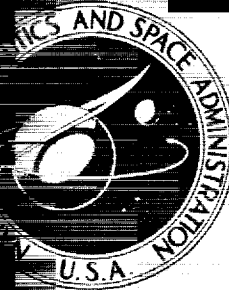


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OBTAINED ON THE X-15 AIRPLANE  
INCLUDING CORRELATIONS WITH  
WIND-TUNNEL RESULTS

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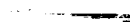
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# HEAT-TRANSFER MEASUREMENTS OBTAINED ON THE X-15 AIRPLANE INCLUDING CORRELATIONS WITH WIND-TUNNEL RESULTS<sup>1</sup>

By Robert D. Quinn and Frank V. Olinger  
Flight Research Center

## SUMMARY

Heat-transfer measurements were obtained on the X-15 airplane from two flights under quasi-steady conditions at a free-stream Mach number of 5.1 and an angle of attack of 2.0° and a free-stream Mach number of 4.98 and an angle of attack of 16.3°. These measurements were made at corresponding free-stream Reynolds numbers of  $2.45 \times 10^6$  and  $1.31 \times 10^6$  per foot ( $8.04 \times 10^6$  and  $4.30 \times 10^6$  per meter). Experimental heat-transfer coefficients derived from temperatures obtained from 200 recording thermocouples on the skin of the airplane are tabulated. Correlations with wind-tunnel results show that the wind-tunnel data are in fair-to-good agreement with the flight data obtained on the wing, ventral tail, and vertical tail at low angles of attack but are generally in poor agreement with the high-angle-of-attack data and the low-angle-of-attack fuselage data.

## INTRODUCTION

During the X-15 flight program, a substantial amount of temperature, flow field, and heat-transfer data has been obtained at various locations on the airplane. Both skin and structural temperature data are presented in references 1 to 3. References 4 to 8 contain results of flow-field and local-surface static-pressure investigations. References 9 to 13 compare measured and calculated heat-transfer data obtained on the fuselage, wing, and vertical tail. The primary purpose of references 9 to 13 was to determine the adequacy of the various theories to predict turbulent heat transfer; the results of these reports were, therefore, limited to the areas on the airplane where the local flow conditions were known.

The purpose of this report is to present the heat-transfer data obtained on all surfaces of the X-15 airplane and to make correlations with wind-tunnel data where possible. The data presented were obtained from two flights with high heating levels (flights 2-22 and 2-28)<sup>2</sup> during which quasi-steady flight conditions were maintained long enough to enable reliable heat-transfer coefficients to be derived from skin-temperature time histories.

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<sup>1</sup>Title, Unclassified.

<sup>2</sup>In the flight-designation system used for the X-15 airplane, the first digit is the number of the airplane, and the following digits indicate the flight number.

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The accuracy of the wind-tunnel data is discussed in appendix A, prepared by James C. Dunavant and Robert L. Stallings, Jr., of Langley Research Center.

## SYMBOLS

The units used for physical quantities in this paper are given both in U. S. Customary Units and the International System of Units (SI). Factors relating the two systems are presented in reference 14; those used in this paper are presented in appendix B.

|                 |                                                                                                                                                                                  |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\frac{b}{2}$   | semispan of wing, 11.18 feet (3.41 meters)                                                                                                                                       |
| $\frac{b_h}{2}$ | semispan of horizontal tail, 9.04 feet (2.76 meters)                                                                                                                             |
| $b_{ven}$       | span of ventral tail, 6.08 feet (1.85 meters)                                                                                                                                    |
| $b_{ver}$       | span of vertical tail, 6.92 feet (2.11 meters)                                                                                                                                   |
| $c_{p,w}$       | specific heat of skin material, British thermal units per pound (mass)-degrees Rankine (joules per kilogram-degrees Kelvin)                                                      |
| $\bar{c}$       | reference chord of wing, 10.65 feet (3.25 meters) (see fig. 3)                                                                                                                   |
| $\bar{c}_h$     | reference chord of horizontal tail, 4.56 feet (1.39 meters) (see fig. 3)                                                                                                         |
| $\bar{c}_v$     | reference chord of vertical and ventral tails, 9.74 feet (2.97 meters) (see fig. 3)                                                                                              |
| $F$             | radiation geometry factor, 1.0                                                                                                                                                   |
| $g$             | gravitational conversion factor, 32.17 pounds (mass)-foot per pound-second <sup>2</sup>                                                                                          |
| $H$             | enthalpy, British thermal units per pound (mass) (joules per kilogram)                                                                                                           |
| $H_R$           | boundary-layer recovery enthalpy, British thermal units per pound (mass) (joules per kilogram)                                                                                   |
| $h$             | geometric altitude, feet (meters)                                                                                                                                                |
| $h_H$           | local heat-transfer coefficient based on enthalpy, pounds (mass) per foot <sup>2</sup> -second (kilograms per meter <sup>2</sup> -second)                                        |
| $h_T$           | local heat-transfer coefficient based on temperature, British thermal units per foot <sup>2</sup> -second-degrees Rankine (joules per meter <sup>2</sup> -second-degrees Kelvin) |
| $h_t$           | height of Unitary Plan wind tunnel test section (appendix A)                                                                                                                     |

|                |                                                                                             |
|----------------|---------------------------------------------------------------------------------------------|
| J              | mechanical equivalent of heat, 778 foot-pounds per British thermal unit                     |
| $l$            | length of fuselage, 49.5 feet (15.09 meters)                                                |
| M              | Mach number                                                                                 |
| $N_{Pr}$       | Prandtl number                                                                              |
| $N_{Re}$       | Reynolds number, $\frac{\rho V x}{\mu}$                                                     |
| $N_{St}$       | Stanton number (nondimensional heat-transfer coefficient), $\frac{h_H}{\rho V}$             |
| $N_{St,i}$     | local incompressible Stanton number (see eq. (6))                                           |
| $p$            | absolute static pressure, pounds per foot <sup>2</sup> (newtons per meter <sup>2</sup> )    |
| $q$            | dynamic pressure, pounds per foot <sup>2</sup> (newtons per meter <sup>2</sup> )            |
| $T$            | temperature, degrees Rankine (degrees Kelvin)                                               |
| $T_R$          | boundary-layer recovery temperature, degrees Rankine (degrees Kelvin)                       |
| $t$            | time, seconds                                                                               |
| $V$            | velocity, feet per second (meters per second)                                               |
| $x$            | chordwise distance along wing measured from leading edge, feet (meters)                     |
| $x_f$          | axial distance along fuselage measured from nose of fuselage, feet (meters)                 |
| $x_h$          | chordwise distance along horizontal tail measured from leading edge, feet (meters)          |
| $x_v$          | chordwise distance along vertical or ventral tail measured from leading edge, feet (meters) |
| $y$            | distance from vertical plane of symmetry, feet (meters)                                     |
| $z$            | distance from horizontal plane containing longitudinal axis, feet (meters)                  |
| $\alpha$       | airplane angle of attack, degrees                                                           |
| $\beta$        | angle of sideslip, degrees                                                                  |
| $\delta_{h,L}$ | left-horizontal-tail deflection, leading edge up positive, degrees                          |
| $\delta_{h,R}$ | right-horizontal-tail deflection, leading edge up positive, degrees                         |
| $\delta_{SB}$  | speed-brake deflection, degrees                                                             |

|            |                                                                                                                                                                                                                        |
|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\delta_v$ | vertical- and ventral-tail deflections, leading edge right positive, degrees                                                                                                                                           |
| $\epsilon$ | emissivity of skin surface                                                                                                                                                                                             |
| $\mu$      | dynamic viscosity, pounds (mass) per foot-second (newton-seconds per meter <sup>2</sup> )                                                                                                                              |
| $\eta$     | recovery factor                                                                                                                                                                                                        |
| $\rho$     | density of air, pounds (mass) per foot <sup>3</sup> (kilograms per meter <sup>3</sup> )                                                                                                                                |
| $\rho_w$   | density of skin material, pounds (mass) per foot <sup>3</sup> (kilograms per meter <sup>3</sup> )                                                                                                                      |
| $\sigma$   | Stefan-Boltzmann constant, $4.78 \times 10^{-13}$ British thermal units per foot <sup>2</sup> -second-degrees Rankine <sup>4</sup> ( $5.67 \times 10^{-8}$ watts per meter <sup>2</sup> -degrees Kelvin <sup>4</sup> ) |
| $\tau$     | skin thickness, feet (meters)                                                                                                                                                                                          |
| $\varphi$  | circumferential angle, zero on lower-fuselage centerline, degrees                                                                                                                                                      |

Subscripts:

|          |              |
|----------|--------------|
| $l$      | local        |
| $w$      | wall or skin |
| $\infty$ | free stream  |

Superscript:

|   |                                 |
|---|---------------------------------|
| * | evaluated at reference enthalpy |
|---|---------------------------------|

## AIRPLANE AND INSTRUMENTATION

For the type of mission discussed in this report, the X-15 airplane (fig. 1) is launched from a B-52 carrier airplane at about 45,000 feet (13,700 meters) altitude, climbs under full power to the desired altitude, attains level flight at reduced throttle to stabilize the velocity, and, after fuel depletion, performs other required maneuvers and glides to a landing at Edwards Air Force Base, Calif. The data for the experiments discussed in this report were obtained during the periods of quasi-steady flight prior to fuel depletion.

A cutaway drawing of the X-15 fuselage showing the arrangement of the major internal components is presented in figure 2. The anhydrous-ammonia and liquid-oxygen tanks are integral parts of the fuselage structure. The skin of the X-15 airplane is constructed of Inconel X. Physical characteristics of the airplane, fuselage coordinates, and wing and horizontal-tail ordinates are presented in tables I to IV, respectively.

There are 290 thermocouples on the inner surface of the skin on the X-15 airplane. During the two flights used in this analysis, outputs from 200 of these skin thermocouples were recorded. The general location of the 200 thermocouples is shown in

figures 3 and 4(a) and 4(b); table V presents, in detail, the locations of each thermocouple and other pertinent structural information.

The thermocouples are constructed of 30-gage chromel-alumel wires spot-welded to the inner surface of the airplane skin. Outputs from each thermocouple were commutated and recorded at 1-second intervals on an onboard 12-channel NACA oscillograph. The thermocouple measurements were accurate to  $\pm 5^\circ \text{R}$  ( $\pm 2.78^\circ \text{K}$ ) (ref. 9), and the resolution was  $\pm 1^\circ \text{R}$  ( $\pm 0.556^\circ \text{K}$ ).

## TEST CONDITIONS

Time histories of free-stream velocity, free-stream dynamic pressure, altitude, and angle of attack for flights 2-22 and 2-28 are shown in figures 5(a) and 5(b), respectively. In these figures, the shaded portion of the flight profiles indicates the quasi-steady period during which data were obtained for the heat-transfer analysis. All pertinent flight parameters for this period are listed in table VI. Heat-transfer coefficients were derived at the following conditions:

| Flight | $M_\infty$ | $\alpha$ ,<br>deg | $N_{\text{Re}, \infty}$ |                    | $p_\infty$         |                   | $T_\infty$        |                   |
|--------|------------|-------------------|-------------------------|--------------------|--------------------|-------------------|-------------------|-------------------|
|        |            |                   | per foot                | per meter          | lb/ft <sup>2</sup> | hN/m <sup>2</sup> | $^\circ \text{R}$ | $^\circ \text{K}$ |
| 2-22   | 5.10       | 2.0               | $2.45 \times 10^6$      | $8.04 \times 10^6$ | 95                 | 45.5              | 390               | 217               |
| 2-28   | 4.98       | 16.3              | 1.31                    | 4.30               | 53                 | 25.4              | 401               | 223               |

## DATA REDUCTION

The heat-transfer coefficients were evaluated from the measured temperature time histories by means of the following thin-skin heat-balance equation:

$$\rho_w c_{p,w} \tau \frac{dT_w}{dt} = h_H (H_R - H_w) - \sigma \epsilon F T_w^4 \quad (1)$$

This equation neglects heat absorbed by the skin from solar radiation and heat lost from internal radiation and conduction. The radiation effects are considered to be negligible for the flight conditions encountered. The heat-transfer data presented in this report have not been corrected for conduction errors. These errors are between 4 percent and 10 percent for the wing midsemispan and upper-vertical-tail midspan and lower-fuselage centerline (refs. 9 and 10). Conduction losses are unknown for the other locations.

By solving equation (1) for the heat-transfer coefficient  $h_H$ , the following expression is obtained:

$$h_H = \frac{\rho_w c_{p,w} \tau \frac{dT_w}{dt} + \sigma \epsilon F T_w^4}{H_R - H_w} \quad (2)$$

where

$$H_w = f(T_w) \text{ (ref. 15)}$$

The recovery enthalpy was computed from the relationship

$$H_R = H_\infty + \eta \frac{V_\infty^2}{2gJ} \quad (3)$$

where  $\eta$  is the recovery factor and was taken to be equal to 0.9 for this analysis.

The Stanton numbers tabulated in tables VII and VIII and plotted in figures 6 to 11 were computed by using the equation

$$N_{St, \infty} = \frac{h_H}{\rho_\infty V_\infty} \quad (4)$$

where  $\rho_\infty V_\infty = 22.54$  pounds (mass) per foot<sup>2</sup>-second (110.00 kilograms per meter<sup>2</sup>-second) and 12.11 pounds (mass) per foot<sup>2</sup>-second (59.10 kilograms per meter<sup>2</sup>-second) for the test conditions of flights 2-22 and 2-28, respectively.

The heat-transfer coefficients tabulated in tables VII and VIII were obtained from the following relationship:

$$h_T = \frac{h_H (H_R - H_w)}{T_R - T_w} \quad (5)$$

where

$$T_R = f(H_R) \text{ (ref. 15)}$$

The skin heating rates  $\frac{dT_w}{dt}$  were determined by fitting least-square second-degree curves through 11 data points (10 seconds of data taken during the quasi-steady portion of the flights). The heating rate at the midpoint of each curve was used to compute the heat-transfer coefficient. These heating rates and the wall temperatures for all thermocouple locations are tabulated in tables VII and VIII. The locations of the thermocouples and the skin thicknesses  $\tau$  were obtained from the X-15 manufacturer's drawings and are presented in table V. The specific heat  $c_{p,w}$  was obtained from reference 16. The emissivity  $\epsilon$  of the test surface had a nominal value of 0.76 (ref. 17). The density  $\rho_w$  of Inconel X was a known constant of 515 pounds (mass) per foot<sup>3</sup> (8250 kilograms per meter<sup>3</sup>). Values for the heat-storage capacity of the skin  $\rho_w c_{p,w} \tau$  are also tabulated in tables VII and VIII.

## RESULTS AND DISCUSSION

Measured heat-transfer data in the form of heat-transfer coefficients and Stanton numbers are listed in tables VII and VIII for all locations on the airplane at which skin temperatures were measured. Most of the measured heat-transfer data in tables VII and VIII are also compared to values calculated by the reference enthalpy method (ref. 18). It should be noted that the comparisons with theory were not made to determine the adequacy of the theory but, rather, to compare the level of the measured data to a known level (for example, values predicted by flat-plate theory). The local flow conditions used to obtain the calculated flat-plate heat-transfer coefficients were computed by the tangent-cone method for the fuselage (ref. 9) and by the oblique-shock Prandtl-Meyer expansion theory (with sweep neglected) for the wing and horizontal and vertical tails. Free-stream conditions were assumed to exist ahead of all surfaces.

### Effect of Angle of Attack on Heat Transfer

Fuselage. - The nondimensional heat-transfer coefficients (Stanton numbers) measured on the bottom centerline and on or near the top centerline are presented in figures 6(a) and 6(b). Also, flat-plate values predicted by the reference enthalpy method (ref. 18) are shown. As expected, the heat-transfer coefficients measured on the bottom centerline at the high angle of attack ( $16.3^\circ$ ) are substantially higher than the low-angle-of-attack ( $2.0^\circ$ ) coefficients. The difference between the data obtained on the upper- and lower-fuselage surfaces is an order of magnitude larger for the high-angle-of-attack flight than for the low-angle-of-attack flight. The effect of angle of attack on the peripheral heat-transfer coefficients is shown in figures 7(a) to 7(g). The calculated Stanton numbers for  $\varphi = 0^\circ$  and  $\varphi = 180^\circ$  are also presented.

Wing. - Measured Stanton numbers obtained on the lower and upper surfaces of the wing at three span locations are presented in figures 8 and 9. Figure 8 shows the effect of angle of attack on the heat-transfer coefficients measured on the lower surface of the wing. As shown, the high-angle-of-attack data ( $16.3^\circ$ ) are 3 to 5 times higher than the low-angle-of-attack data ( $2.0^\circ$ ). Figure 9 shows the effect of angle of attack on the heat-transfer measurements obtained on the upper surface of the wing. As expected, the Stanton numbers obtained at the high angle of attack are lower than the Stanton numbers obtained at the low angle of attack. Also shown in these figures are values predicted by the reference enthalpy method.

Horizontal tail. - Measured heat-transfer coefficients obtained on the upper and lower surfaces of the horizontal tail are presented in figures 10(a) and 10(b). The measured Stanton numbers obtained on the upper surface at the high angle of attack are higher than the corresponding values obtained on the lower surface. Higher heating was expected on the upper surface because the effective angle of attack<sup>1</sup> of the horizontal tail was negative (leading edge down). Also, figure 10 shows that the high-angle-of-attack data measured on both the upper and lower surfaces are considerably higher than

---

<sup>1</sup>The effective angle of attack of the horizontal tail is equal to the angle of attack  $\alpha$  plus the horizontal-tail deflection  $\delta_{h,R}$  minus the downwash angle; the downwash angles were  $-1.3^\circ$  and  $2.4^\circ$  for flight 2-22 and flight 2-28, respectively (ref. 19).

[REDACTED]

the low-angle-of-attack data. These higher heating rates probably resulted from the horizontal tail being in a high-pressure region produced by the proximity of the wing shock waves at high angles of attack. The Stanton numbers predicted by the flat-plate theory (ref. 18) for an isolated airfoil are also shown in figure 10. The calculated values do not show the large difference between the upper and lower surfaces at the high angle of attack that is shown by the measured data, which indicates that the downwash angle in flight was larger than the value obtained from reference 19.

Ventral and vertical tails. - Figure 11(a) shows the heat transfer measured on the ventral tail. The data obtained at an angle of attack of  $16.3^\circ$  (flight 2-28) are on the average about 100 percent higher than the data obtained at an angle of attack of  $2.0^\circ$  (flight 2-22). These higher heating rates measured during flight 2-28 resulted from the high pressure in the ventral area produced by the proximity of the bow shock at this high angle of attack (ref. 4). Also shown in figure 11(a), for reference, are the calculated flat-plate values. These calculations do not predict the large differences in heat transfer between flight 2-22 and flight 2-28 that are seen in the measured data because the calculations do not account for the bow-shock effects. The small differences in the calculated heat-transfer coefficients that are shown in figure 11 are due primarily to Reynolds number effect.

Measured Stanton numbers obtained on the vertical tail at the three span locations are shown in figures 11(b), 11(c), and 11(d). As shown, the heat transfer decreases with increasing angle of attack, with the largest decrease occurring at the root station ( $\frac{z}{b_{ver}} = 0.455$ ) and the smallest decrease occurring at the tip station ( $\frac{z}{b_{ver}} = 0.963$ ). These results were expected, since at high angles of attack the vertical tail is in the wake of the fuselage, which results in lower pressures and correspondingly lower heating rates. Stanton numbers computed by the reference enthalpy method are also presented in figures 11(b), 11(c), and 11(d).

Heat-transfer measurements obtained on the speed brake of the ventral and vertical tails are shown in figures 11(a) and 11(b), respectively. The data obtained on the speed brakes show a sharp rise over the data measured forward of the speed brakes. This increase is not a result of speed-brake deflection, since measurements show that the speed brakes were closed (see table VI). It is believed that the increased heating on the speed brakes resulted from a bleedoff of the boundary layer into the low-pressure region behind the hinge-line gap (see fig. 12). This bleedoff would result in a thin boundary layer on the speed brake and, consequently, higher heating rates.

### Correlation of Flight and Wind-Tunnel Data

Reynolds number correlations of flight and wind-tunnel data obtained on the lower-fuselage centerline, wing, and ventral and vertical tails for low and high angles of attack are presented in figures 13(a) to 13(f). The wind-tunnel data (ref. 20) were measured at  $M_\infty = 4.65$  in the Langley Unitary Plan wind tunnel. The wind-tunnel heat-transfer tests and their accuracy are discussed in appendix A. However, no attempt was made to apply the approximate corrections given in appendix A to the wind-tunnel data presented in the following correlations. To obtain the desired Reynolds number correlation, the measured local Stanton numbers from flight and wind-tunnel tests were transformed to incompressible values by using the reference enthalpy method. The incompressible relationship used in these correlations was based on the Blasius skin-friction law (ref. 21) and Colburn's Reynolds analogy factor (ref. 22), which result in the

following equation:

$$N_{St,i} = \frac{0.0296}{(N_{Pr,l})^{2/3} (N_{Re,l})^{.2}} \quad (6)$$

Assuming  $N_{Pr,l} = 0.726$ , equation (6) may be put in the following form:

$$\frac{N_{St,i}}{(N_{Re,l})^{.8}} = \frac{0.0366}{(N_{Re,l})} \quad (7)$$

By using equation (7) in conjunction with the reference enthalpy method, the following relationship between the compressible local Stanton number and the incompressible local Stanton number can be obtained (ref. 11):

$$\frac{N_{St,l}}{(N_{Re,l})^{.8}} \left( \frac{T^*}{T_l} \right)^{.65} = \frac{N_{St,i}}{(N_{Re,l})^{.8}} \quad (8)$$

The solid line in figure 13 represents values predicted by equation (7), and the data in these figures are the measured compressible local Stanton numbers that have been reduced to their incompressible values by using equation (8). In this way, the measured data should agree with the solid line in these figures if the reference enthalpy method is assumed to predict correct values of turbulent heat transfer<sup>1</sup>. However, the purpose of figure 13 is not to determine how well the data agree with theory but to show the correlation between flight and wind-tunnel data. The agreement obtained between flight and wind-tunnel data depends to some extent on the theory used to correlate the data, primarily because of the different effect of the ratio of wall-to-recovery temperature on heat transfer predicted by the various theories (refs. 18, 23, and 24) and the fact that the wind-tunnel and flight data were obtained at different temperature ratios. The effect of wall temperature on heat transfer has been the subject of considerable investigation (for example, refs. 24 to 28) but has still not been completely determined. The reference enthalpy method was used to correlate the data in this report because of its wide usage and simplicity, although better agreement would have been obtained if a method that predicts less effect of wall temperature had been chosen (for example, ref. 23). This possibility of improving the correlation between flight and wind-tunnel data by 20 percent to 30 percent was considered when the conclusions were made from the results in figure 13.

