  $Re_a/ft \times 10^{-6} = 1.1$ 



Fig. 37t Configuration IX,  $\alpha = 0$ ,  $\delta_2 = \delta_3 = +39$ Nu/ $\sqrt{Re_x}$  vs. X' upper surface  $Re_{\infty}/ft \times 10^{-6} = 1.1$ 





Nu Re<sub>x</sub>



Fig. 38b Configuration X, 
$$r = 0$$
,  $b_1 = b_2 = b_3 = +20$ ,  $\text{Re}_{\infty}/\text{ft} \ge 10^{-6} = 3.3$ 

Nu/ Re vs. X' lower surface



Fig. 38c Configuration X,  $\alpha = 0$ ,  $b_1 = b_2 = b_3 = +20$ ,  $\text{Re}_{\infty}/\text{ft} \ge 10^{-6} = 3.3$ Nu/ $\sqrt{\text{Re}_{x}}$  vs. Y' upper surface



Fig. 38d Configuration X,  $\alpha = 0$ ,  $\delta_1 = \delta_2 = \delta_3 = +20$ ,  $\text{Re}_{\infty}/\text{ft} \ge 10^{-6} = 3.3$  $Nu/\sqrt{Re_x}$  vs. X' upper surface

 $\sqrt{\frac{Nu}{Re}_x}$ 



Fig. 38e Configuration X,  $\alpha = 0$ ,  $\delta_1 = \delta_2 = \delta_3 = +20$ ,  $Re_{\infty}/ft \ge 10^{-6} = 1.1$ Nu/ $\sqrt{Re_{\chi}}$  vs. Y' lower surface







 $Nu/\sqrt{Re_{\chi}}$  vs. Y' upper surface



Fig. 38h Configuration X,  $\alpha = 0$ ,  $\delta_1 = \delta_2 = \delta_3 = +20$ ,  $\text{Re}_{\infty}/\text{ft x } 10^{-6} = 1.1$ Nu/ $\sqrt{\text{Re}_x}$  vs. X<sup>s</sup> upper surface



 $\sqrt{\frac{N}{R}}$ 

Fig. 38i Configuration X,  $\alpha = \pm 10$ ,  $\delta_1 = \delta_2 = \delta_3 = \pm 20$ , Re /ft x  $10^{-6} = 3.3$ Nu/ $\sqrt{\text{Re}_x}$  vs. Y' lower surface



Fig. 38j Configuration X,  $\alpha = \pm 10$ ,  $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \pm 20$ ,  $\text{Re}_{\alpha}/\text{ft} \ge 10^{-6} = 3.3$ Nu/ $\sqrt{\text{Re}_{\alpha}}$  vs. X' lower surface



Fig. 38k Configuration X,  $\alpha = \pm 10$ ,  $\delta_1 = \delta_2 = \delta_3 = \pm 20$ , Re<sub>o</sub>/ft x  $10^{-6} = 3.3$ Nu/ $\sqrt{\text{Re}_x}$  vs. Y' upper surface


Fig. 382 Configuration X,  $\alpha = \pm 10$ ,  $b_1 = b_2 = b_3 = \pm 20$ ,  $\text{Re}_{\infty}/\text{ft} \times 10^{-6} = 3.3$  $\text{Nu}/\sqrt{\text{Re}_{x}}$  vs. X' upper surface



Fig. 38m Configuration X,  $\alpha = +20$ ,  $\delta_1 = \delta_2 = \delta_3 = +20$ ,  $\text{Re}_{\infty}/\text{ft} \ge 10^{-6} = 3.3$ Nu/ $\sqrt{\text{Re}_{x}} \ge 5.3^{\circ}$  lower surface



Fig. 38n Configuration X, 
$$\tau = +20$$
,  $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = +20$ , Re /ft x  $10^{-6} = 3.3$   
Nu/ $\sqrt{Re_x}$  vs. X<sup>1</sup> lower surface



Fig. 380 Configuration X,  $\alpha = +20$ ,  $\delta_1 = \delta_2 = \delta_3 = +20$ ,  $\text{Re}_{\infty}/\text{ft} \times 10^{-6} = 3.3$ Nu/ $\sqrt{\text{Re}_{x}}$  vs. Y' upper surface



Fig. 38p Configuration X, i = +20,  $t_1 = t_2 = t_3 = +20$ ,  $\text{Re}_{o}/\text{ft} \times 10^{-6} = 3.3$ Nu/  $\frac{\text{Re}_{x}}{\text{re}_{x}}$  vs. X' upper surface