Fuselage. - Figure 13(a) shows the flight and wind-tunnel data obtained on the lower-fuselage centerline at high and low angles of attack. The wind-tunnel data are 50 percent to 100 percent higher than the flight data for the low-angle-of-attack condition and about 300 percent higher than the flight data for the high-angle-of-attack condition; the agreement is considered poor. The high heat transfer obtained in the wind tunnel is believed to be the result of roughness effects caused by the transition strip on the model, as discussed in reference 12.

<sup>1</sup>This, of course, also assumes that the local flow conditions used in this analysis are the correct boundary-layer-edge conditions; these local flow conditions were computed in the manner described on page 7.

[REDACTED]

Wing. - Correlation of flight and wind-tunnel data obtained on the wing at low angles of attack is shown in figure 13(b). The correlation is considered to be good, with the wind-tunnel data averaging 30 percent higher than the flight data. Figure 13(c) shows the correlation of the high-angle-of-attack data. For this condition the agreement between flight and wind-tunnel data is poor, with the wind-tunnel data being generally 100 percent higher than the flight data.

Ventral and vertical tails. - Correlation of flight and wind-tunnel data obtained on the ventral and vertical tails at low angles of attack is presented in figure 13(d). The agreement between flight and wind-tunnel data is considered to be fair, even though the wind-tunnel data are 50 percent to 60 percent higher than the flight data. Figure 13(e) shows the correlation of data obtained on the ventral tail at high angles of attack. The wind-tunnel data are 300 percent higher than the flight data, and the correlation is considered poor. Figure 13(f) shows the correlation between flight and wind-tunnel data obtained on the vertical tail at high angles of attack. Only the data obtained at the mid-span station ( $\frac{z}{b_{ver}} = 0.670$  and  $0.729$  for wind tunnel and flight, respectively) and the tip station ( $\frac{z}{b_{ver}} = 0.890$  and  $0.963$  for wind tunnel and flight, respectively) are presented. The agreement between the flight and wind-tunnel data at the midspan station is good, but the data obtained at the tip station are only in fair agreement, with the wind-tunnel data being approximately 60 percent higher than the flight data.

#### CONCLUDING REMARKS

Heat-transfer coefficients were obtained at 200 locations on the X-15 airplane at a free-stream Mach number of 5.1 and an angle of attack of  $2.0^\circ$  and a free-stream Mach number of 4.98 and an angle of attack of  $16.3^\circ$ . The data obtained showed the effect of angle of attack on the distribution of heat-transfer coefficients on the fuselage, wing, horizontal tail, and ventral and vertical tails. As expected, an increase in the angle of attack resulted in (1) increased differences between the data obtained on the upper and lower fuselage and wing surfaces, (2) increased ventral-tail heating, and (3) decreased vertical-tail heating. In addition, increasing angle of attack resulted in higher heating on the upper and lower surfaces of the horizontal tail.

Correlations of the measured data obtained on the fuselage, wing, and ventral and vertical tails with wind-tunnel results showed that the high-angle-of-attack wind-tunnel data were generally in poor agreement with the flight data. Also, the correlation of the low-angle-of-attack fuselage data was poor. However, good agreement was obtained between the low-angle-of-attack flight and wind-tunnel data measured on the lower surface of the wing, and correlation was fair between the flight and wind-tunnel data measured on the ventral and vertical tails at low angles of attack.

Flight Research Center,  
National Aeronautics and Space Administration,  
Edwards, Calif., July 31, 1968,  
719-01-00-03-24.



## APPENDIX A

### HEAT-TRANSFER MEASUREMENTS ON THE X-15 IN THE LANGLEY UNITARY PLAN WIND TUNNEL AT MACH 4.65

By James C. Dunavant and Robert L. Stallings, Jr.  
Langley Research Center

The purpose of this appendix is to discuss the wind-tunnel tests reported in reference 20 and errors in the heat-transfer measurements which resulted from a transient nonuniform vertical temperature distribution found in the tunnel subsequent to the tests.

The X-15 heat-transfer coefficients were determined from the transient skin temperature response to an increase in the tunnel total temperature. The increase is obtained during operation by quickly bypassing the cooler between the last compressor and the test section. Before the temperature increase, the model is at recovery temperature and the ratio measured at that time of recovery temperature to total temperature is assumed to be constant through the transient. The heat-transfer coefficient is evaluated from an integral form of the calorimeter equation (eq. (4) of ref. 20) using the transient difference between the recovery temperature (calculated from the constant ratio of recovery temperature to total temperature) and model skin temperature.

Total-temperature surveys along the vertical centerline at Mach 4.65 in the Unitary Plan wind tunnel during a transient total-temperature increase are shown in figure 14. The increase is usually between 54 R° (30 K°) and 81 R° (45 K°), and the heat-transfer data-taking period is 15 seconds, starting about 6 seconds after opening of the bypass ( $t = 0$  in fig. 14). The highest temperatures were measured near the top of the tunnel, and, although not shown in the figure, the temperatures in a horizontal plane through the tunnel centerline were approximately uniform.

The 0.0667-scale X-15 model was mounted below the center of the tunnel by using an offset sting, as shown in figure 15, to allow for movement to 28° angle of attack. In these tests, total temperature was measured at thermocouples (also shown in fig. 15) attached to the strut at a point aft of the ventral tail but displaced to one side about 9.72 in. (12 cm) from the tunnel vertical centerline. The two shielded probes were mounted so that one was approximately aligned to the flow at low angle of attack and the other at high angle of attack. At  $\alpha = 0^\circ$  the stagnation thermocouples were located about 4.72 in. (12 cm) below the centerline of the model. Rotating the model to 15° angle of attack placed the forward instrumented section ( $\frac{x_f}{l} = 0$  to 34.3) about 3.15 in. (8 cm) to 5.91 in. (15 cm) above the tunnel centerline, while the stagnation thermocouples were about 9.84 in. (25 cm) below. The total-temperature difference between the two vertical stations from figure 14 is from 12.6 R° (7 K°) to 25.2 R° (14 K°), which would produce an estimated error in heat-transfer coefficient of 50 percent. For locations on the model nearer the stagnation-temperature-measurement location, the error would be less. However, where heating (and, hence, wall temperature) is high, thereby reducing the difference ( $T_R - T_w$ ), greater errors in the heat-transfer

[REDACTED]

coefficients result. Exact determination of the error can be made only from temperature histories of the model and the tunnel stagnation temperature at the appropriate vertical station. The zero angle-of-attack results would have a minimum error because the model and stagnation thermocouple "see" approximately the same stream.

The large vertical transient temperature did not exist at the other test Mach number of 2.88 in reference 20. At this Mach number, the increase in heating with angle of attack over the bottom forward fuselage was consistent with theory but deviated greatly at Mach 4.65. Thus, only the high angle-of-attack results at Mach 4.65 appear to be incorrect.

## APPENDIX B

### CONVERSION OF U. S. CUSTOMARY UNITS TO SI UNITS

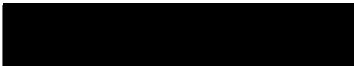
The International System of Units (SI) was adopted by the Eleventh General Conference on Weights and Measures, Paris, October 1960, in Resolution No. 12 (ref. 14). Conversion factors for the units used herein are given in the following table:

| Physical quantity         | U. S. Customary Unit        | Conversion factor*  | SI Unit                  |
|---------------------------|-----------------------------|---------------------|--------------------------|
| Density                   | lbm/ft <sup>3</sup>         | 16.02               | kg/m <sup>3</sup>        |
| Enthalpy                  | Btu/lbm                     | $2.32 \times 10^3$  | J/kg                     |
| Specific heat             | Btu/lbm-°R                  | $4.18 \times 10^3$  | J/kg-°K                  |
| Heat-transfer coefficient | Btu/ft <sup>2</sup> -sec-°R | $2.042 \times 10^4$ | J/m <sup>2</sup> -sec-°K |
| Length                    | ft                          | 0.3048              | m                        |
|                           | in.                         | 2.54                | cm                       |
| Pressure                  | lb/ft <sup>2</sup>          | 0.4788              | hN/m <sup>2</sup>        |
| Temperature               | °R                          | 0.556               | °K                       |
| Dynamic viscosity         | lbm/ft-sec                  | 1.488               | N-sec/m <sup>2</sup>     |
| Velocity                  | ft/sec                      | 0.3048              | m/sec                    |

\*Multiply value given in U. S. Customary Unit by conversion factor to obtain equivalent value in SI Unit.

Prefixes to indicate multiple of units are:

| Prefix    | Multiple  |
|-----------|-----------|
| centi (c) | $10^{-2}$ |
| hecto (h) | $10^2$    |
| kilo (k)  | $10^3$    |



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TABLE I. - PHYSICAL CHARACTERISTICS OF THE X-15 AIRPLANE

|                                                                                                                                     |                       |         |
|-------------------------------------------------------------------------------------------------------------------------------------|-----------------------|---------|
| Wing -                                                                                                                              |                       |         |
| Airfoil section . . . . .                                                                                                           | NACA 66005 (modified) |         |
| Total area (includes 94.98 ft <sup>2</sup> (8.82 m <sup>2</sup> ) covered by fuselage), ft <sup>2</sup> (m <sup>2</sup> ) . . . . . | 200                   | (18.58) |
| Span, ft (m) . . . . .                                                                                                              | 22.36                 | (6.82)  |
| Mean aerodynamic chord, ft (m) . . . . .                                                                                            | 10.27                 | (3.13)  |
| Root chord, ft (m) . . . . .                                                                                                        | 14.91                 | (4.54)  |
| Tip chord, ft (m) . . . . .                                                                                                         | 2.98                  | (0.91)  |
| Taper ratio . . . . .                                                                                                               | 0.20                  |         |
| Aspect ratio . . . . .                                                                                                              | 2.50                  |         |
| Sweep at leading edge, deg . . . . .                                                                                                | 36.75                 |         |
| Sweep at 25-percent-chord line, deg . . . . .                                                                                       | 25.64                 |         |
| Sweep at trailing edge, deg . . . . .                                                                                               | -17.74                |         |
| Incidence, deg . . . . .                                                                                                            | 0                     |         |
| Horizontal tail -                                                                                                                   |                       |         |
| Airfoil section . . . . .                                                                                                           | NACA 66005 (modified) |         |
| Total area (includes 63.29 ft <sup>2</sup> (5.88 m <sup>2</sup> ) covered by fuselage), ft <sup>2</sup> (m <sup>2</sup> ) . . . . . | 115.34                | (10.72) |
| Span, ft (m) . . . . .                                                                                                              | 18.08                 | (5.51)  |
| Mean aerodynamic chord, ft (m) . . . . .                                                                                            | 7.05                  | (2.15)  |
| Root chord, ft (m) . . . . .                                                                                                        | 10.22                 | (3.12)  |
| Tip chord, ft (m) . . . . .                                                                                                         | 2.11                  | (0.64)  |
| Taper ratio . . . . .                                                                                                               | 0.21                  |         |
| Aspect ratio . . . . .                                                                                                              | 2.83                  |         |
| Sweep at leading edge, deg . . . . .                                                                                                | 50.58                 |         |
| Sweep at 25-percent-chord line, deg . . . . .                                                                                       | 45                    |         |
| Sweep at trailing edge, deg . . . . .                                                                                               | 19.28                 |         |
| Ratio horizontal-tail area to wing area . . . . .                                                                                   | 0.58                  |         |
| Upper vertical tail-                                                                                                                |                       |         |
| Airfoil section . . . . .                                                                                                           | 10° single wedge      |         |
| Area (excluding area covered by fuselage), ft <sup>2</sup> (m <sup>2</sup> ) . . . . .                                              | 40.91                 | (3.80)  |
| Span, ft (m) . . . . .                                                                                                              | 6.92                  | (2.11)  |
| Mean aerodynamic chord, ft (m) . . . . .                                                                                            | 8.95                  | (2.73)  |
| Root chord, ft (m) . . . . .                                                                                                        | 10.21                 | (3.11)  |
| Tip chord, ft (m) . . . . .                                                                                                         | 7.56                  | (2.30)  |
| Taper ratio . . . . .                                                                                                               | 0.74                  |         |
| Aspect ratio . . . . .                                                                                                              | 0.51                  |         |
| Sweep at leading edge, deg . . . . .                                                                                                | 30                    |         |
| Sweep at 25-percent-chord line, deg . . . . .                                                                                       | 23.41                 |         |
| Ratio vertical-tail area to wing area . . . . .                                                                                     | 0.20                  |         |
| Speed-brake total surface area, ft <sup>2</sup> (m <sup>2</sup> ) . . . . .                                                         | 11.18                 | (1.04)  |
| Lower vertical tail -                                                                                                               |                       |         |
| Airfoil section . . . . .                                                                                                           | 10° single wedge      |         |
| Area (excluding area covered by fuselage), ft <sup>2</sup> (m <sup>2</sup> ) . . . . .                                              | 34.41                 | (3.20)  |
| Span, ft (m) . . . . .                                                                                                              | 6.17                  | (1.88)  |
| Mean aerodynamic chord, ft (m) . . . . .                                                                                            | 9.17                  | (2.80)  |
| Root chord, ft (m) . . . . .                                                                                                        | 10.21                 | (3.11)  |
| Tip chord, ft (m) . . . . .                                                                                                         | 8.00                  | (2.44)  |
| Taper ratio . . . . .                                                                                                               | 0.78                  |         |
| Aspect ratio . . . . .                                                                                                              | 0.43                  |         |
| Sweep at leading edge, deg . . . . .                                                                                                | 30                    |         |
| Sweep at 25-percent-chord line, deg . . . . .                                                                                       | 23.41                 |         |
| Ratio vertical-tail area to wing area . . . . .                                                                                     | 0.17                  |         |
| Speed-brake total surface area, ft <sup>2</sup> (m <sup>2</sup> ) . . . . .                                                         | 11.18                 | (1.04)  |
| Fuselage -                                                                                                                          |                       |         |
| Length, ft (m) . . . . .                                                                                                            | 49.5                  | (15.09) |
| Maximum width, ft (m) . . . . .                                                                                                     | 7.33                  | (2.23)  |
| Maximum depth, ft (m) . . . . .                                                                                                     | 4.67                  | (1.42)  |
| Maximum depth over canopy, ft (m) . . . . .                                                                                         | 4.97                  | (1.51)  |
| Side area (total), ft <sup>2</sup> (m <sup>2</sup> ) . . . . .                                                                      | 215.66                | (20.03) |
| Fineness ratio . . . . .                                                                                                            | 10.91                 |         |
| Sweep at canopy leading edge, deg . . . . .                                                                                         | 60                    |         |

TABLE II. - FUSELAGE CONTOUR COORDINATES

| $\frac{x_f}{l}$ , percent<br>(a) | Fuselage station | Radius, |       |
|----------------------------------|------------------|---------|-------|
|                                  |                  | in.     | cm    |
| 0.54                             | 1.6              | 3.270   | 8.31  |
| .77                              | 3.0              | 3.656   | 9.29  |
| 1.11                             | 5.0              | 4.195   | 10.66 |
| 1.95                             | 10.0             | 5.513   | 14.00 |
| 2.79                             | 15.0             | 6.792   | 17.25 |
| 3.64                             | 20.0             | 8.032   | 20.40 |
| 4.48                             | 25.0             | 9.233   | 23.45 |
| 5.32                             | 30.0             | 10.396  | 26.41 |
| 6.16                             | 35.0             | 11.520  | 29.26 |
| 7.00                             | 40.0             | 12.605  | 32.02 |
| 7.84                             | 45.0             | 13.652  | 34.68 |
| 8.68                             | 50.0             | 14.662  | 37.24 |
| 10.37                            | 60.0             | 16.566  | 42.08 |
| 12.05                            | 70.0             | 18.322  | 46.54 |
| 13.73                            | 80.0             | 19.928  | 50.62 |
| 15.42                            | 90.0             | 21.386  | 54.32 |
| 17.10                            | 100.0            | 22.697  | 57.65 |
| 20.47                            | 120.0            | 24.882  | 63.20 |
| 23.83                            | 140.0            | 26.487  | 67.28 |
| 28.88                            | 170.0            | 27.817  | 70.66 |
| 31.75                            | 187.0            | 28.000  | 71.12 |
| 90.00                            | 533.0            | 28.000  | 71.12 |
| 95.38                            | 565.0            | 26.548  | 67.43 |
| 99.25                            | 588.0            | 24.000  | 60.96 |

<sup>a</sup> $l = 594$  in. (1509 cm). Fuselage station 0 located  
at  $\frac{x_f}{l} = 0.27$  percent.

TABLE III. - WING AIRFOIL ORDINATES<sup>a</sup>  
[NACA 66005 modified<sup>b</sup>]

| Percent chord | $\frac{y}{b/2} = 0.357$<br>(wing station 47.88 <sup>c</sup> ) |        |           |      | $\frac{y}{b/2} = 0.629$<br>(wing station 84.50 <sup>c</sup> ) |        |           |      | $\frac{y}{b/2} = 0.953$<br>(wing station 127.67 <sup>c</sup> ) |        |           |      |
|---------------|---------------------------------------------------------------|--------|-----------|------|---------------------------------------------------------------|--------|-----------|------|----------------------------------------------------------------|--------|-----------|------|
|               | Distance to leading edge,                                     |        | Ordinate, |      | Distance to leading edge,                                     |        | Ordinate, |      | Distance to leading edge,                                      |        | Ordinate, |      |
|               | in.                                                           | cm     | in.       | cm   | in.                                                           | cm     | in.       | cm   | in.                                                            | cm     | in.       | cm   |
| 0             | 0                                                             | 0      | 0         | 0    | 0                                                             | 0      | 0         | 0    | 0                                                              | 0      | 0         | 0    |
| Tangent point | .38                                                           | .97    | .37       | .94  | .38                                                           | .97    | .37       | .94  | .38                                                            | .97    | .37       | .94  |
| .88           | 1.12                                                          | 2.84   | .42       | 1.07 | .78                                                           | 1.98   | .40       | 1.02 | .38                                                            | .97    | .37       | .94  |
| 1.25          | 1.60                                                          | 4.06   | .55       | 1.40 | 1.11                                                          | 2.82   | .47       | 1.19 | .54                                                            | 1.37   | .40       | 1.02 |
| 5.00          | 6.39                                                          | 16.23  | 1.15      | 2.92 | 4.44                                                          | 11.28  | .87       | 2.21 | 2.16                                                           | 5.49   | .51       | 1.30 |
| 10.00         | 12.78                                                         | 32.46  | 1.79      | 4.55 | 8.88                                                          | 22.56  | 1.27      | 3.23 | 4.32                                                           | 10.97  | .64       | 1.63 |
| 15.00         | 19.17                                                         | 48.69  | 2.26      | 5.74 | 13.32                                                         | 33.83  | 1.66      | 4.22 | 6.48                                                           | 16.46  | .75       | 1.91 |
| 20.00         | 25.56                                                         | 64.92  | 2.56      | 6.50 | 17.76                                                         | 45.11  | 1.79      | 4.55 | 8.64                                                           | 21.95  | .86       | 2.18 |
| 25.00         | 31.95                                                         | 81.15  | 2.79      | 7.09 | 22.20                                                         | 56.39  | 1.96      | 4.98 | 10.80                                                          | 27.43  | .93       | 2.36 |
| 32.00         | 40.90                                                         | 103.89 | 3.02      | 7.67 | 28.42                                                         | 72.19  | 2.12      | 5.38 | 13.82                                                          | 35.10  | 1.01      | 2.57 |
| 38.00         | 48.56                                                         | 123.34 | 3.14      | 7.98 | 33.74                                                         | 85.70  | 2.20      | 5.59 | 16.42                                                          | 41.71  | 1.05      | 2.67 |
| 44.00         | 56.23                                                         | 142.82 | 3.20      | 8.13 | 39.07                                                         | 99.24  | 2.24      | 5.69 | 19.01                                                          | 48.29  | 1.07      | 2.72 |
| 50.00         | 63.90                                                         | 162.31 | 3.18      | 8.08 | 44.40                                                         | 112.78 | 2.23      | 5.66 | 21.60                                                          | 54.86  | 1.05      | 2.67 |
| 55.90         | 71.44                                                         | 181.46 | 3.10      | 7.87 | 49.64                                                         | 126.09 | 2.17      | 5.51 | 24.15                                                          | 61.34  | 1.04      | 2.64 |
| 61.90         | 79.11                                                         | 200.94 | 2.94      | 7.47 | 54.97                                                         | 139.62 | 2.15      | 5.46 | 26.74                                                          | 67.92  | .98       | 2.49 |
| 68.00         | 86.90                                                         | 220.73 | 2.61      | 6.63 | 60.38                                                         | 153.37 | 1.83      | 4.65 | 29.38                                                          | 74.63  | .73       | 1.85 |
| 75.00         | 95.85                                                         | 243.46 | 2.18      | 5.54 | 66.60                                                         | 169.16 | 1.52      | 3.86 | 32.40                                                          | 82.30  | .73       | 1.85 |
| 100.00        | 127.80                                                        | 324.61 | .66       | 1.68 | 88.80                                                         | 225.55 | .45       | 1.14 | 43.20                                                          | 109.73 | .21       | .53  |

<sup>a</sup>Measured from chord line.

<sup>b</sup>Leading-edge radius 0.375 in. (0.953 cm) constant, tangent to leading-edge. Basic airfoil modified forward of 17-percent plane and modified to straight side aft of 67-percent plane to 1-percent blunt trailing edge.

<sup>c</sup>Wing side-fairing juncture at wing station 44.00 ( $\frac{y}{b/2} = 0.328$ ).

TABLE IV. - HORIZONTAL-TAIL AIRFOIL ORDINATES<sup>a</sup>  
[NACA 66005 modified<sup>b</sup>]

| Percent chord       | $\frac{y}{b_h/2} = 0.434$<br>(butt plane 47.00) |        |           |      | $\frac{y}{b_h/2} = 0.696$<br>(butt plane 75.50) |        |           |      | $\frac{y}{b_h/2} = 0.966$<br>(butt plane 104.75) |       |           |      |
|---------------------|-------------------------------------------------|--------|-----------|------|-------------------------------------------------|--------|-----------|------|--------------------------------------------------|-------|-----------|------|
|                     | Distance to leading edge,                       |        | Ordinate, |      | Distance to leading edge,                       |        | Ordinate, |      | Distance to leading edge,                        |       | Ordinate, |      |
|                     | in.                                             | cm     | in.       | cm   | in.                                             | cm     | in.       | cm   | in.                                              | cm    | in.       | cm   |
| 0                   | 0                                               | 0      | 0         | 0    | 0                                               | 0      | 0         | 0    | 0                                                | 0     | 0         | 0    |
| .10                 | .81                                             | 2.06   | .21       | .53  | .55                                             | 1.40   | .13       | .33  | .29                                              | .74   | .10       | .25  |
| 1.25                | 1.01                                            | 2.57   | .53       | 1.35 | .69                                             | 1.75   | .33       | .84  | .36                                              | .91   | .26       | .66  |
| 5.00                | 4.02                                            | 10.21  | .84       | 2.13 | 2.74                                            | 6.96   | .43       | 1.09 | 1.43                                             | 3.63  | .34       | .86  |
| 10.00               | 8.05                                            | 20.45  | 1.18      | 3.00 | 5.49                                            | 13.94  | .61       | 1.55 | 2.86                                             | 7.26  | .43       | 1.09 |
| 25.00               | 20.11                                           | 51.08  | 1.75      | 4.45 | 13.72                                           | 34.85  | .90       | 2.29 | 7.16                                             | 18.19 | .62       | 1.57 |
| 45.00               | 36.20                                           | 91.95  | 2.01      | 5.11 | 24.69                                           | 62.71  | 1.03      | 2.62 | 12.88                                            | 32.72 | .71       | 1.80 |
| 60.00               | 48.27                                           | 122.61 | 1.89      | 4.80 | 32.92                                           | 83.62  | .97       | 2.46 | 17.17                                            | 43.61 | .67       | 1.70 |
| 67.00               | 53.90                                           | 136.91 | 1.63      | 4.14 | 36.76                                           | 93.37  | .86       | 2.18 | 19.18                                            | 48.72 | .58       | 1.47 |
| <sup>c</sup> 100.00 | 80.45                                           | 204.34 | .40       | 1.02 | 54.87                                           | 139.37 | .27       | .69  | 28.62                                            | 72.69 | .14       | .36  |

<sup>a</sup>Airfoil ordinates measured perpendicular to chord plane.

<sup>b</sup>Leading-edge radius at root and tip thermocouple stations, 0.500 in. (1.27 cm) and 0.250 in. (0.64 cm), respectively, normal to the leading edge. Root modified forward of 5-percent chord. Tip modified forward of 15-percent chord. Horizontal-tail side-fairing juncture at butt plane 42.74

( $\frac{y}{b_h/2} = 0.396$ ).

<sup>c</sup>Airfoil tapers linearly from 67-percent to 100-percent chord.

TABLE V. - THERMOCOUPLE LOCATIONS AND WALL THICKNESSES

| (a) Fuselage <sup>a</sup> |                 |                    |          |         | (b) Wing upper surface |               |                 |          |         |
|---------------------------|-----------------|--------------------|----------|---------|------------------------|---------------|-----------------|----------|---------|
| Thermo-<br>couple         | $\frac{x_f}{l}$ | $\varphi$ ,<br>deg | $\tau$ , |         | Thermo-<br>couple      | $\frac{x}{c}$ | $\frac{y}{b/2}$ | $\tau$ , |         |
|                           |                 |                    | ft       | m       |                        |               |                 | ft       | m       |
| 1                         | 0.047           | 0                  | 0.0113   | 0.00345 | 51                     | 0.028         | 0.357           | 0.0058   | 0.00175 |
| 2                         | .047            | 36                 | .0102    | .00310  | 52                     | .056          | .357            | .0058    | .00175  |
| 3                         | .047            | 64                 | .0075    | .00229  | 53                     | .104          | .357            | .0057    | .00173  |
| 4                         | .047            | 100                | .0066    | .00201  | 54                     | .132          | .357            | .0056    | .00170  |
| 5                         | .047            | 128                | .0066    | .00201  | 55                     | .181          | .357            | .0055    | .00168  |
| 6                         | .047            | 169                | .0066    | .00201  | 56                     | .278          | .357            | .0073    | .00224  |
| 7                         | .047            | 260                | .0066    | .00201  | 57                     | .341          | .357            | .0073    | .00224  |
| 8                         | .080            | 166                | .0058    | .00178  | 58                     | .403          | .357            | .0073    | .00224  |
| 9                         | .080            | 265                | .0058    | .00178  | 59                     | .459          | .357            | .0073    | .00224  |
| 10                        | .125            | 0                  | .0063    | .00191  | 60                     | .639          | .357            | .0073    | .00224  |
| 11                        | .125            | 60                 | .0059    | .00180  | 61                     | .674          | .357            | .0073    | .00224  |
| 12                        | .125            | 130                | .0048    | .00147  | 62                     | .744          | .357            | .0073    | .00224  |
| 13                        | .125            | 154                | .0048    | .00147  | 63                     | .834          | .357            | .0032    | .00097  |
| 14                        | .125            | 260                | .0048    | .00147  | 64                     | .890          | .357            | .0032    | .00097  |
| 15                        | .137            | 166                | .0042    | .00127  | 65                     | .938          | .357            | .0032    | .00097  |
| 16                        | .137            | 180                | .0104    | .00318  | 66                     | .028          | .629            | .0048    | .00145  |
| 17                        | .150            | 0                  | .0045    | .00137  | 67                     | .049          | .629            | .0048    | .00145  |
| 18                        | .150            | 45                 | .0045    | .00137  | 68                     | .070          | .629            | .0048    | .00145  |
| 19                        | .150            | 85                 | .0045    | .00137  | 69                     | .132          | .629            | .0048    | .00145  |
| 20                        | .150            | 135                | .0042    | .00127  | 70                     | .188          | .629            | .0057    | .00173  |
| 21                        | .150            | 180                | .0104    | .00318  | 71                     | .229          | .629            | .0057    | .00173  |
| 22                        | .150            | 275                | .0045    | .00137  | 72                     | .278          | .629            | .0057    | .00173  |
| 23                        | .169            | 180                | .0104    | .00318  | 73                     | .320          | .629            | .0057    | .00173  |
| 24                        | .200            | 2                  | .0043    | .00132  | 74                     | .382          | .629            | .0057    | .00173  |
| 25                        | .200            | 43                 | .0043    | .00132  | 75                     | .424          | .629            | .0057    | .00173  |
| 26                        | .200            | 135                | .0042    | .00127  | 76                     | .473          | .629            | .0057    | .00173  |
| 27                        | .200            | 167                | .0042    | .00127  | 77                     | .521          | .629            | .0057    | .00173  |
| 28                        | .200            | 180                | .0042    | .00127  | 78                     | .612          | .629            | .0032    | .00097  |
| 29                        | .200            | 270                | .0043    | .00132  | 79                     | .653          | .629            | .0032    | .00097  |
| 30                        | .309            | 0                  | .0043    | .00132  | 80                     | .688          | .629            | .0055    | .00168  |
| 31                        | .309            | 45                 | .0043    | .00132  | 81                     | .021          | .953            | .0035    | .00107  |
| 32                        | .309            | 135                | .0043    | .00132  | 82                     | .035          | .953            | .0035    | .00107  |
| 33                        | .309            | 180                | .0042    | .00127  | 83                     | .049          | .953            | .0035    | .00107  |
| 34                        | .326            | 170                | .0053    | .00160  | 84                     | .097          | .953            | .0037    | .00112  |
| 35                        | .343            | 33                 | .0043    | .00132  | 85                     | .118          | .953            | .0037    | .00112  |
| 36                        | .343            | 44                 | .0043    | .00132  | 86                     | .139          | .953            | .0037    | .00112  |
| 37                        | .343            | 60                 | .0043    | .00132  | 87                     | .160          | .953            | .0037    | .00112  |
| 38                        | .343            | 80                 | .0031    | .00094  | 88                     | .195          | .953            | .0037    | .00112  |
| 39                        | .343            | 90                 | .0031    | .00094  | 89                     | .222          | .953            | .0037    | .00112  |
| 40                        | .343            | 124                | .0108    | .00328  | 90                     | .243          | .953            | .0037    | .00112  |
| 41                        | .343            | 138                | .0053    | .00160  | 91                     | .278          | .953            | .0033    | .00102  |
| 42                        | .343            | 152                | .0053    | .00160  | 92                     | .313          | .953            | .0033    | .00102  |
| 43                        | .567            | 80                 | .0027    | .00081  |                        |               |                 |          |         |
| 44                        | .567            | 86                 | .0027    | .00081  |                        |               |                 |          |         |
| 45                        | .567            | 94                 | .0027    | .00081  |                        |               |                 |          |         |
| 46                        | .567            | 100                | .0027    | .00081  |                        |               |                 |          |         |
| 47                        | .567            | 107                | .0027    | .00081  |                        |               |                 |          |         |
| 48                        | .567            | 124                | .0053    | .00160  |                        |               |                 |          |         |
| 49                        | .567            | 150                | .0053    | .00160  |                        |               |                 |          |         |
| 50                        | .567            | 180                | .0053    | .00160  |                        |               |                 |          |         |

<sup>a</sup>See figure 4.

TABLE V. - THERMOCOUPLE LOCATIONS AND WALL THICKNESSES - Continued

(c) Wing lower surface

| Thermo-<br>couple | $\frac{x}{c}$ | $\frac{y}{b/2}$ | $\tau$ , |         |
|-------------------|---------------|-----------------|----------|---------|
|                   |               |                 | ft       | m       |
| 93                | 0.028         | 0.357           | 0.0062   | 0.00188 |
| 94                | .056          | .357            | .0062    | .00188  |
| 95                | .104          | .357            | .0062    | .00188  |
| 96                | .132          | .357            | .0062    | .00188  |
| 97                | .181          | .357            | .0062    | .00188  |
| 98                | .209          | .357            | .0062    | .00188  |
| 99                | .278          | .357            | .0053    | .00163  |
| 100               | .341          | .357            | .0053    | .00163  |
| 101               | .403          | .357            | .0053    | .00163  |
| 102               | .459          | .357            | .0053    | .00163  |
| 103               | .619          | .357            | .0053    | .00163  |
| 104               | .674          | .357            | .0053    | .00163  |
| 105               | .744          | .357            | .0053    | .00163  |
| 106               | .834          | .357            | .0032    | .00097  |
| 107               | .938          | .357            | .0032    | .00097  |
| 108               | .028          | .629            | .0049    | .00150  |
| 109               | .049          | .629            | .0049    | .00150  |
| 110               | .070          | .629            | .0049    | .00150  |
| 111               | .132          | .629            | .0049    | .00150  |
| 112               | .188          | .629            | .0045    | .00137  |
| 113               | .229          | .629            | .0045    | .00137  |
| 114               | .278          | .629            | .0045    | .00137  |
| 115               | .320          | .629            | .0045    | .00137  |
| 116               | .382          | .629            | .0045    | .00137  |
| 117               | .424          | .629            | .0045    | .00137  |
| 118               | .473          | .629            | .0045    | .00137  |
| 119               | .521          | .629            | .0045    | .00137  |
| 120               | .612          | .629            | .0032    | .00097  |
| 121               | .653          | .629            | .0032    | .00097  |
| 122               | .021          | .953            | .0036    | .00109  |
| 123               | .063          | .953            | .0036    | .00109  |
| 124               | .097          | .953            | .0035    | .00107  |
| 125               | .118          | .953            | .0035    | .00107  |
| 126               | .139          | .953            | .0035    | .00107  |
| 127               | .160          | .953            | .0035    | .00107  |
| 128               | .181          | .953            | .0035    | .00107  |
| 129               | .202          | .953            | .0035    | .00107  |
| 130               | .222          | .953            | .0035    | .00107  |
| 131               | .243          | .953            | .0035    | .00107  |
| 132               | .278          | .953            | .0033    | .00102  |
| 133               | .313          | .953            | .0033    | .00102  |
| 134               | .334          | .953            | .0033    | .00102  |

(d) Horizontal-tail upper surface

| Thermo-<br>couple | $\frac{x_h}{\bar{c}_h}$ | $\frac{y}{b_h/2}$ | $\tau$ , |         |
|-------------------|-------------------------|-------------------|----------|---------|
|                   |                         |                   | ft       | m       |
| 135               | 0.189                   | 0.696             | 0.0042   | 0.00127 |
| 136               | .281                    | .696              | .0042    | .00127  |
| 137               | .410                    | .696              | .0042    | .00127  |
| 138               | .531                    | .696              | .0042    | .00127  |
| 139               | .640                    | .696              | .0042    | .00127  |
| 140               | .741                    | .696              | .0042    | .00127  |
| 141               | .899                    | .696              | .0042    | .00127  |

(e) Horizontal-tail lower surface

| Thermo-<br>couple | $\frac{x_h}{\bar{c}_h}$ | $\frac{y}{b_h/2}$ | $\tau$ , |         |
|-------------------|-------------------------|-------------------|----------|---------|
|                   |                         |                   | ft       | m       |
| 142               | 0.189                   | 0.696             | 0.0042   | 0.00127 |
| 143               | .281                    | .696              | .0042    | .00127  |
| 144               | .410                    | .696              | .0042    | .00127  |
| 145               | .531                    | .696              | .0042    | .00127  |
| 146               | .640                    | .696              | .0042    | .00127  |
| 147               | .899                    | .696              | .0042    | .00127  |

TABLE V. - THERMOCOUPLE LOCATIONS AND WALL THICKNESSES - Concluded

| (f) Vertical tail |                         |                     |         |         | (g) Ventral tail  |                         |                     |         |         |
|-------------------|-------------------------|---------------------|---------|---------|-------------------|-------------------------|---------------------|---------|---------|
| Thermo-<br>couple | $\frac{x_v}{\bar{c}_v}$ | $\frac{z}{b_{ver}}$ | $\tau,$ |         | Thermo-<br>couple | $\frac{x_v}{\bar{c}_v}$ | $\frac{z}{b_{ven}}$ | $\tau,$ |         |
|                   |                         |                     | ft      | m       |                   |                         |                     | ft      | m       |
| 148               | 0.037                   | 0.455               | 0.0078  | 0.00236 | 181               | 0.037                   | 0.517               | 0.0078  | 0.00236 |
| 149               | .060                    | .455                | .0059   | .00180  | 182               | .060                    | .517                | .0059   | .00180  |
| 150               | .120                    | .455                | .0031   | .00094  | 183               | .120                    | .517                | .0031   | .00094  |
| 151               | .150                    | .455                | .0031   | .00094  | 184               | .251                    | .517                | .0031   | .00094  |
| 152               | .251                    | .455                | .0017   | .00051  | 185               | .300                    | .517                | .0017   | .00051  |
| 153               | .300                    | .455                | .0017   | .00051  | 186               | .380                    | .517                | .0017   | .00051  |
| 154               | .380                    | .455                | .0017   | .00051  | 187               | .509                    | .517                | .0017   | .00051  |
| 155               | .509                    | .455                | .0017   | .00051  | 188               | .560                    | .517                | .0017   | .00051  |
| 156               | .560                    | .455                | .0017   | .00051  | 189               | .611                    | .517                | .0017   | .00051  |
| 157               | .611                    | .455                | .0017   | .00051  | 190               | .690                    | .517                | .0109   | .00333  |
| 158               | .690                    | .455                | .0109   | .00333  | 191               | .709                    | .517                | .0106   | .00323  |
| 159               | .709                    | .455                | .0106   | .00323  |                   |                         |                     |         |         |
| 160               | .770                    | .455                | .0095   | .00290  |                   |                         |                     |         |         |
| 161               | .840                    | .455                | .0088   | .00269  |                   |                         |                     |         |         |
| 162               | .910                    | .455                | .0079   | .00241  |                   |                         |                     |         |         |
| 163               | .970                    | .455                | .0072   | .00218  |                   |                         |                     |         |         |
| 164               | .030                    | .729                | .0082   | .00249  |                   |                         |                     |         |         |
| <sup>a</sup> 164L | .030                    | .729                | .0082   | .00249  |                   |                         |                     |         |         |
| 165               | .050                    | .729                | .0065   | .00198  |                   |                         |                     |         |         |
| 165L              | .050                    | .729                | .0065   | .00198  |                   |                         |                     |         |         |
| 166               | .132                    | .729                | .0031   | .00094  |                   |                         |                     |         |         |
| 166L              | .132                    | .729                | .0031   | .00094  |                   |                         |                     |         |         |
| 167               | .160                    | .729                | .0031   | .00094  |                   |                         |                     |         |         |
| 167L              | .160                    | .729                | .0031   | .00094  |                   |                         |                     |         |         |
| 168               | .220                    | .729                | .0031   | .00094  |                   |                         |                     |         |         |
| 168L              | .220                    | .729                | .0031   | .00094  |                   |                         |                     |         |         |
| 169L              | .261                    | .729                | .0031   | .00094  |                   |                         |                     |         |         |
| 170               | .370                    | .729                | .0025   | .00076  |                   |                         |                     |         |         |
| 170L              | .370                    | .729                | .0025   | .00076  |                   |                         |                     |         |         |
| 171               | .520                    | .729                | .0025   | .00076  |                   |                         |                     |         |         |
| 171L              | .520                    | .729                | .0025   | .00076  |                   |                         |                     |         |         |
| 172               | .660                    | .729                | .0025   | .00076  |                   |                         |                     |         |         |
| 172L              | .660                    | .729                | .0025   | .00076  |                   |                         |                     |         |         |
| 173               | .730                    | .729                | .0025   | .00076  |                   |                         |                     |         |         |
| 174               | .801                    | .729                | .0025   | .00076  |                   |                         |                     |         |         |
| 174L              | .801                    | .729                | .0025   | .00076  |                   |                         |                     |         |         |
| 175               | .050                    | .963                | .0071   | .00216  |                   |                         |                     |         |         |
| 176               | .160                    | .963                | .0031   | .00094  |                   |                         |                     |         |         |
| 177               | .251                    | .963                | .0031   | .00094  |                   |                         |                     |         |         |
| 178               | .431                    | .963                | .0025   | .00076  |                   |                         |                     |         |         |
| 179               | .580                    | .963                | .0025   | .00076  |                   |                         |                     |         |         |
| 180               | .690                    | .963                | .0025   | .00076  |                   |                         |                     |         |         |

<sup>a</sup>L indicates thermocouple on left side.

TABLE VI. - FLIGHT PARAMETERS

| t,<br>sec   | M <sub>∞</sub> | p <sub>∞</sub> ,   |                   | T <sub>∞</sub> , |     | α,<br>deg | β,<br>deg | δ <sub>h, L</sub> ,<br>deg | δ <sub>h, R</sub> ,<br>deg | δ <sub>v</sub> ,<br>deg | δ <sub>SB</sub> ,<br>deg |
|-------------|----------------|--------------------|-------------------|------------------|-----|-----------|-----------|----------------------------|----------------------------|-------------------------|--------------------------|
|             |                | lb/ft <sup>2</sup> | hN/m <sup>2</sup> | °R               | °K  |           |           |                            |                            |                         |                          |
| Flight 2-22 |                |                    |                   |                  |     |           |           |                            |                            |                         |                          |
| 76          | 4.95           | 97                 | 46.4              | 390              | 217 | 1.6       | 0.07      | -5.4                       | -4.3                       | -0.39                   | 0                        |
| 77          | 4.99           | 96                 | 46.0              | 390              | 217 | 1.6       | .07       | -5.1                       | -4.1                       | -.46                    | 0                        |
| 78          | 5.02           | 96                 | 46.0              | 390              | 217 | 1.8       | .11       | -4.5                       | -3.7                       | -.50                    | 0                        |
| 79          | 5.06           | 95                 | 45.5              | 390              | 217 | 1.7       | .03       | -4.0                       | -3.6                       | -.50                    | 0                        |
| 80          | 5.08           | 95                 | 45.5              | 390              | 217 | 1.9       | .07       | -3.4                       | -3.7                       | -.50                    | 0                        |
| a81         | 5.10           | 95                 | 45.5              | 390              | 217 | 2.0       | .04       | -3.9                       | -3.8                       | -.24                    | 0                        |
| 82          | 5.12           | 95                 | 45.5              | 390              | 217 | 2.0       | .19       | -4.1                       | -4.1                       | -.28                    | 0                        |
| 83          | 5.14           | 95                 | 45.5              | 390              | 217 | 1.9       | .19       | -4.4                       | -4.3                       | -.31                    | 0                        |
| 84          | 5.16           | 95                 | 45.5              | 390              | 217 | 2.2       | .19       | -4.5                       | -4.5                       | -.28                    | 0                        |
| 85          | 5.19           | 95                 | 45.5              | 390              | 217 | 2.2       | .21       | -4.7                       | -4.4                       | -.28                    | 0                        |
| 86          | 5.21           | 95                 | 45.5              | 390              | 217 | 2.2       | .21       | -4.6                       | -4.7                       | -.28                    | 0                        |
| Flight 2-28 |                |                    |                   |                  |     |           |           |                            |                            |                         |                          |
| 83          | 4.82           | 57                 | 27.3              | 400              | 222 | 15.7      | -.76      | -16.2                      | -15.8                      | -.03                    | 0                        |
| 84          | 4.85           | 56                 | 26.8              | 400              | 222 | 16.1      | -.06      | -15.8                      | -16.0                      | -1.18                   | 0                        |
| 85          | 4.88           | 55                 | 26.3              | 400              | 222 | 16.3      | .82       | -16.4                      | -15.4                      | .47                     | 0                        |
| 86          | 4.91           | 55                 | 26.3              | 401              | 223 | 16.6      | -.72      | -16.3                      | -15.3                      | -.65                    | 0                        |
| 87          | 4.94           | 54                 | 25.9              | 401              | 223 | 16.0      | .58       | -15.8                      | -15.4                      | -.46                    | 0                        |
| a88         | 4.98           | 53                 | 25.4              | 401              | 223 | 16.3      | -.74      | -15.5                      | -15.0                      | -.11                    | 0                        |
| 89          | 5.00           | 53                 | 25.4              | 401              | 223 | 15.9      | .08       | -15.3                      | -14.3                      | -1.14                   | 0                        |
| 90          | 5.03           | 52                 | 24.9              | 401              | 223 | 15.2      | -.36      | -14.3                      | -14.3                      | -.09                    | 0                        |
| 91          | 5.06           | 52                 | 24.9              | 402              | 223 | 16.3      | -.42      | -14.5                      | -14.1                      | -1.14                   | 0                        |
| 92          | 5.09           | 51                 | 24.4              | 402              | 223 | 16.0      | .68       | -15.4                      | -14.6                      | .21                     | 0                        |
| 93          | 5.12           | 51                 | 24.4              | 402              | 223 | 16.7      | -.68      | -15.3                      | -15.1                      | -.56                    | 0                        |

<sup>a</sup>Time at which heat-transfer coefficients were derived.

TABLE VII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-22

(a) Fuselage

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ |       | $\frac{dT_w}{dt}$ |            | $\rho_w^c \rho_{p,w} \tau$ |                         | $h_T$                          |                             | $N_{St, \infty}$ |
|-------------------|-------------------|-------|-------|-------------------|------------|----------------------------|-------------------------|--------------------------------|-----------------------------|------------------|
|                   |                   | °R    | °K    | R° per sec        | K° per sec | Btu<br>ft <sup>2</sup> -°R | J<br>m <sup>2</sup> -°K | Btu<br>ft <sup>2</sup> -sec-°R | J<br>m <sup>2</sup> -sec-°K |                  |
|                   |                   |       |       |                   |            |                            |                         |                                |                             |                  |
| 1                 | 0.429             | 896   | 498   | 14.5              | 8.06       | 0.675                      | 13,780                  | 0.00839                        | 171.3                       | 0.00140          |
| 2                 | .437              | 913   | 508   | 16.0              | 8.90       | .609                       | 12,440                  | .00848                         | 173.3                       | .00142           |
| 3                 | .433              | 906   | 504   | 15.7              | 8.73       | .447                       | 9,130                   | .00612                         | 124.9                       | .00102           |
| 4                 | .492              | 1029  | 572   | 17.5              | 9.73       | .405                       | 8,270                   | .00703                         | 143.6                       | .00117           |
| 5                 | .487              | 1019  | 567   | 18.2              | 10.12      | .405                       | 8,270                   | .00722                         | 192.0                       | .00120           |
| 6                 | .497              | 1040  | 578   | 17.0              | 9.45       | .408                       | 8,330                   | .00697                         | 185.4                       | .00116           |
| 7                 | .521              | 1090  | 606   | 18.7              | 10.40      | .411                       | 8,390                   | .00816                         | 166.8                       | .00136           |
| 8                 | .494              | 1033  | 574   | 15.9              | 8.84       | .293                       | 5,980                   | .00477                         | 97.5                        | .00080           |
| 9                 | .523              | 1095  | 609   | 17.5              | 9.73       | .366                       | 7,470                   | .00691                         | 141.1                       | .00115           |
| 10                | .467              | 977   | 543   | 17.5              | 9.73       | .378                       | 7,720                   | .00623                         | 127.1                       | .00104           |
| 11                | .478              | 1000  | 556   | 17.5              | 9.73       | .359                       | 7,330                   | .00608                         | 124.2                       | .00101           |
| 12                | .490              | 1026  | 570   | 17.6              | 9.79       | .293                       | 5,980                   | .00519                         | 106.0                       | .00087           |
| 13                | .491              | 1028  | 572   | 16.0              | 8.90       | .293                       | 5,980                   | .00478                         | 97.6                        | .00080           |
| 14                | .527              | 1104  | 614   | 17.0              | 9.45       | .300                       | 6,130                   | .00569                         | 116.1                       | .00095           |
| 15                | .446              | 932   | 518   | 14.9              | 8.28       | .251                       | 5,130                   | .00345                         | 70.4                        | .00058           |
| 16                | -----             | ----- | ----- | -----             | -----      | -----                      | -----                   | -----                          | -----                       | -----            |
| 17                | .506              | 1059  | 589   | 17.4              | 9.67       | .277                       | 5,660                   | .00509                         | 103.9                       | .00085           |
| 18                | .515              | 1077  | 599   | 18.4              | 10.23      | .280                       | 5,720                   | .00554                         | 113.1                       | .00092           |
| 19                | .510              | 1066  | 593   | 16.6              | 9.23       | .277                       | 5,660                   | .00492                         | 100.4                       | .00082           |
| 20                | -----             | ----- | ----- | -----             | -----      | -----                      | -----                   | -----                          | -----                       | -----            |
| 21                | -----             | ----- | ----- | -----             | -----      | -----                      | -----                   | -----                          | -----                       | -----            |
| 22                | .506              | 1059  | 589   | 16.5              | 9.17       | .277                       | 5,660                   | .00485                         | 99.1                        | .00081           |
| 23                | -----             | ----- | ----- | -----             | -----      | -----                      | -----                   | -----                          | -----                       | -----            |
| 24                | .507              | 1061  | 590   | 16.8              | 9.34       | .266                       | 5,430                   | .00478                         | 97.5                        | .00080           |
| 25                | .492              | 1029  | 572   | 16.7              | 9.29       | .265                       | 5,411                   | .00454                         | 92.7                        | .00076           |
| 26                | -----             | ----- | ----- | -----             | -----      | -----                      | -----                   | -----                          | -----                       | -----            |
| 27                | -----             | ----- | ----- | -----             | -----      | -----                      | -----                   | -----                          | -----                       | -----            |
| 28                | -----             | ----- | ----- | -----             | -----      | -----                      | -----                   | -----                          | -----                       | -----            |
| 29                | .488              | 1020  | 567   | 14.8              | 8.23       | .264                       | 5,390                   | .00399                         | 81.5                        | .00067           |
| 30                | .412              | 861   | 479   | 9.9               | 5.50       | .256                       | 5,230                   | .00221                         | 45.2                        | .00037           |
| 31                | .408              | 854   | 475   | 10.8              | 6.00       | .256                       | 5,230                   | .00238                         | 48.7                        | .00040           |
| 32                | -----             | ----- | ----- | -----             | -----      | -----                      | -----                   | -----                          | -----                       | -----            |
| 33                | -----             | ----- | ----- | -----             | -----      | -----                      | -----                   | -----                          | -----                       | -----            |
| 34                | .423              | 884   | 492   | 10.0              | 5.56       | .363                       | 7,410                   | .00320                         | 65.3                        | .00054           |
| 35                | .402              | 840   | 467   | 11.9              | 6.62       | .254                       | 5,190                   | .00256                         | 52.4                        | .00043           |
| 36                | .394              | 823   | 458   | 11.2              | 6.23       | .254                       | 5,190                   | .00238                         | 48.5                        | .00040           |
| 37                | .413              | 864   | 480   | 10.4              | 5.78       | .256                       | 5,230                   | .00234                         | 47.7                        | .00039           |
| 38                | .522              | 1093  | 608   | 16.6              | 9.23       | .192                       | 3,920                   | .00370                         | 75.5                        | .00062           |
| 39                | .488              | 1021  | 568   | 15.6              | 8.67       | .189                       | 3,860                   | .00311                         | 63.5                        | .00052           |
| 40                | .283              | 591   | 329   | 4.7               | 2.61       | .587                       | 11,990                  | .00186                         | 37.9                        | .00032           |
| 41                | .321              | 670   | 373   | 11.7              | 6.51       | .298                       | 6,090                   | .00250                         | 51.0                        | .00042           |
| 42                | .374              | 782   | 435   | 11.0              | 6.12       | .306                       | 6,250                   | .00267                         | 54.5                        | .00045           |
| 43                | .453              | 947   | 527   | 12.8              | 7.12       | .160                       | 3,270                   | .00204                         | 41.7                        | .00034           |
| 44                | .582              | 1219  | 678   | 20.5              | 11.40      | .171                       | 3,490                   | .00490                         | 100.0                       | .00081           |
| 45                | .462              | 966   | 537   | 13.8              | 7.67       | .162                       | 3,310                   | .00225                         | 46.0                        | .00038           |
| 46                | .383              | 801   | 445   | 9.5               | 5.28       | .155                       | 3,170                   | .00125                         | 25.6                        | .00021           |
| 47                | .414              | 866   | 481   | 10.7              | 5.95       | .158                       | 3,230                   | .00155                         | 31.6                        | .00026           |
| 48                | .334              | 699   | 389   | 6.4               | 3.56       | .300                       | 6,130                   | .00144                         | 29.4                        | .00024           |
| 49                | .354              | 739   | 411   | 7.0               | 3.89       | .302                       | 6,170                   | .00166                         | 33.8                        | .00028           |
| 50                | .411              | 860   | 478   | 11.6              | 6.45       | .310                       | 6,330                   | .00308                         | 63.0                        | .00052           |

TABLE VII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-22 - Continued

(b) Wing upper surface

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ |       | $\frac{dT_w}{dt}$ |            | $\rho_w^c c_{p,w} \tau$ |                    | $h_T$                   |                        | $N_{St, \infty}$ |
|-------------------|-------------------|-------|-------|-------------------|------------|-------------------------|--------------------|-------------------------|------------------------|------------------|
|                   |                   | °R    | °K    | R° per sec        | K° per sec | Btu                     | J                  | Btu                     | J                      |                  |
|                   |                   |       |       |                   |            | ft <sup>2</sup> -°R     | m <sup>2</sup> -°K | ft <sup>2</sup> -sec-°R | m <sup>2</sup> -sec-°K |                  |
| 51                | 0.401             | 838   | 466   | 10.2              | 5.67       | 0.338                   | 6,900              | 0.00288                 | 58.9                   | 0.00048          |
| 52                | .423              | 884   | 492   | 9.8               | 5.45       | .343                    | 7,000              | .00298                  | 60.8                   | .00050           |
| 53                | .464              | 970   | 539   | 17.4              | 9.67       | .345                    | 7,050              | .00563                  | 114.9                  | .00094           |
| 54                | .442              | 925   | 514   | 15.3              | 8.51       | .332                    | 6,780              | .00457                  | 93.3                   | .00076           |
| 55                | .424              | 886   | 493   | 14.2              | 7.90       | .328                    | 6,700              | .00406                  | 82.8                   | .00068           |
| 56                | .343              | 716   | 398   | 8.3               | 4.61       | .419                    | 8,560              | .00260                  | 53.0                   | .00044           |
| 57                | .345              | 721   | 401   | 7.6               | 4.23       | .419                    | 8,560              | .00243                  | 49.6                   | .00041           |
| 58                | .340              | 710   | 395   | 7.3               | 4.06       | .419                    | 8,560              | .00227                  | 46.3                   | .00038           |
| 59                | .338              | 707   | 393   | 6.9               | 3.84       | .418                    | 8,540              | .00216                  | 44.1                   | .00037           |
| 60                | .313              | 653   | 363   | 5.1               | 2.84       | .415                    | 8,470              | .00151                  | 30.8                   | .00026           |
| 61                | .300              | 627   | 349   | 4.3               | 2.39       | .407                    | 8,310              | .00123                  | 25.2                   | .00021           |
| 62                | .303              | 634   | 353   | 4.2               | 2.34       | .407                    | 8,310              | .00121                  | 24.8                   | .00021           |
| 63                | .373              | 779   | 433   | 6.5               | 3.61       | .185                    | 3,780              | .00102                  | 20.9                   | .00017           |
| 64                | .377              | 788   | 438   | 7.3               | 4.06       | .185                    | 3,780              | .00115                  | 23.4                   | .00019           |
| 65                | .377              | 788   | 438   | 7.2               | 4.00       | .185                    | 3,780              | .00113                  | 23.0                   | .00019           |
| 66                | .777              | 1327  | 738   | 26.4              | 14.68      | .311                    | 6,350              | .01166                  | 238.0                  | .00193           |
| 67                | .593              | 1242  | 691   | 22.8              | 12.68      | .304                    | 6,210              | .00921                  | 188.1                  | .00153           |
| 68                | .536              | 1121  | 623   | 20.6              | 11.45      | .297                    | 6,070              | .00673                  | 137.4                  | .00112           |
| 69                | .519              | 1085  | 603   | 20.1              | 11.18      | .294                    | 6,000              | .00624                  | 127.4                  | .00104           |
| 70                | .431              | 901   | 501   | 15.5              | 8.62       | .336                    | 6,860              | .00457                  | 93.3                   | .00076           |
| 71                | .422              | 883   | 491   | 14.3              | 7.95       | .336                    | 6,860              | .00415                  | 84.8                   | .00070           |
| 72                | .410              | 858   | 477   | 13.4              | 7.45       | .333                    | 6,800              | .00378                  | 77.1                   | .00064           |
| 73                | .409              | 856   | 476   | 13.2              | 7.34       | .333                    | 6,800              | .00369                  | 75.4                   | .00062           |
| 74                | .388              | 810   | 450   | 11.7              | 6.51       | .330                    | 6,740              | .00314                  | 64.0                   | .00053           |
| 75                | .375              | 783   | 435   | 10.6              | 5.89       | .327                    | 6,680              | .00275                  | 56.2                   | .00046           |
| 76                | .360              | 752   | 418   | 9.9               | 5.50       | .324                    | 6,620              | .00249                  | 50.9                   | .00042           |
| 77                | .355              | 741   | 412   | 9.3               | 5.17       | .324                    | 6,620              | .00230                  | 47.1                   | .00039           |
| 78                | .418              | 872   | 485   | 13.3              | 7.39       | .188                    | 3,840              | .00222                  | 45.3                   | .00037           |
| 79                | .409              | 856   | 476   | 11.7              | 6.51       | .188                    | 3,840              | .00194                  | 39.6                   | .00033           |
| 80                | -----             | ----- | ----- | -----             | -----      | -----                   | -----              | -----                   | -----                  | -----            |
| 81                | .521              | 1089  | 605   | 13.0              | 7.23       | .218                    | 4,450              | .00332                  | 67.7                   | .00055           |
| 82                | .532              | 1113  | 619   | 9.4               | 5.23       | .220                    | 4,490              | .00267                  | 54.6                   | .00045           |
| 83                | .570              | 1192  | 663   | 14.0              | 7.78       | .224                    | 4,570              | .00428                  | 87.4                   | .00071           |
| 84                | .514              | 1075  | 598   | 16.8              | 9.34       | .230                    | 4,700              | .00427                  | 87.1                   | .00071           |
| 85                | .510              | 1067  | 593   | 16.9              | 9.40       | .228                    | 4,660              | .00421                  | 85.9                   | .00070           |
| 86                | .511              | 1069  | 594   | 15.9              | 8.84       | .228                    | 4,660              | .00399                  | 81.5                   | .00067           |
| 87                | .499              | 1043  | 580   | 15.9              | 8.84       | .228                    | 4,660              | .00386                  | 78.8                   | .00064           |
| 88                | .468              | 980   | 545   | 13.9              | 7.73       | .224                    | 4,570              | .00309                  | 63.1                   | .00052           |
| 89                | .474              | 991   | 551   | 13.3              | 7.39       | .225                    | 4,600              | .00296                  | 60.4                   | .00049           |
| 90                | .451              | 942   | 524   | 12.4              | 6.89       | .222                    | 4,530              | .00262                  | 53.5                   | .00044           |
| 91                | .448              | 937   | 521   | 11.8              | 6.56       | .199                    | 4,060              | .00223                  | 45.5                   | .00037           |
| 92                | .455              | 952   | 529   | 12.8              | 7.12       | .199                    | 4,060              | .00249                  | 50.9                   | .00042           |

TABLE VII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-22 - Continued

(c) Wing lower surface

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$       |             | $\frac{dT_w}{dt}$   |                     | $\rho_w c_{p,w} \tau$                |                                   | $h_T$                                    |                                       | $N_{St, \infty}$ |
|-------------------|-------------------|-------------|-------------|---------------------|---------------------|--------------------------------------|-----------------------------------|------------------------------------------|---------------------------------------|------------------|
|                   |                   |             |             |                     |                     |                                      |                                   |                                          |                                       |                  |
|                   |                   | $^{\circ}R$ | $^{\circ}K$ | $R^{\circ}$ per sec | $K^{\circ}$ per sec | Btu<br>ft <sup>2</sup> - $^{\circ}R$ | J<br>m <sup>2</sup> - $^{\circ}K$ | Btu<br>ft <sup>2</sup> -sec- $^{\circ}R$ | J<br>m <sup>2</sup> -sec- $^{\circ}K$ |                  |
| 93                | 0.445             | 931         | 518         | 11.5                | 6.39                | 0.372                                | 7,600                             | 0.00392                                  | 80.0                                  | 0.00065          |
| 94                | .503              | 1052        | 585         | 9.9                 | 5.50                | .382                                 | 7,800                             | .00405                                   | 82.8                                  | .00068           |
| 95                | .508              | 1062        | 590         | 18.3                | 10.17               | .382                                 | 7,800                             | .00724                                   | 147.8                                 | .00121           |
| 96                | .464              | 971         | 540         | 15.1                | 8.40                | .375                                 | 7,660                             | .00534                                   | 109.0                                 | .00089           |
| 97                | .444              | 929         | 517         | 14.0                | 7.78                | .372                                 | 7,600                             | .00469                                   | 95.8                                  | .00078           |
| 98                | .430              | 900         | 500         | 13.5                | 7.51                | .368                                 | 7,520                             | .00436                                   | 89.0                                  | .00073           |
| 99                | .420              | 879         | 489         | 11.7                | 6.51                | .316                                 | 6,450                             | .00322                                   | 65.7                                  | .00054           |
| 100               | .417              | 871         | 484         | 12.3                | 6.84                | .316                                 | 6,450                             | .00335                                   | 68.4                                  | .00056           |
| 101               | .407              | 852         | 474         | 10.8                | 6.00                | .316                                 | 6,450                             | .00290                                   | 59.3                                  | .00049           |
| 102               | .412              | 861         | 479         | 11.7                | 6.51                | .316                                 | 6,450                             | .00317                                   | 64.7                                  | .00053           |
| 103               | .375              | 784         | 436         | 8.8                 | 4.89                | .311                                 | 6,350                             | .00219                                   | 44.8                                  | .00037           |
| 104               | .367              | 766         | 426         | 8.7                 | 4.84                | .308                                 | 6,290                             | .00210                                   | 42.9                                  | .00035           |
| 105               | .375              | 783         | 435         | 8.8                 | 4.89                | .311                                 | 6,350                             | .00220                                   | 45.0                                  | .00037           |
| 106               | .390              | 815         | 453         | 8.8                 | 4.89                | .187                                 | 3,820                             | .00142                                   | 29.0                                  | .00024           |
| 107               | .402              | 841         | 468         | 9.3                 | 5.17                | .189                                 | 3,860                             | .00154                                   | 31.5                                  | .00026           |
| 108               | .654              | 1370        | 762         | 29.5                | 16.40               | .328                                 | 6,700                             | .01504                                   | 307.2                                 | .00248           |
| 109               | .612              | 1282        | 713         | 24.5                | 13.62               | .320                                 | 6,530                             | .01083                                   | 221.2                                 | .00179           |
| 110               | .570              | 1193        | 663         | 22.8                | 12.68               | .316                                 | 6,450                             | .00859                                   | 175.5                                 | .00143           |
| 111               | .521              | 1089        | 605         | 20.8                | 11.56               | .308                                 | 6,290                             | .00688                                   | 140.4                                 | .00115           |
| 112               | .505              | 1060        | 589         | 19.5                | 10.84               | .277                                 | 5,660                             | .00562                                   | 114.8                                 | .00094           |
| 113               | .492              | 1030        | 573         | 18.0                | 10.01               | .276                                 | 5,640                             | .00505                                   | 103.0                                 | .00084           |
| 114               | .472              | 987         | 549         | 16.6                | 9.23                | .272                                 | 5,550                             | .00439                                   | 89.7                                  | .00073           |
| 115               | .476              | 995         | 553         | 16.8                | 9.34                | .273                                 | 5,580                             | .00450                                   | 91.8                                  | .00075           |
| 116               | .469              | 981         | 545         | 16.0                | 8.90                | .272                                 | 5,550                             | .00419                                   | 85.6                                  | .00070           |
| 117               | .451              | 943         | 524         | 14.6                | 8.12                | .270                                 | 5,510                             | .00368                                   | 75.1                                  | .00061           |
| 118               | .427              | 893         | 497         | 13.3                | 7.39                | .268                                 | 5,470                             | .00316                                   | 64.6                                  | .00053           |
| 119               | .407              | 852         | 474         | 11.9                | 6.62                | .265                                 | 5,410                             | .00270                                   | 55.2                                  | .00045           |
| 120               | .425              | 888         | 494         | 12.5                | 6.95                | .189                                 | 3,860                             | .00215                                   | 44.0                                  | .00036           |
| 121               | .426              | 891         | 495         | 12.2                | 6.78                | .189                                 | 3,860                             | .00211                                   | 43.2                                  | .00035           |
| 122               | .514              | 1076        | 598         | 11.3                | 6.28                | .224                                 | 4,570                             | .00296                                   | 60.5                                  | .00049           |
| 123               | .631              | 1321        | 734         | 22.5                | 12.51               | .237                                 | 4,840                             | .00830                                   | 169.5                                 | .00137           |
| 124               | .614              | 1286        | 715         | 21.8                | 12.12               | .227                                 | 4,640                             | .00732                                   | 149.5                                 | .00121           |
| 125               | .593              | 1242        | 691         | 17.7                | 9.84                | .227                                 | 4,640                             | .00571                                   | 116.7                                 | .00095           |
| 126               | .590              | 1236        | 687         | 16.5                | 9.17                | .226                                 | 4,620                             | .00531                                   | 108.4                                 | .00088           |
| 127               | .556              | 1164        | 647         | 17.2                | 9.56                | .222                                 | 4,530                             | .00480                                   | 98.0                                  | .00080           |
| 128               | .569              | 1191        | 662         | 17.6                | 9.79                | .226                                 | 4,620                             | .00519                                   | 105.9                                 | .00086           |
| 129               | .524              | 1096        | 609         | 16.5                | 9.17                | .218                                 | 4,450                             | .00413                                   | 84.3                                  | .00069           |
| 130               | .528              | 1105        | 614         | 15.7                | 8.73                | .220                                 | 4,490                             | .00402                                   | 82.1                                  | .00067           |
| 131               | .491              | 1027        | 571         | 14.4                | 8.01                | .214                                 | 4,370                             | .00327                                   | 66.7                                  | .00055           |
| 132               | .477              | 997         | 554         | 13.2                | 7.34                | .202                                 | 4,130                             | .00273                                   | 55.8                                  | .00046           |
| 133               | .471              | 986         | 548         | 13.3                | 7.39                | .202                                 | 4,130                             | .00274                                   | 56.0                                  | .00046           |
| 134               | .456              | 954         | 530         | 12.5                | 6.95                | .200                                 | 4,080                             | .00243                                   | 49.6                                  | .00041           |

TABLE VII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-22 - Continued

## (d) Horizontal-tail upper surface

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ ,    |            | $\frac{dT_w}{dt}$ , |                   | $\rho_w c_p w \tau$ ,                |                                   | $h_T$ ,                                           |                                                | $N_{St, \infty}$ |
|-------------------|-------------------|------------|------------|---------------------|-------------------|--------------------------------------|-----------------------------------|---------------------------------------------------|------------------------------------------------|------------------|
|                   |                   |            |            |                     |                   | $\frac{Btu}{ft^2 \text{--}^\circ R}$ | $\frac{J}{m^2 \text{--}^\circ K}$ | $\frac{Btu}{ft^2 \text{--}sec \text{--}^\circ R}$ | $\frac{J}{m^2 \text{--}sec \text{--}^\circ K}$ |                  |
|                   |                   | $^\circ R$ | $^\circ K$ | $R^\circ$ per sec   | $K^\circ$ per sec |                                      |                                   |                                                   |                                                |                  |
| 135               | 0.578             | 1210       | 673        | 22.4                | 12.45             | 0.266                                | 5,430                             | 0.00761                                           | 155.3                                          | 0.00126          |
| 136               | .498              | 1042       | 579        | 14.8                | 8.23              | .256                                 | 5,230                             | .00401                                            | 81.8                                           | .00067           |
| 137               | .473              | 989        | 550        | 13.1                | 7.28              | .253                                 | 5,170                             | .00331                                            | 67.6                                           | .00055           |
| 138               | .509              | 1065       | 592        | 17.5                | 9.73              | .258                                 | 5,270                             | .00484                                            | 98.8                                           | .00081           |
| 139               | .431              | 902        | 502        | 11.7                | 6.51              | .249                                 | 5,090                             | .00265                                            | 54.0                                           | .00044           |
| 140               | .429              | 898        | 499        | 11.6                | 6.45              | .243                                 | 4,960                             | .00255                                            | 52.0                                           | .00043           |
| 141               | .430              | 900        | 500        | 12.6                | 7.01              | .249                                 | 5,090                             | .00283                                            | 57.8                                           | .00047           |

## (e) Horizontal-tail lower surface

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ |     | $\frac{dT_w}{dt}$ |            | $\rho_w c_p w \tau$ |                    | $h_T$                   |                        | $N_{St, \infty}$ |
|-------------------|-------------------|-------|-----|-------------------|------------|---------------------|--------------------|-------------------------|------------------------|------------------|
|                   |                   | °R    | °K  | R° per sec        | K° per sec | Btu                 | J                  | Btu                     | J                      |                  |
|                   |                   |       |     |                   |            | ft <sup>2</sup> -°R | m <sup>2</sup> -°K | ft <sup>2</sup> -sec-°R | m <sup>2</sup> -sec-°K |                  |
| 142               | 0.539             | 1128  | 627 | 16.1              | 8.95       | 0.262               | 5,350              | 0.00497                 | 101.4                  | 0.00083          |
| 143               | .476              | 995   | 553 | 11.1              | 6.17       | .253                | 5,170              | .00288                  | 58.8                   | .00048           |
| 144               | .511              | 1068  | 594 | 15.2              | 8.45       | .258                | 5,270              | .00428                  | 87.3                   | .00071           |
| 145               | .453              | 947   | 527 | 13.2              | 7.34       | .251                | 5,130              | .00315                  | 64.3                   | .00053           |
| 146               | .402              | 841   | 468 | 9.6               | 5.34       | .245                | 5,000              | .00203                  | 41.4                   | .00034           |
| 147               | .405              | 846   | 470 | 9.3               | 5.17       | .245                | 5,000              | .00198                  | 40.5                   | .00033           |

TABLE VII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-22 - Continued

(f) Vertical tail

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$       |             | $\frac{dT_w}{dt}$   |                     | $\rho_w c_p w \tau$ |                 | $h_T$                |                     | $N_{St, \infty}$ |
|-------------------|-------------------|-------------|-------------|---------------------|---------------------|---------------------|-----------------|----------------------|---------------------|------------------|
|                   |                   | $^{\circ}R$ | $^{\circ}K$ | $R^{\circ}$ per sec | $K^{\circ}$ per sec | Btu                 | J               | Btu                  | J                   |                  |
|                   |                   |             |             |                     |                     | $ft^2-^{\circ}R$    | $m^2-^{\circ}K$ | $ft^2-sec-^{\circ}R$ | $m^2-sec-^{\circ}K$ |                  |
| 148               | 0.354             | 740         | 411         | 8.3                 | 4.61                | 0.447               | 9,130           | 0.00282              | 57.7                | 0.00048          |
| 149               | .413              | 864         | 480         | 8.3                 | 4.61                | .338                | 6,900           | .00244               | 49.8                | .00041           |
| 150               | .597              | 1250        | 695         | 21.9                | 12.18               | .200                | 4,080           | .00622               | 127.0               | .00103           |
| 151               | .550              | 1151        | 640         | 17.7                | 9.84                | .193                | 3,940           | .00429               | 87.6                | .00071           |
| 152               | .628              | 1315        | 731         | 16.1                | 8.95                | .109                | 2,230           | .00360               | 73.5                | .00060           |
| 153               | .574              | 1202        | 668         | 16.2                | 9.01                | .106                | 2,170           | .00276               | 56.4                | .00046           |
| 154               | -----             | -----       | -----       | -----               | -----               | -----               | -----           | -----                | -----               | -----            |
| 155               | .557              | 1165        | 648         | 17.1                | 9.51                | .105                | 2,140           | .00264               | 53.9                | .00044           |
| 156               | -----             | -----       | -----       | -----               | -----               | -----               | -----           | -----                | -----               | -----            |
| 157               | .570              | 1192        | 663         | 16.9                | 9.40                | .106                | 2,170           | .00279               | 56.9                | .00046           |
| 158               | .343              | 717         | 399         | 10.1                | 5.62                | .625                | 12,760          | .00466               | 95.2                | .00079           |
| 159               | .357              | 747         | 415         | 9.7                 | 5.39                | .610                | 12,460          | .00448               | 91.5                | .00076           |
| 160               | -----             | -----       | -----       | -----               | -----               | -----               | -----           | -----                | -----               | -----            |
| 161               | .375              | 784         | 436         | 10.5                | 5.84                | .514                | 10,500          | .00425               | 86.8                | .00072           |
| 162               | .375              | 783         | 435         | 11.3                | 6.28                | .460                | 9,390           | .00408               | 83.3                | .00069           |
| 163               | .396              | 827         | 460         | 11.7                | 6.51                | .421                | 8,600           | .00404               | 82.5                | .00068           |
| 164               | .395              | 825         | 459         | 10.3                | 5.73                | .480                | 9,800           | .00403               | 82.4                | .00068           |
| <sup>a</sup> 164L | .327              | 684         | 380         | 3.2                 | 1.78                | .462                | 9,430           | .00112               | 22.9                | .00019           |
| 165               | .446              | 933         | 519         | 12.5                | 6.95                | .389                | 7,940           | .00442               | 90.2                | .00074           |
| 165L              | .449              | 939         | 522         | 11.9                | 6.62                | .388                | 7,920           | .00423               | 86.4                | .00071           |
| 166               | .583              | 1220        | 678         | 17.8                | 9.90                | .197                | 4,020           | .00476               | 97.2                | .00079           |
| 166L              | .568              | 1189        | 661         | 16.5                | 9.17                | .196                | 4,000           | .00437               | 89.2                | .00073           |
| 167               | -----             | -----       | -----       | -----               | -----               | -----               | -----           | -----                | -----               | -----            |
| 167L              | .572              | 1197        | 666         | 16.6                | 9.23                | .196                | 4,000           | .00443               | 90.4                | .00074           |
| 168               | -----             | -----       | -----       | -----               | -----               | -----               | -----           | -----                | -----               | -----            |
| 168L              | .571              | 1196        | 665         | 18.4                | 10.23               | .196                | 4,000           | .00483               | 98.5                | .00080           |
| 169L              | .544              | 1138        | 633         | 16.6                | 9.23                | .193                | 3,940           | .00397               | 81.1                | .00066           |
| 170               | .529              | 1108        | 616         | 14.6                | 8.12                | .157                | 3,210           | .00287               | 58.6                | .00048           |
| 170L              | .524              | 1096        | 609         | 14.1                | 7.84                | .156                | 3,190           | .00271               | 55.4                | .00045           |
| 171               | .591              | 1237        | 688         | 19.2                | 10.68               | .160                | 3,270           | .00455               | 92.9                | .00075           |
| 171L              | .579              | 1212        | 674         | 18.8                | 10.45               | .159                | 3,250           | .00425               | 86.9                | .00071           |
| 172               | .554              | 1160        | 645         | 16.7                | 9.29                | .158                | 3,230           | .00351               | 71.6                | .00058           |
| 172L              | -----             | -----       | -----       | -----               | -----               | -----               | -----           | -----                | -----               | -----            |
| 173               | .530              | 1110        | 617         | 15.4                | 8.56                | .157                | 3,210           | .00303               | 61.9                | .00051           |
| 174               | .532              | 1114        | 619         | 15.0                | 8.34                | .157                | 3,210           | .00296               | 60.5                | .00049           |
| 174L              | .581              | 1217        | 677         | 19.6                | 10.90               | .160                | 3,270           | .00447               | 91.3                | .00074           |
| 175               | .401              | 839         | 466         | 11.2                | 6.23                | .416                | 8,500           | .00388               | 79.2                | .00065           |
| 176               | .570              | 1192        | 663         | 17.8                | 9.90                | .197                | 4,020           | .00468               | 95.6                | .00078           |
| 177               | .538              | 1125        | 626         | 14.5                | 8.06                | .194                | 3,960           | .00350               | 71.5                | .00058           |
| 178               | .527              | 1103        | 613         | 13.5                | 7.51                | .194                | 3,960           | .00317               | 64.7                | .00053           |
| 179               | .552              | 1155        | 642         | 15.6                | 8.67                | .195                | 3,980           | .00391               | 79.8                | .00065           |
| 180               | .529              | 1107        | 615         | 14.3                | 7.95                | .194                | 3,960           | .00335               | 68.3                | .00056           |

<sup>a</sup>L indicates thermocouple on left side.

TABLE VII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-22 - Concluded

(g) Ventral tail

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ , |     | $\frac{dT_w}{dt}$ , |            | $\rho_w c_{p,w} \tau$ ,    |                         | $h_T$ ,                        |                             | $N_{St, \infty}$ |
|-------------------|-------------------|---------|-----|---------------------|------------|----------------------------|-------------------------|--------------------------------|-----------------------------|------------------|
|                   |                   |         |     |                     |            | Btu<br>ft <sup>2</sup> -°R | J<br>m <sup>2</sup> -°K | Btu<br>ft <sup>2</sup> -sec-°R | J<br>m <sup>2</sup> -sec-°K |                  |
|                   |                   | °R      | °K  | R° per sec          | K° per sec |                            |                         |                                |                             |                  |
| 181               | 0.405             | 847     | 471 | 10.5                | 5.84       | 0.460                      | 9,390                   | 0.00403                        | 82.2                        | 0.00068          |
| 182               | .506              | 1059    | 589 | 15.1                | 8.40       | .372                       | 7,600                   | .00586                         | 119.6                       | .00098           |
| 183               | .584              | 1224    | 681 | 19.4                | 10.79      | .198                       | 4,040                   | .00533                         | 108.8                       | .00088           |
| 184               | .549              | 1149    | 639 | 17.3                | 9.62       | .195                       | 3,980                   | .00424                         | 86.5                        | .00070           |
| 185               | .628              | 1315    | 731 | 16.4                | 9.12       | .109                       | 2,230                   | .00364                         | 74.4                        | .00060           |
| 186               | .591              | 1237    | 688 | 16.6                | 9.23       | .108                       | 2,210                   | .00306                         | 62.5                        | .00051           |
| 187               | .628              | 1315    | 731 | 15.9                | 8.84       | .109                       | 2,230                   | .00358                         | 73.1                        | .00059           |
| 188               | .594              | 1243    | 691 | 17.5                | 9.73       | .109                       | 2,230                   | .00324                         | 66.1                        | .00054           |
| 189               | .573              | 1200    | 667 | 12.7                | 7.06       | .107                       | 2,190                   | .00234                         | 47.8                        | .00039           |
| 190               | .361              | 754     | 419 | 11.0                | 6.12       | .630                       | 12,870                  | .00527                         | 107.6                       | .00089           |
| 191               | .369              | 772     | 429 | 10.5                | 5.84       | .610                       | 12,460                  | .00497                         | 101.6                       | .00084           |

TABLE VIII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-28

(a) Fuselage

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ |       | $\frac{dT_w}{dt}$ |            | $\rho_w c_{p,w} \tau$ |                    | $h_T$                   |                        | $N_{St, \infty}$ |
|-------------------|-------------------|-------|-------|-------------------|------------|-----------------------|--------------------|-------------------------|------------------------|------------------|
|                   |                   | °R    | °K    | R° per sec        | K° per sec | Btu                   | J                  | Btu                     | J                      |                  |
|                   |                   |       |       |                   |            | ft <sup>2</sup> -°R   | m <sup>2</sup> -°K | ft <sup>2</sup> -sec-°R | m <sup>2</sup> -sec-°K |                  |
| 1                 | 0.464             | 961   | 534   | 23.1              | 12.84      | 0.684                 | 13,970             | 0.01452                 | 296.5                  | 0.00452          |
| 2                 | .483              | 1000  | 556   | 21.6              | 12.01      | .619                  | 12,640             | .01280                  | 261.4                  | .00398           |
| 3                 | .447              | 924   | 514   | 16.3              | 9.06       | .451                  | 9,210              | .00665                  | 135.8                  | .00207           |
| 4                 | .435              | 901   | 501   | 9.7               | 5.39       | .394                  | 8,040              | .00347                  | 70.9                   | .00108           |
| 5                 | .410              | 849   | 472   | 3.5               | 1.95       | .390                  | 7,960              | .00127                  | 25.9                   | .00040           |
| 6                 | .410              | 848   | 471   | 4.0               | 2.22       | .390                  | 7,960              | .00144                  | 29.4                   | .00045           |
| 7                 | .455              | 942   | 524   | 10.7              | 5.95       | .396                  | 8,090              | .00401                  | 81.9                   | .00125           |
| 8                 | .395              | 818   | 455   | 2.3               | 1.28       | .342                  | 6,980              | .00075                  | 15.3                   | .00023           |
| 9                 | .471              | 974   | 542   | 11.7              | 6.51       | .354                  | 7,230              | .00407                  | 83.1                   | .00127           |
| 10                | .513              | 1063  | 591   | 24.6              | 13.68      | .386                  | 7,880              | .00989                  | 202.0                  | .00307           |
| 11                | .490              | 1015  | 564   | 17.6              | 9.79       | .361                  | 7,370              | .00638                  | 130.3                  | .00198           |
| 12                | .419              | 866   | 481   | 5.5               | 3.06       | .286                  | 5,840              | .00148                  | 30.2                   | .00046           |
| 13                | .399              | 826   | 459   | 2.1               | 1.17       | .284                  | 5,800              | .00062                  | 12.7                   | .00020           |
| 14                | .474              | 982   | 546   | 11.0              | 6.12       | .294                  | 6,000              | .00329                  | 67.2                   | .00102           |
| 15                | .254              | 524   | 291   | 2.0               | 1.11       | .221                  | 4,510              | .00031                  | 6.3                    | .00010           |
| 16                | .459              | 950   | 528   | 6.1               | 3.39       | .627                  | 12,800             | .00366                  | 74.7                   | .00114           |
| 17                | .551              | 1142  | 635   | 24.0              | 13.34      | .282                  | 5,760              | .00793                  | 161.9                  | .00246           |
| 18                | .540              | 1118  | 622   | 19.4              | 10.79      | .282                  | 5,760              | .00633                  | 129.3                  | .00196           |
| 19                | .465              | 963   | 535   | 11.9              | 6.62       | .273                  | 5,580              | .00321                  | 65.6                   | .00100           |
| 20                | .411              | 851   | 473   | 4.3               | 2.39       | .247                  | 5,040              | .00102                  | 20.8                   | .00032           |
| 21                | .439              | 909   | 505   | 4.6               | 2.56       | .620                  | 12,660             | .00264                  | 53.9                   | .00082           |
| 22                | .449              | 930   | 517   | 8.6               | 4.78       | .272                  | 5,550              | .00228                  | 46.6                   | .00071           |
| 23                | .457              | 945   | 525   | .8                | .44        | .590                  | 12,050             | .00066                  | 13.5                   | .00021           |
| 24                | .553              | 1145  | 637   | 23.9              | 13.29      | .271                  | 5,530              | .00764                  | 156.0                  | .00237           |
| 25                | .518              | 1073  | 597   | 20.5              | 11.40      | .267                  | 5,450              | .00594                  | 121.3                  | .00185           |
| 26                | .392              | 811   | 451   | 4.0               | 2.22       | .244                  | 4,980              | .00090                  | 18.4                   | .00028           |
| 27                | .390              | 806   | 448   | 7.0               | 3.89       | .244                  | 4,980              | .00148                  | 30.2                   | .00046           |
| 28                | .411              | 850   | 473   | 5.7               | 3.17       | .245                  | 5,000              | .00130                  | 26.6                   | .00041           |
| 29                | .441              | 912   | 507   | 10.8              | 6.00       | .285                  | 5,270              | .00263                  | 53.7                   | .00082           |
| 30                | .459              | 950   | 528   | 19.1              | 10.62      | .260                  | 5,310              | .00470                  | 96.0                   | .00146           |
| 31                | .428              | 886   | 493   | 13.8              | 7.67       | .258                  | 5,270              | .00319                  | 65.1                   | .00100           |
| 32                | .342              | 707   | 393   | 1.9               | 1.06       | .247                  | 5,040              | .00041                  | 8.4                    | .00013           |
| 33                | .274              | 566   | 315   | 2.4               | 1.33       | .224                  | 4,570              | .00038                  | 7.8                    | .00012           |
| 34                | .393              | 814   | 453   | 4.3               | 2.39       | .357                  | 7,290              | .00136                  | 27.8                   | .00043           |
| 35                | .440              | 910   | 506   | 16.5              | 9.17       | .258                  | 5,270              | .00387                  | 79.0                   | .00121           |
| 36                | .439              | 908   | 505   | 13.7              | 7.62       | .258                  | 5,270              | .00325                  | 66.4                   | .00101           |
| 37                | .437              | 904   | 503   | 13.7              | 7.62       | .258                  | 5,270              | .00325                  | 66.4                   | .00101           |
| 38                | .529              | 1096  | 609   | 16.2              | 9.01       | .192                  | 3,920              | .00371                  | 75.8                   | .00115           |
| 39                | .438              | 906   | 504   | 6.8               | 3.78       | .184                  | 3,760              | .00128                  | 26.1                   | .00040           |
| 40                | .265              | 547   | 304   | 1.0               | .56        | .576                  | 11,760             | .00040                  | 8.2                    | .00013           |
| 41                | .285              | 590   | 328   | 1.8               | 1.00       | .287                  | 5,860              | .00037                  | 7.6                    | .00012           |
| 42                | .317              | 656   | 365   | 1.6               | .89        | .300                  | 6,130              | .00040                  | 8.2                    | .00013           |
| 43                | -----             | ----- | ----- | -----             | -----      | -----                 | -----              | -----                   | -----                  | -----            |
| 44                | .613              | 1270  | 706   | 20.8              | 11.56      | .126                  | 2,570              | .00441                  | 90.1                   | .00136           |
| 45                | .385              | 797   | 443   | -.9               | -.50       | .114                  | 2,330              | .00003                  | .6                     | .00001           |
| 46                | .340              | 704   | 391   | 1.3               | .72        | .114                  | 2,330              | .00018                  | 3.7                    | .00006           |
| 47                | -----             | ----- | ----- | -----             | -----      | -----                 | -----              | -----                   | -----                  | -----            |
| 48                | -----             | ----- | ----- | -----             | -----      | -----                 | -----              | -----                   | -----                  | -----            |
| 49                | .311              | 644   | 358   | 1.9               | 1.06       | .110                  | 2,250              | .00019                  | 3.9                    | .00006           |
| 50                | .365              | 756   | 420   | 3.8               | 2.11       | .112                  | 2,290              | .00041                  | 8.4                    | .00013           |

TABLE VIII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-28 - Continued

(b) Wing upper surface

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ , |       | $\frac{dT_w}{dt}$ , |            | $\rho_w c_p w^T$ ,         |                         | $h_T$ ,                        |                             | $N_{St, \infty}$ |
|-------------------|-------------------|---------|-------|---------------------|------------|----------------------------|-------------------------|--------------------------------|-----------------------------|------------------|
|                   |                   |         |       |                     |            | Btu<br>ft <sup>2</sup> -°R | J<br>m <sup>2</sup> -°K | Btu<br>ft <sup>2</sup> -sec-°R | J<br>m <sup>2</sup> -sec-°K |                  |
|                   |                   | °R      | °K    | R° per sec          | K° per sec |                            |                         |                                |                             |                  |
| 51                | 0.321             | 663     | 369   | 4.2                 | 2.34       | 0.326                      | 6,660                   | 0.00101                        | 20.6                        | 0.00032          |
| 52                | .311              | 644     | 358   | 3.6                 | 2.00       | .326                       | 6,660                   | .00086                         | 17.6                        | .00027           |
| 53                | .323              | 667     | 371   | 2.4                 | 1.33       | .322                       | 6,580                   | .00061                         | 12.5                        | .00019           |
| 54                | .341              | 706     | 393   | .4                  | .22        | .318                       | 6,490                   | .00016                         | 3.3                         | .00005           |
| 55                | .342              | 708     | 394   | .2                  | .11        | .314                       | 6,410                   | .00010                         | 2.0                         | .00003           |
| 56                | .295              | 610     | 339   | .2                  | .11        | .404                       | 8,250                   | .00009                         | 1.8                         | .00003           |
| 57                | -----             | -----   | ----- | -----               | -----      | -----                      | -----                   | -----                          | -----                       | -----            |
| 58                | .298              | 617     | 343   | .5                  | .28        | .404                       | 8,250                   | .00017                         | 3.5                         | .00006           |
| 59                | .300              | 620     | 447   | 1.4                 | .78        | .407                       | 8,310                   | .00042                         | 8.6                         | .00013           |
| 60                | .278              | 575     | 320   | 1.7                 | .95        | .396                       | 8,090                   | .00047                         | 9.6                         | .00015           |
| 61                | .271              | 560     | 311   | 1.2                 | .67        | .396                       | 8,090                   | .00035                         | 7.2                         | .00011           |
| 62                | .277              | 573     | 319   | 1.1                 | .61        | .396                       | 8,090                   | .00032                         | 6.5                         | .00010           |
| 63                | .330              | 682     | 379   | 1.1                 | .61        | .180                       | 3,680                   | .00020                         | 4.1                         | .00006           |
| 64                | .332              | 687     | 382   | 1.8                 | 1.00       | .180                       | 3,680                   | .00029                         | 5.9                         | .00009           |
| 65                | .336              | 694     | 386   | 2.4                 | 1.33       | .180                       | 3,680                   | .00037                         | 7.6                         | .00012           |
| 66                | .368              | 762     | 424   | 8.4                 | 4.67       | .272                       | 5,550                   | .00184                         | 37.6                        | .00058           |
| 67                | .357              | 739     | 411   | 7.8                 | 4.34       | .270                       | 5,510                   | .00166                         | 33.9                        | .00052           |
| 68                | .352              | 728     | 405   | 9.4                 | 5.23       | .270                       | 5,510                   | .00197                         | 40.2                        | .00062           |
| 69                | .379              | 785     | 436   | 7.4                 | 4.11       | .275                       | 5,620                   | .00169                         | 34.5                        | .00053           |
| 70                | .369              | 763     | 424   | 4.5                 | 2.50       | .325                       | 6,640                   | .00120                         | 24.5                        | .00038           |
| 71                | .365              | 754     | 419   | 5.6                 | 3.11       | .325                       | 6,640                   | .00146                         | 29.8                        | .00046           |
| 72                | .353              | 731     | 406   | 5.0                 | 2.78       | .322                       | 6,580                   | .00127                         | 25.9                        | .00040           |
| 73                | .354              | 732     | 407   | 4.9                 | 2.72       | .322                       | 6,580                   | .00125                         | 25.5                        | .00039           |
| 74                | .335              | 693     | 385   | 3.6                 | 2.00       | .319                       | 6,510                   | .00089                         | 18.2                        | .00028           |
| 75                | .324              | 669     | 372   | 2.8                 | 1.56       | .319                       | 6,510                   | .00070                         | 14.3                        | .00022           |
| 76                | .315              | 651     | 362   | 3.3                 | 1.83       | .319                       | 6,510                   | .00078                         | 15.9                        | .00025           |
| 77                | .313              | 647     | 360   | 2.7                 | 1.50       | .319                       | 6,510                   | .00066                         | 13.5                        | .00021           |
| 78                | .347              | 718     | 399   | 2.2                 | 1.22       | .181                       | 3,700                   | .00036                         | 7.4                         | .00011           |
| 79                | .346              | 715     | 398   | 3.3                 | 1.83       | .181                       | 3,700                   | .00051                         | 10.4                        | .00016           |
| 80                | .313              | 647     | 360   | 3.5                 | 1.95       | .180                       | 3,680                   | .00049                         | 10.0                        | .00015           |
| 81                | .392              | 810     | 450   | 5.5                 | 3.06       | .206                       | 4,210                   | .00102                         | 20.8                        | .00032           |
| 82                | .388              | 802     | 446   | 4.9                 | 2.72       | .206                       | 4,210                   | .00090                         | 18.4                        | .00028           |
| 83                | .385              | 796     | 443   | 2.9                 | 1.61       | .206                       | 4,210                   | .00058                         | 11.8                        | .00018           |
| 84                | .367              | 759     | 422   | 1.8                 | 1.00       | .213                       | 4,350                   | .00038                         | 7.8                         | .00012           |
| 85                | .380              | 787     | 438   | 2.5                 | 1.39       | .216                       | 4,410                   | .00053                         | 10.8                        | .00017           |
| 86                | .400              | 827     | 460   | 2.1                 | 1.17       | .217                       | 4,430                   | .00050                         | 10.2                        | .00016           |
| 87                | .402              | 832     | 463   | 3.5                 | 1.95       | .218                       | 4,450                   | .00076                         | 15.5                        | .00024           |
| 88                | .396              | 820     | 456   | 3.6                 | 2.00       | .218                       | 4,450                   | .00076                         | 15.5                        | .00024           |
| 89                | .397              | 822     | 457   | 3.7                 | 2.06       | .217                       | 4,430                   | .00077                         | 15.7                        | .00024           |
| 90                | .385              | 797     | 443   | 3.8                 | 2.11       | .218                       | 4,450                   | .00077                         | 15.7                        | .00024           |
| 91                | .393              | 814     | 453   | 3.6                 | 2.00       | .194                       | 3,960                   | .00066                         | 13.5                        | .00021           |
| 92                | .404              | 836     | 465   | 4.3                 | 2.39       | .194                       | 3,960                   | .00081                         | 16.5                        | .00025           |

TABLE VIII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-28 - Continued

(c) Wing lower surface

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ |     | $\frac{dT_w}{dt}$ |            | $\rho_w c_p w \tau$ |                    | $h_T$                   |                        | $N_{St, \infty}$ |
|-------------------|-------------------|-------|-----|-------------------|------------|---------------------|--------------------|-------------------------|------------------------|------------------|
|                   |                   | °R    | °K  | R° per sec        | K° per sec | Btu                 | J                  | Btu                     | J                      |                  |
|                   |                   |       |     |                   |            | ft <sup>2</sup> -°R | m <sup>2</sup> -°K | ft <sup>2</sup> -sec-°R | m <sup>2</sup> -sec-°K |                  |
| 93                | 0.468             | 968   | 538 | 24.4              | 13.57      | 0.375               | 7,660              | 0.00857                 | 175.0                  | 0.00267          |
| 94                | .516              | 1069  | 594 | 30.9              | 17.18      | .385                | 7,860              | .01233                  | 251.8                  | .00383           |
| 95                | .540              | 1119  | 622 | 28.3              | 15.73      | .388                | 7,920              | .01212                  | 247.5                  | .00376           |
| 96                | .511              | 1059  | 589 | 24.0              | 13.34      | .382                | 7,800              | .00907                  | 185.2                  | .00295           |
| 97                | .495              | 1026  | 570 | 24.2              | 13.46      | .378                | 7,720              | .00913                  | 186.4                  | .00284           |
| 98                | .482              | 998   | 555 | 24.7              | 13.73      | .375                | 7,660              | .00895                  | 182.8                  | .00278           |
| 99                | .480              | 993   | 552 | 19.7              | 10.96      | .324                | 6,620              | .00624                  | 127.4                  | .00194           |
| 100               | .486              | 1006  | 559 | 24.9              | 13.84      | .324                | 6,620              | .00792                  | 161.7                  | .00246           |
| 101               | .477              | 987   | 549 | 21.2              | 11.79      | .324                | 6,620              | .00667                  | 136.2                  | .00207           |
| 102               | .484              | 1002  | 557 | 23.6              | 13.12      | .324                | 6,620              | .00749                  | 153.0                  | .00233           |
| 103               | .459              | 950   | 528 | 22.6              | 12.57      | .321                | 6,560              | .00670                  | 136.8                  | .00209           |
| 104               | .446              | 923   | 513 | 21.0              | 11.68      | .319                | 6,510              | .00605                  | 123.5                  | .00189           |
| 105               | .463              | 959   | 533 | 23.9              | 13.29      | .321                | 6,560              | .00732                  | 149.5                  | .00222           |
| 106               | .475              | 984   | 547 | 20.3              | 11.29      | .193                | 3,940              | .00392                  | 80.1                   | .00122           |
| 107               | .476              | 986   | 548 | 20.8              | 11.56      | .193                | 3,940              | .00402                  | 82.1                   | .00125           |
| 108               | .556              | 1153  | 641 | 29.7              | 16.51      | .314                | 6,410              | .01085                  | 221.6                  | .00336           |
| 109               | .589              | 1220  | 678 | 39.7              | 22.07      | .316                | 6,450              | .01562                  | 319.0                  | .00483           |
| 110               | .560              | 1160  | 645 | 34.7              | 19.29      | .314                | 6,410              | .01265                  | 258.3                  | .00392           |
| 111               | .556              | 1152  | 641 | 31.5              | 17.51      | .313                | 6,390              | .01139                  | 232.6                  | .00353           |
| 112               | .563              | 1166  | 648 | 27.1              | 15.07      | .284                | 5,800              | .00923                  | 188.5                  | .00286           |
| 113               | .553              | 1146  | 637 | 25.4              | 14.12      | .284                | 5,800              | .00845                  | 172.6                  | .00262           |
| 114               | .533              | 1104  | 614 | 25.1              | 13.96      | .282                | 5,760              | .00787                  | 160.7                  | .00244           |
| 115               | .537              | 1112  | 618 | 24.4              | 13.57      | .282                | 5,760              | .00773                  | 157.9                  | .00240           |
| 116               | .534              | 1105  | 614 | 25.2              | 14.01      | .282                | 5,760              | .00789                  | 161.1                  | .00245           |
| 117               | .513              | 1062  | 590 | 23.9              | 13.29      | .278                | 5,680              | .00703                  | 143.6                  | .00218           |
| 118               | .485              | 1004  | 558 | 22.3              | 12.40      | .276                | 5,640              | .00610                  | 124.6                  | .00190           |
| 119               | .462              | 956   | 532 | 20.6              | 11.45      | .272                | 5,550              | .00528                  | 107.8                  | .00164           |
| 120               | .483              | 999   | 555 | 21.5              | 11.95      | .195                | 3,980              | .00423                  | 86.4                   | .00132           |
| 121               | .483              | 999   | 555 | 20.5              | 11.40      | .195                | 3,980              | .00406                  | 82.9                   | .00126           |
| 122               | .476              | 985   | 548 | 18.1              | 10.06      | .218                | 4,450              | .00395                  | 80.7                   | .00123           |
| 123               | .484              | 1001  | 557 | 14.6              | 8.12       | .220                | 4,490              | .00333                  | 68.0                   | .00103           |
| 124               | .563              | 1167  | 649 | 7.3               | 4.06       | .222                | 4,530              | .00251                  | 51.3                   | .00078           |
| 125               | .615              | 1275  | 709 | 14.8              | 8.23       | .228                | 4,660              | .00539                  | 110.1                  | .00166           |
| 126               | .624              | 1294  | 719 | 19.2              | 10.68      | .229                | 4,680              | .00692                  | 141.3                  | .00213           |
| 127               | .611              | 1267  | 704 | 22.9              | 12.73      | .227                | 4,640              | .00759                  | 155.0                  | .00234           |
| 128               | .617              | 1280  | 712 | 22.6              | 12.57      | .228                | 4,660              | .00770                  | 157.2                  | .00238           |
| 129               | .571              | 1184  | 658 | 22.6              | 12.57      | .226                | 4,620              | .00655                  | 133.8                  | .00203           |
| 130               | .574              | 1190  | 662 | 21.3              | 11.84      | .226                | 4,620              | .00628                  | 128.2                  | .00194           |
| 131               | .544              | 1126  | 626 | 21.9              | 12.18      | .220                | 4,490              | .00569                  | 116.2                  | .00176           |
| 132               | .525              | 1087  | 604 | 18.9              | 10.51      | .208                | 4,250              | .00447                  | 91.3                   | .00139           |
| 133               | .523              | 1083  | 602 | 19.5              | 10.84      | .208                | 4,250              | .00460                  | 93.9                   | .00143           |
| 134               | .506              | 1048  | 583 | 20.8              | 11.56      | .207                | 4,230              | .00458                  | 93.5                   | .00142           |

TABLE VIII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-28 - Continued

## (d) Horizontal-tail upper surface

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ |      | $\frac{dT_w}{dt}$ |            | $\rho_w c_{p,w} T$  |                    | $h_T$                   |                        | $N_{St, \infty}$ |
|-------------------|-------------------|-------|------|-------------------|------------|---------------------|--------------------|-------------------------|------------------------|------------------|
|                   |                   | °R    | °K   | R° per sec        | K° per sec | Btu                 | J                  | Btu                     | J                      |                  |
|                   |                   |       |      |                   |            | ft <sup>2</sup> -°R | m <sup>2</sup> -°K | ft <sup>2</sup> -sec-°R | m <sup>2</sup> -sec-°K |                  |
| 135               | 0.637             | 1320  | 734  | 29.6              | 16.46      | 0.275               | 5,620              | 0.01223                 | 249.7                  | 0.00377          |
| 136               | .550              | 1139  | 633  | 21.4              | 11.90      | .264                | 5,390              | .00669                  | 136.6                  | .00207           |
| 137               | .496              | 1027  | 571  | 16.2              | 9.01       | .256                | 5,230              | .00436                  | 89.0                   | .00135           |
| 138               | .523              | 1084  | 603  | 19.1              | 10.62      | .260                | 5,310              | .00553                  | 112.9                  | .00172           |
| 139               | .430              | 890   | 495  | 12.6              | 7.01       | .249                | 5,090              | .00285                  | 58.2                   | .00089           |
| 140               | .425              | 880   | 489  | 11.9              | 6.62       | .249                | 5,090              | .00268                  | 54.7                   | .00084           |
| 141               | -----             | ----- | ---- | -----             | -----      | -----               | -----              | -----                   | -----                  | -----            |

## (e) Horizontal-tail lower surface

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ |     | $\frac{dT_w}{dt}$ |            | $\rho_w c_{p,w} T$  |                    | $h_T$                   |                        | $N_{St, \infty}$ |
|-------------------|-------------------|-------|-----|-------------------|------------|---------------------|--------------------|-------------------------|------------------------|------------------|
|                   |                   | °R    | °K  | R° per sec        | K° per sec | Btu                 | J                  | Btu                     | J                      |                  |
|                   |                   |       |     |                   |            | ft <sup>2</sup> -°R | m <sup>2</sup> -°K | ft <sup>2</sup> -sec-°R | m <sup>2</sup> -sec-°K |                  |
| 142               | 0.536             | 1110  | 617 | 23.5              | 13.07      | 0.262               | 5,350              | 0.00697                 | 142.3                  | 0.00216          |
| 143               | .458              | 948   | 527 | 14.4              | 8.01       | .251                | 5,130              | .00347                  | 70.9                   | .00108           |
| 144               | .504              | 1044  | 580 | 16.7              | 9.29       | .258                | 5,270              | .00461                  | 94.1                   | .00143           |
| 145               | .448              | 927   | 515 | 13.5              | 7.51       | .251                | 5,130              | .00321                  | 65.6                   | .00100           |
| 146               | .394              | 816   | 454 | 10.0              | 5.56       | .245                | 5,000              | .00208                  | 42.5                   | .00065           |
| 147               | .396              | 819   | 455 | 10.7              | 5.95       | .245                | 5,000              | .00222                  | 45.3                   | .00070           |

TABLE VIII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-28 - Continued

(f) Vertical tail

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$ |       | $\frac{dT_w}{dt}$ |            | $\rho_w c_p w \tau$ |                    | $h_T$                   |                        | $N_{St, \infty}$ |
|-------------------|-------------------|-------|-------|-------------------|------------|---------------------|--------------------|-------------------------|------------------------|------------------|
|                   |                   | °R    | °K    | R° per sec        | K° per sec | Btu                 | J                  | Btu                     | J                      |                  |
|                   |                   |       |       |                   |            | ft <sup>2</sup> -°R | m <sup>2</sup> -°K | ft <sup>2</sup> -sec-°R | m <sup>2</sup> -sec-°K |                  |
| 148               | 0.290             | 599   | 333   | 3.3               | 1.83       | 0.427               | 8,720              | 0.00098                 | 20.0                   | 0.00031          |
| 149               | .307              | 635   | 353   | 2.1               | 1.17       | .333                | 6,800              | .00053                  | 10.8                   | .00017           |
| 150               | .382              | 790   | 439   | 1.1               | .61        | .179                | 3,660              | .00026                  | 5.3                    | .00008           |
| 151               | .403              | 833   | 463   | .9                | .50        | .177                | 3,610              | .00015                  | 3.1                    | .00005           |
| 152               | .493              | 1020  | 567   | -.5               | -.28       | .102                | 2,080              | .00032                  | 6.5                    | .00010           |
| 153               | .463              | 958   | 533   | 1.1               | .61        | .101                | 2,060              | .00037                  | 7.6                    | .00012           |
| 154               | .297              | 615   | 342   | -.6               | -.33       | .092                | 1,880              | .00003                  | .6                     | .00001           |
| 155               | .431              | 892   | 496   | -1.2              | -.67       | .100                | 2,040              | .00008                  | 1.6                    | .00003           |
| 156               | .411              | 851   | 473   | -1.5              | -.83       | .098                | 2,000              | .00003                  | .6                     | .00001           |
| 157               | .425              | 879   | 489   | -2.2              | -1.22      | .100                | 2,040              | .00000                  | 0                      | .00000           |
| 158               | .298              | 617   | 343   | 2.3               | 1.28       | .602                | 12,290             | .00099                  | 20.2                   | .00031           |
| 159               | .303              | 627   | 349   | 1.4               | .78        | .589                | 12,030             | .00063                  | 12.9                   | .00020           |
| 160               | .265              | 547   | 304   | .7                | .39        | .505                | 10,310             | .00003                  | .6                     | .00008           |
| 161               | .318              | 658   | 366   | 2.3               | 1.28       | .500                | 10,210             | .00086                  | 17.6                   | .00027           |
| 162               | .323              | 667   | 371   | 3.0               | 1.67       | .452                | 9,230              | .00101                  | 20.6                   | .00032           |
| 163               | .335              | 692   | 385   | 2.8               | 1.56       | .406                | 8,290              | .00089                  | 18.2                   | .00028           |
| 164               | .332              | 686   | 381   | 5.4               | 3.00       | .467                | 9,540              | .00188                  | 38.4                   | .00059           |
| 164L              | .311              | 644   | 358   | 1.3               | .72        | .462                | 9,430              | .00046                  | 9.4                    | .00015           |
| 165               | .346              | 715   | 398   | 5.5               | 3.06       | .372                | 7,600              | .00158                  | 32.3                   | .00050           |
| 165L              | .360              | 744   | 414   | 5.0               | 2.78       | .375                | 7,660              | .00150                  | 30.7                   | .00047           |
| 166               | .480              | 993   | 552   | 4.1               | 2.28       | .187                | 3,820              | .00103                  | 21.0                   | .00032           |
| 166L              | .501              | 1037  | 577   | 5.2               | 2.89       | .191                | 3,900              | .00136                  | 27.8                   | .00042           |
| 167               | .503              | 1041  | 579   | 6.1               | 3.39       | .191                | 3,900              | .00154                  | 31.5                   | .00048           |
| 167L              | .508              | 1052  | 585   | 5.4               | 3.00       | .191                | 3,900              | .00143                  | 29.2                   | .00044           |
| 168               | .483              | 1000  | 556   | 5.8               | 3.22       | .189                | 3,860              | .00136                  | 27.8                   | .00042           |
| 168L              | .503              | 1041  | 579   | 6.2               | 3.45       | .191                | 3,900              | .00156                  | 31.8                   | .00048           |
| 169L              | .479              | 992   | 552   | 4.6               | 2.56       | .188                | 3,840              | .00112                  | 22.8                   | .00035           |
| 170               | .475              | 983   | 547   | 5.5               | 3.06       | .152                | 3,100              | .00107                  | 21.9                   | .00033           |
| 170L              | .486              | 1006  | 559   | 3.7               | 2.06       | .154                | 3,150              | .00087                  | 17.9                   | .00027           |
| 171               | .512              | 1060  | 589   | 6.5               | 3.61       | .155                | 3,170              | .00144                  | 29.5                   | .00045           |
| 171L              | -----             | ----- | ----- | -----             | -----      | -----               | -----              | -----                   | -----                  | -----            |
| 172               | .482              | 997   | 554   | 3.8               | 2.11       | .152                | 3,100              | .00086                  | 17.6                   | .00027           |
| 172L              | .354              | 733   | 408   | 1.0               | .56        | .144                | 2,940              | .00018                  | 3.7                    | .00006           |
| 173               | .455              | 941   | 523   | 4.4               | 2.45       | .151                | 3,080              | .00083                  | 16.9                   | .00026           |
| 174               | .451              | 933   | 519   | 4.6               | 2.56       | .151                | 3,080              | .00085                  | 17.4                   | .00027           |
| a174L             | .478              | 990   | 550   | 2.8               | 1.56       | .152                | 3,100              | .00071                  | 14.5                   | .00022           |
| 175               | .328              | 679   | 378   | 2.8               | 1.56       | .401                | 8,190              | .00087                  | 17.8                   | .00027           |
| 176               | .494              | 1024  | 569   | 9.3               | 5.17       | .189                | 3,860              | .00206                  | 42.1                   | .00064           |
| 177               | .479              | 992   | 552   | 8.3               | 4.61       | .189                | 3,860              | .00177                  | 36.1                   | .00055           |
| 178               | .475              | 983   | 547   | 6.7               | 3.73       | .152                | 3,100              | .00125                  | 25.5                   | .00039           |
| 179               | .476              | 986   | 548   | 6.6               | 3.67       | .152                | 3,100              | .00124                  | 25.3                   | .00039           |
| 180               | .471              | 975   | 542   | 7.1               | 3.95       | .152                | 3,100              | .00127                  | 25.9                   | .00040           |

<sup>a</sup>L indicates thermocouple on left side.

TABLE VIII. - HEAT-TRANSFER MEASUREMENTS ON FLIGHT 2-28 - Concluded

(g) Ventral tail

| Thermo-<br>couple | $\frac{T_w}{T_R}$ | $T_w$       |             | $\frac{dT_w}{dt}$   |                     | $\rho_w c_{p,w} T$           |                           | $h_T$                            |                               | $N_{St, \infty}$ |
|-------------------|-------------------|-------------|-------------|---------------------|---------------------|------------------------------|---------------------------|----------------------------------|-------------------------------|------------------|
|                   |                   | $^{\circ}R$ | $^{\circ}K$ | $R^{\circ}$ per sec | $K^{\circ}$ per sec | $\frac{Btu}{ft^2-^{\circ}R}$ | $\frac{J}{m^2-^{\circ}K}$ | $\frac{Btu}{ft^2-sec-^{\circ}R}$ | $\frac{J}{m^2-sec-^{\circ}K}$ |                  |
| 181               | 0.382             | 791         | 440         | 11.5                | 6.39                | 0.444                        | 9,070                     | 0.00411                          | 83.9                          | 0.00129          |
| 182               | .446              | 924         | 514         | 16.4                | 9.12                | .347                         | 7,090                     | .00519                           | 106.0                         | .00162           |
| 183               | .598              | 1239        | 689         | 24.5                | 13.62               | .198                         | 4,040                     | .00681                           | 139.1                         | .00210           |
| 184               | .576              | 1194        | 664         | 21.1                | 11.73               | .196                         | 4,000                     | .00552                           | 112.7                         | .00171           |
| 185               | .631              | 1309        | 728         | 18.9                | 10.51               | .109                         | 2,230                     | .00406                           | 82.9                          | .00125           |
| 186               | .601              | 1246        | 693         | 18.4                | 10.23               | .108                         | 2,210                     | .00343                           | 70.0                          | .00106           |
| 187               | .635              | 1317        | 732         | 18.3                | 10.17               | .109                         | 2,230                     | .00405                           | 82.7                          | .00125           |
| 188               | .605              | 1254        | 697         | 22.0                | 12.23               | .108                         | 2,210                     | .00398                           | 81.3                          | .00123           |
| 189               | .584              | 1210        | 673         | 17.7                | 9.84                | .107                         | 2,190                     | .00308                           | 62.9                          | .00095           |
| 190               | .357              | 739         | 411         | 12.5                | 6.95                | .630                         | 12,870                    | .00600                           | 122.5                         | .00189           |
| 191               | .363              | 752         | 418         | 12.2                | 6.78                | .610                         | 12,460                    | .00574                           | 96.8                          | .00181           |

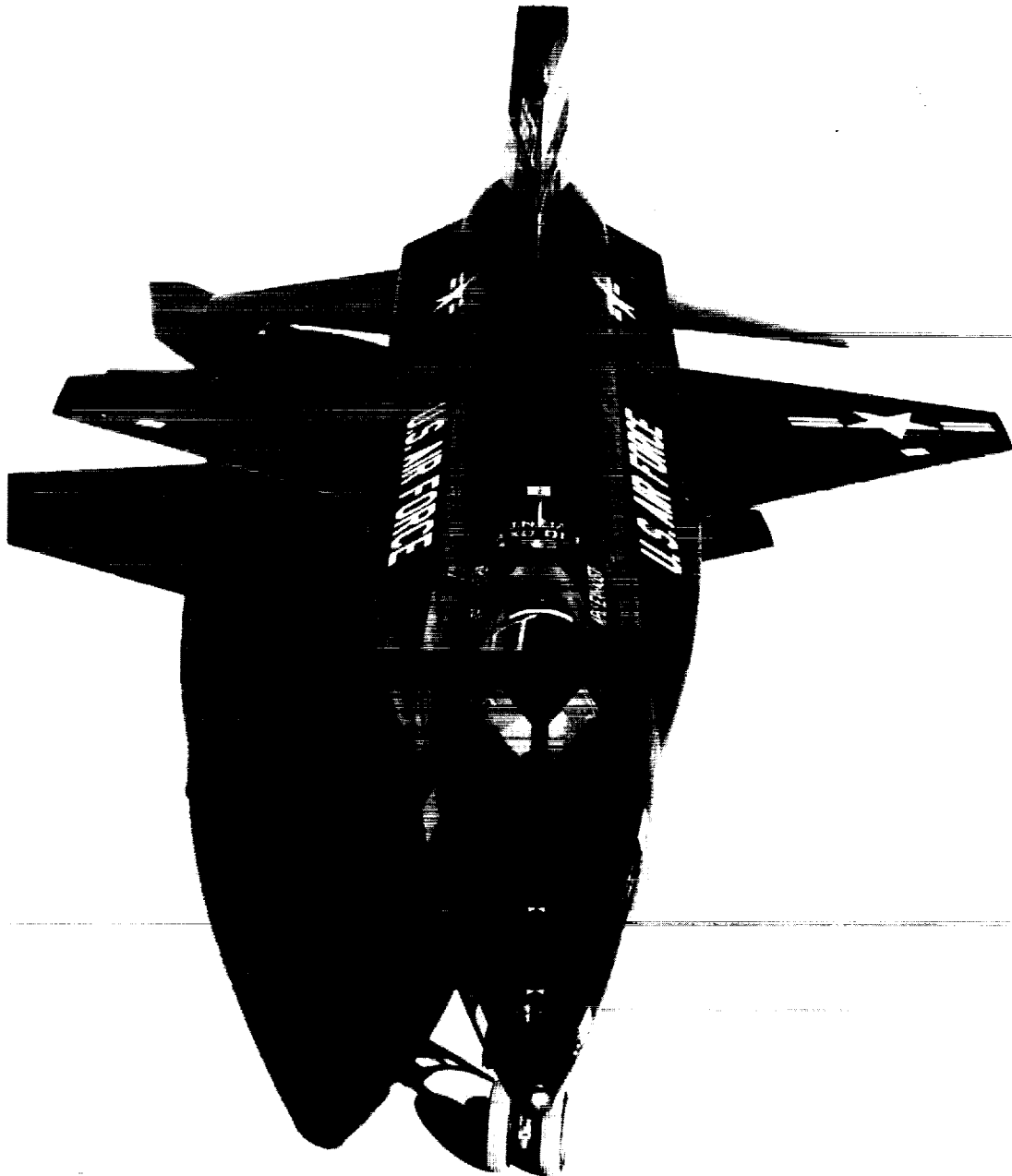


Figure 1.— Photograph of the X-15 airplane.

E-7903

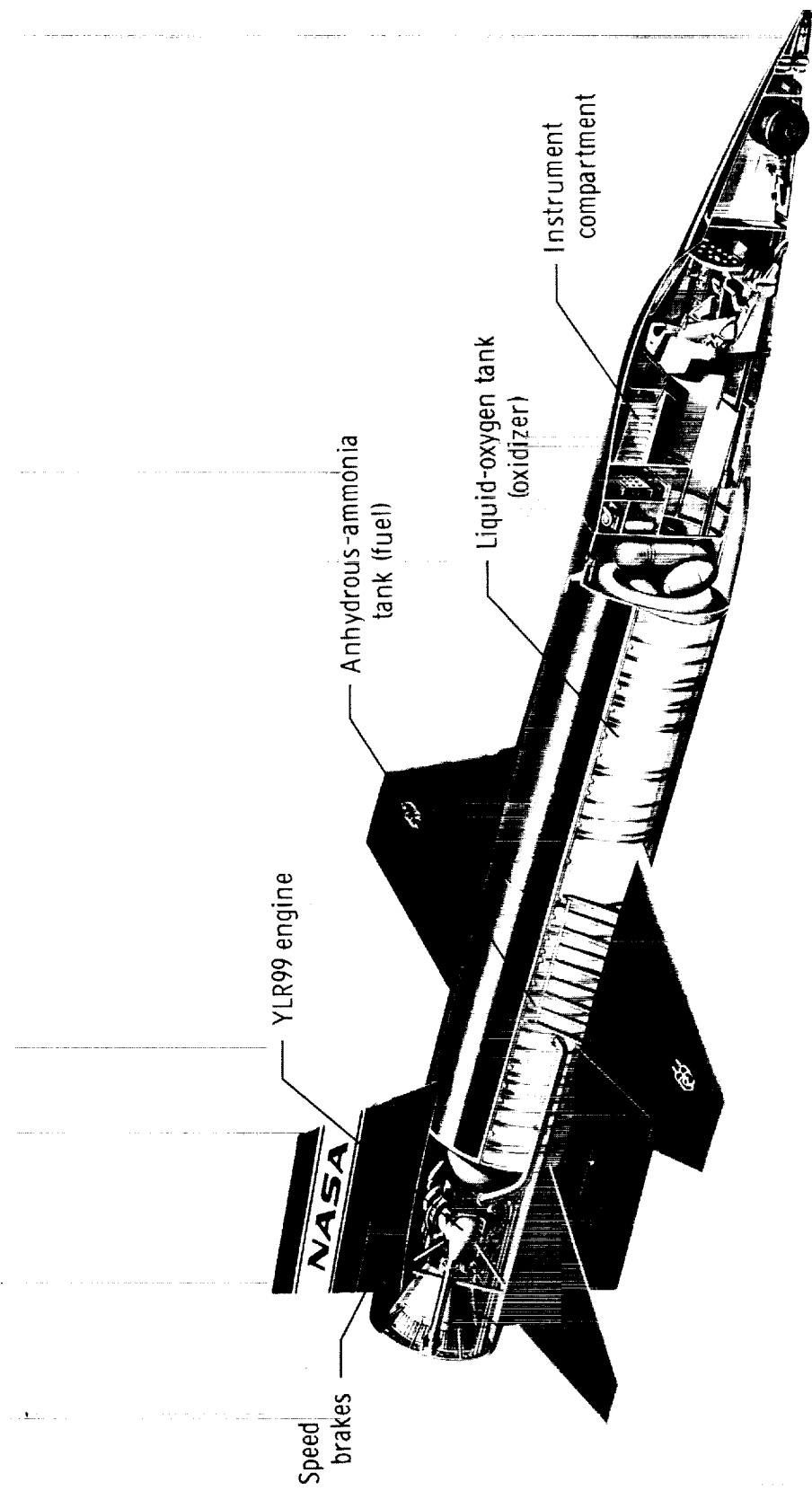
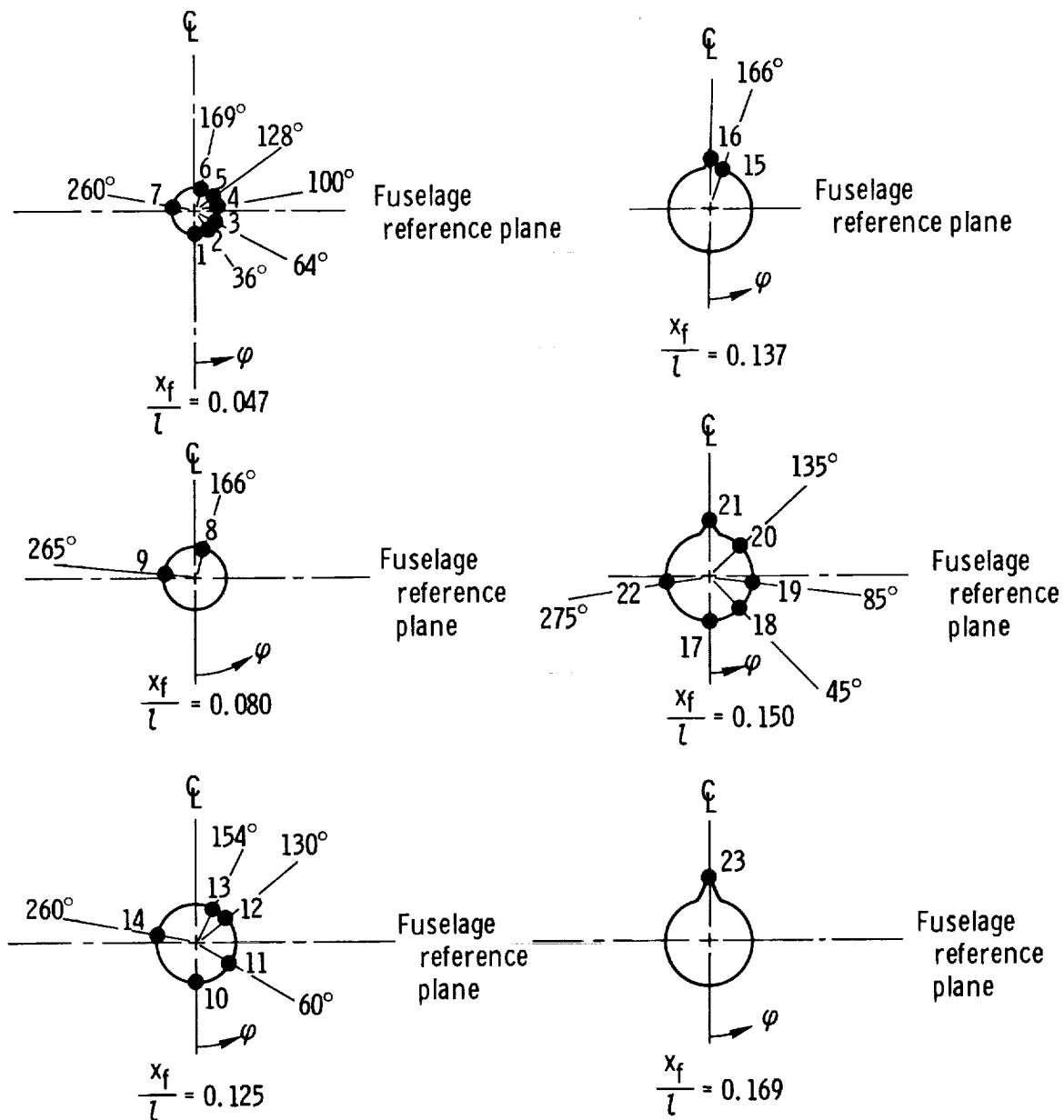


Figure 2. — Cutaway drawing of the X-15 airplane.

E-6990

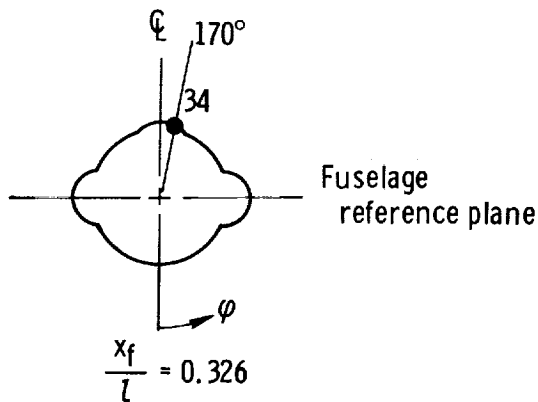
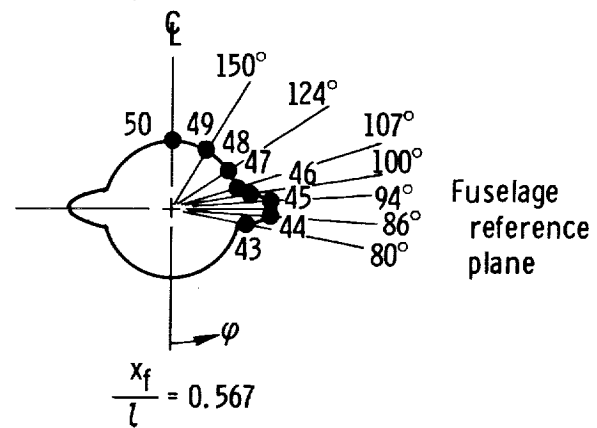
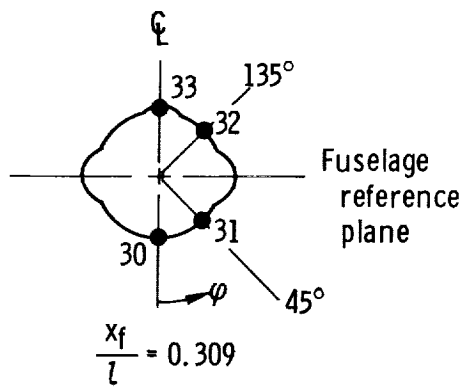
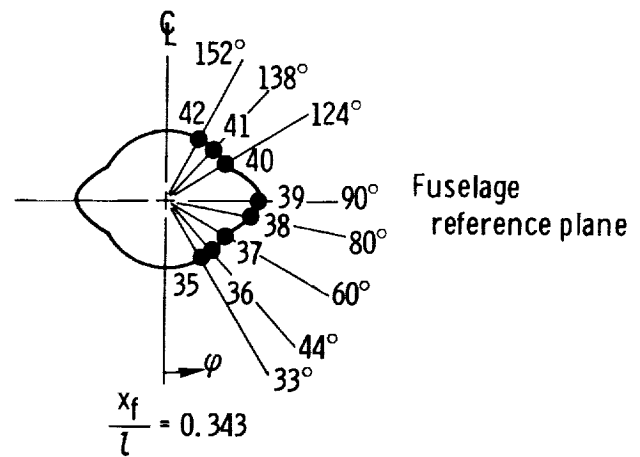
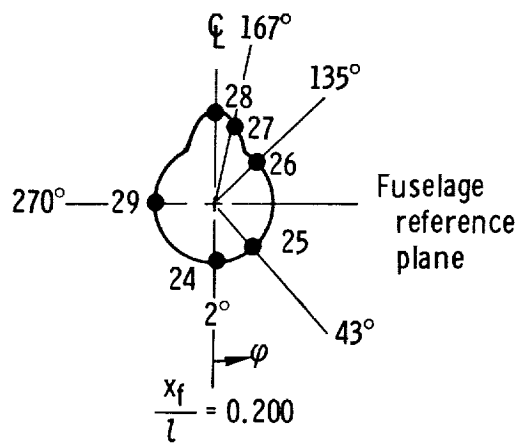


Figure 3. — Thermocouple locations on the X-15 airplane.



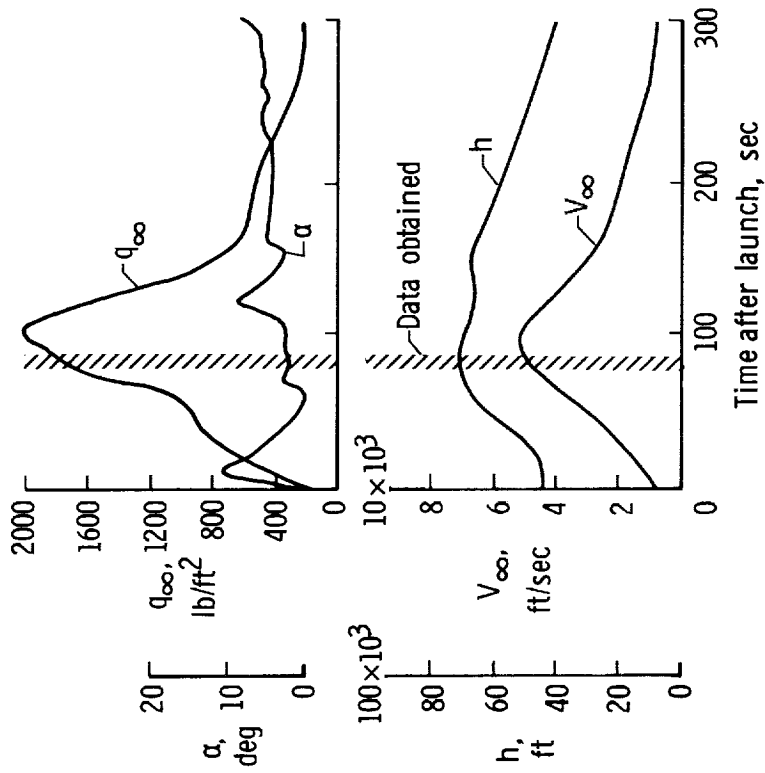
(a)  $\frac{x_f}{l} = 0.047$  to  $0.169$ .

Figure 4.— Fuselage cross sections showing thermocouple locations.

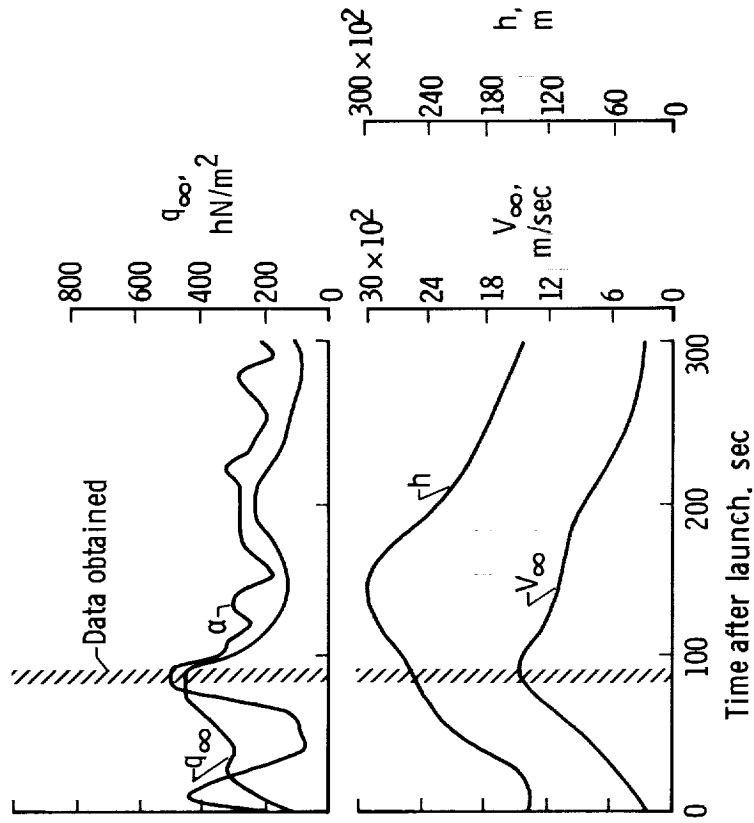


(b)  $\frac{x_f}{l} = 0.200$  to  $0.567$ .

Figure 4. — Concluded.

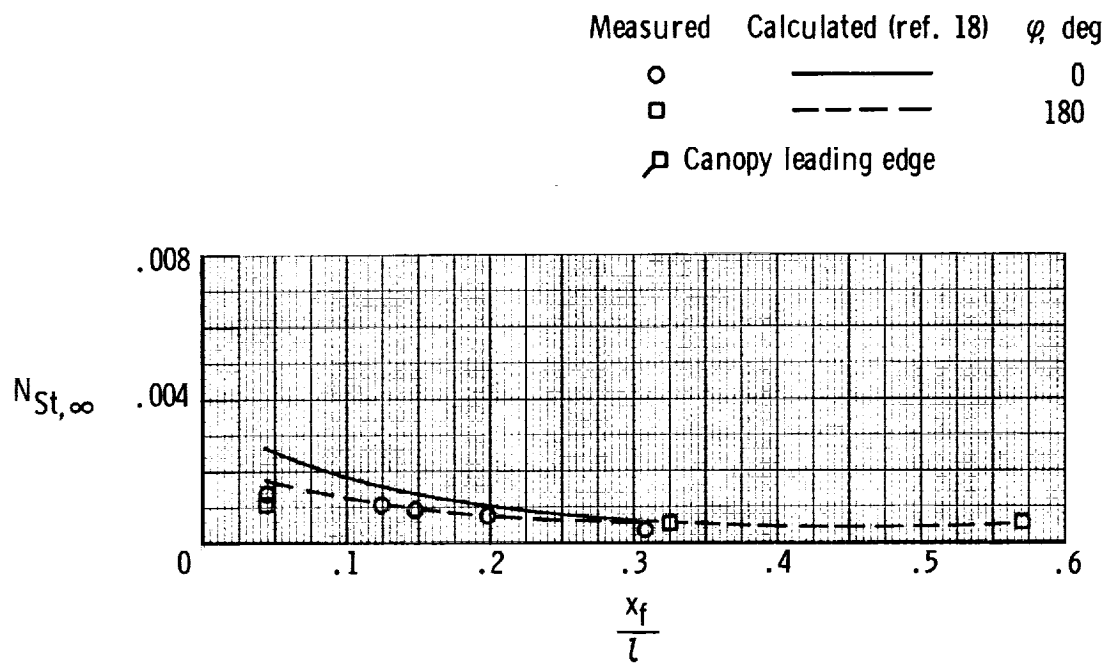


(a) Flight 2-22, low angle of attack.

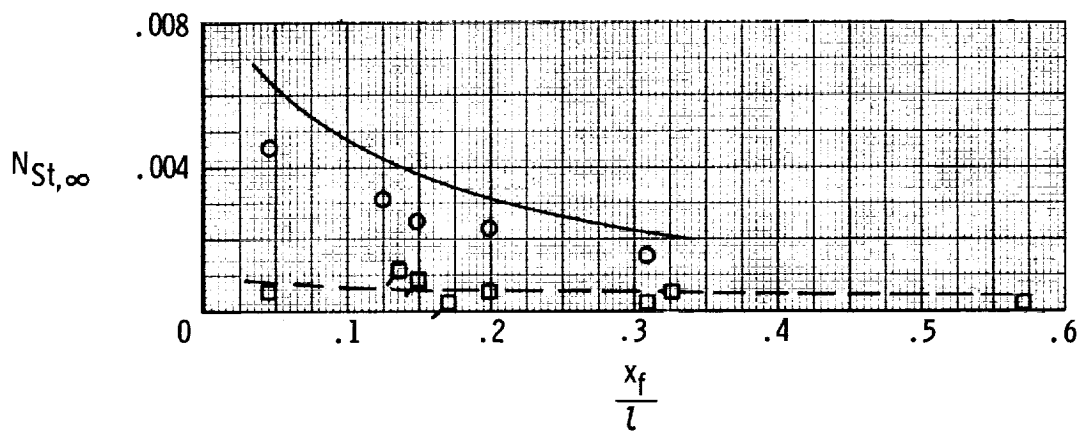


(b) Flight 2-28, high angle of attack.

Figure 5. - Time histories of flights 2-22 and 2-28.



(a)  $\alpha = 2.0^\circ$ ,  $M_\infty = 5.10$ .



(b)  $\alpha = 16.3^\circ$ ,  $M_\infty = 4.98$ .

Figure 6. — Effect of angle of attack on distribution of Stanton numbers on vertical center plane of fuselage.

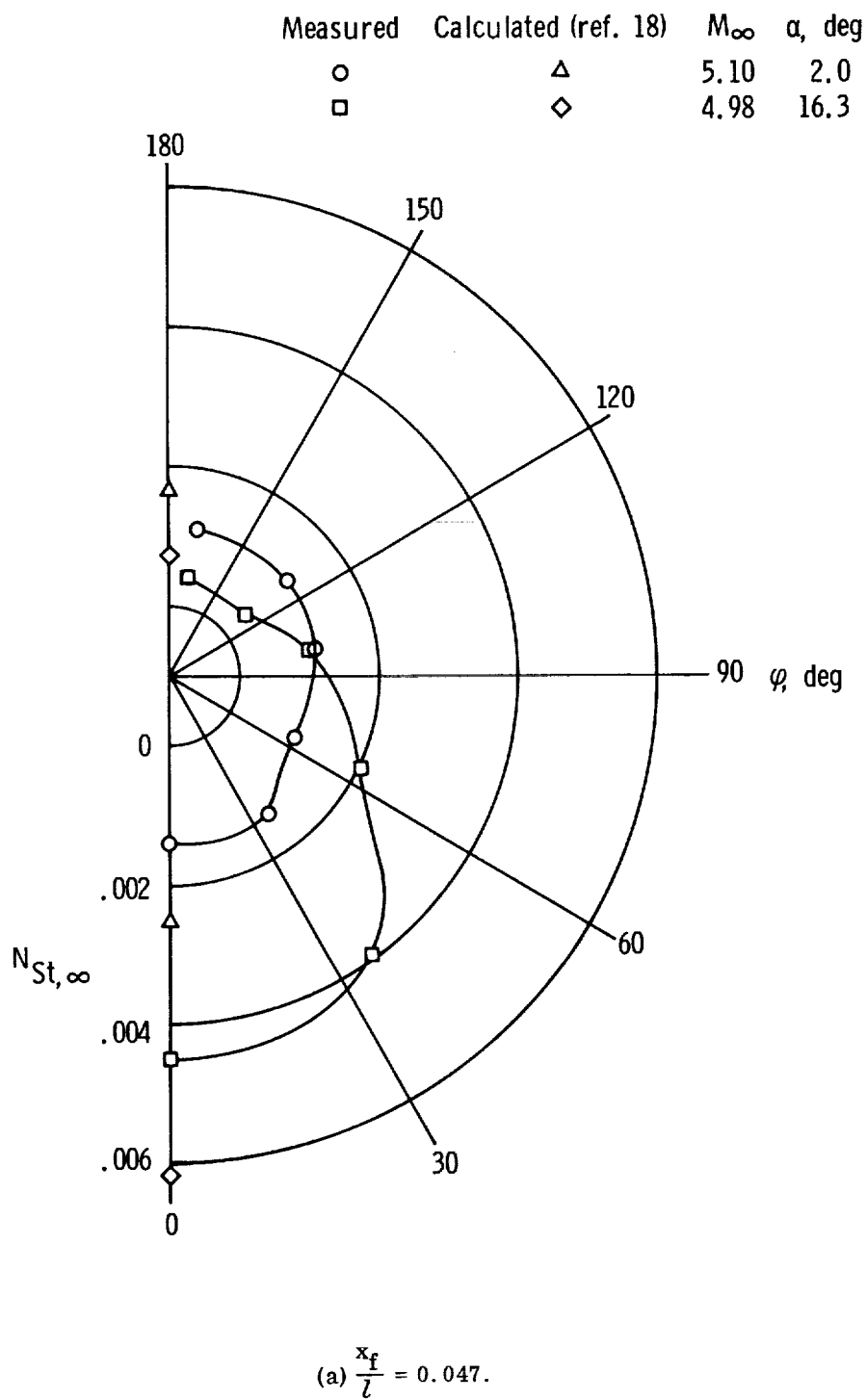
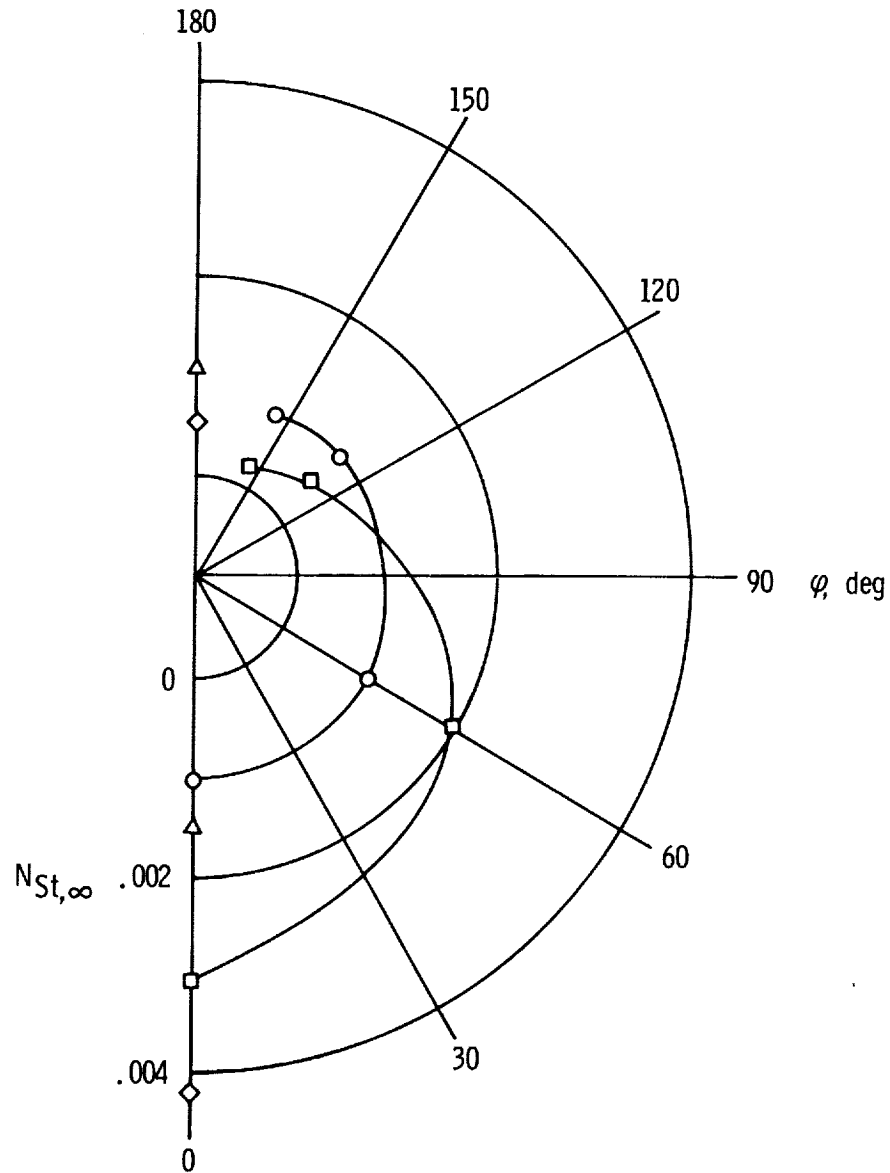


Figure 7. — Effect of angle of attack on peripheral distribution of Stanton numbers.

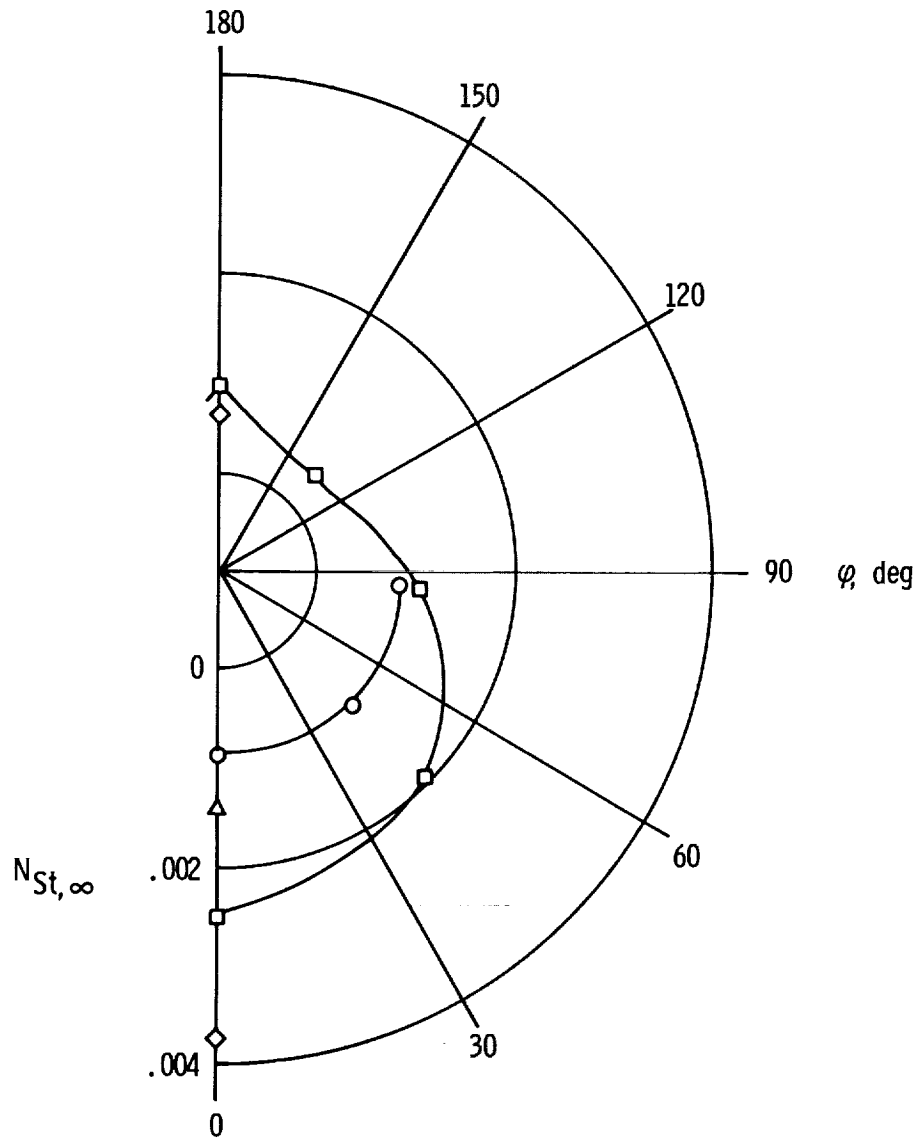
| Measured | Calculated (ref. 18) | $M_\infty$ | $\alpha$ , deg |
|----------|----------------------|------------|----------------|
| ○        | △                    | 5.10       | 2.0            |
| □        | ◇                    | 4.98       | 16.3           |



(b)  $\frac{x_f}{l} = 0.125$ .

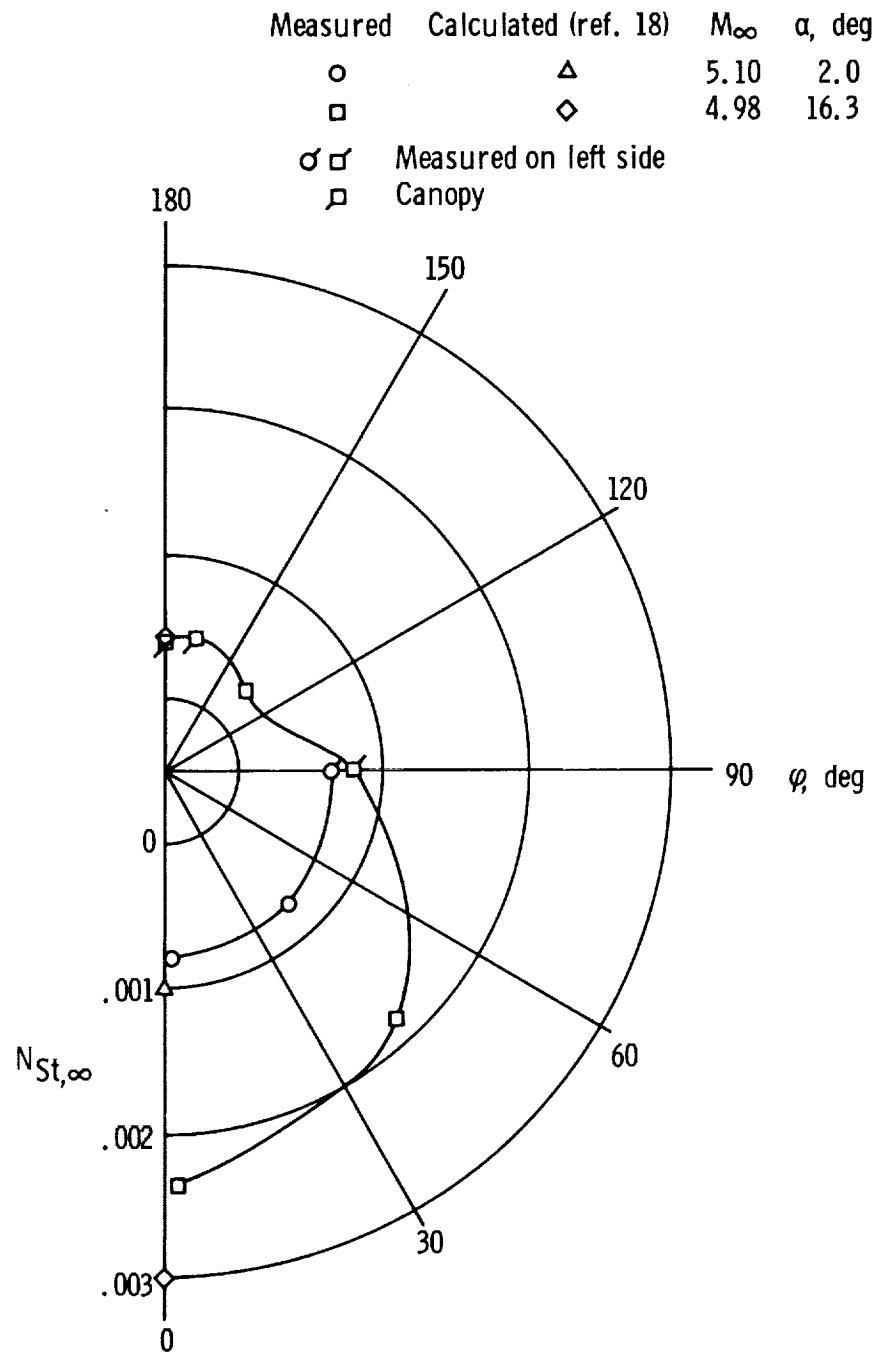
Figure 7. - Continued.

| Measured              | Calculated (ref. 18) | $M_\infty$ | $\alpha$ , deg |
|-----------------------|----------------------|------------|----------------|
| ○                     | △                    | 5.10       | 2.0            |
| □                     | ◇                    | 4.98       | 16.3           |
| ▣ Canopy leading edge |                      |            |                |



(c)  $\frac{x_f}{l} = 0.150.$

Figure 7. - Continued.

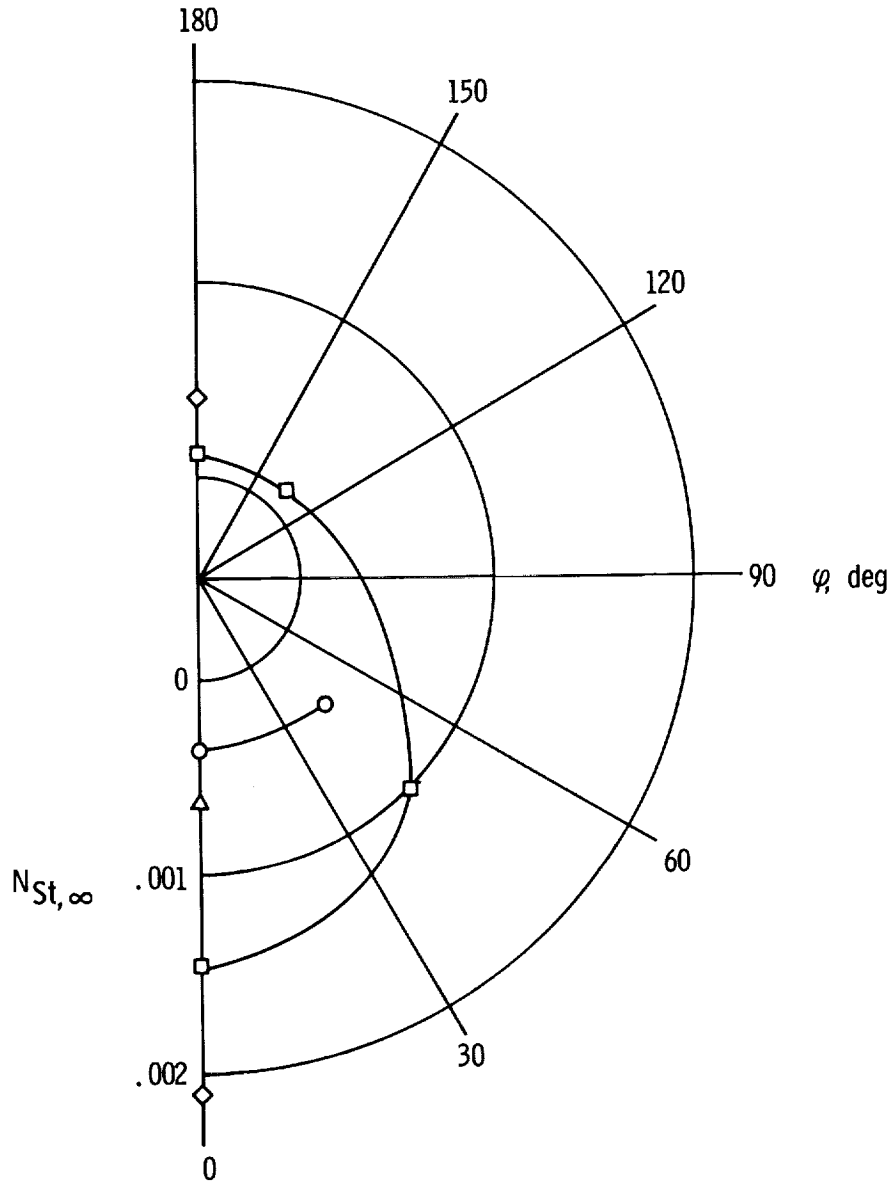


(d)  $\frac{x_f}{l} = 0.200.$

Figure 7. - Continued.

[REDACTED]

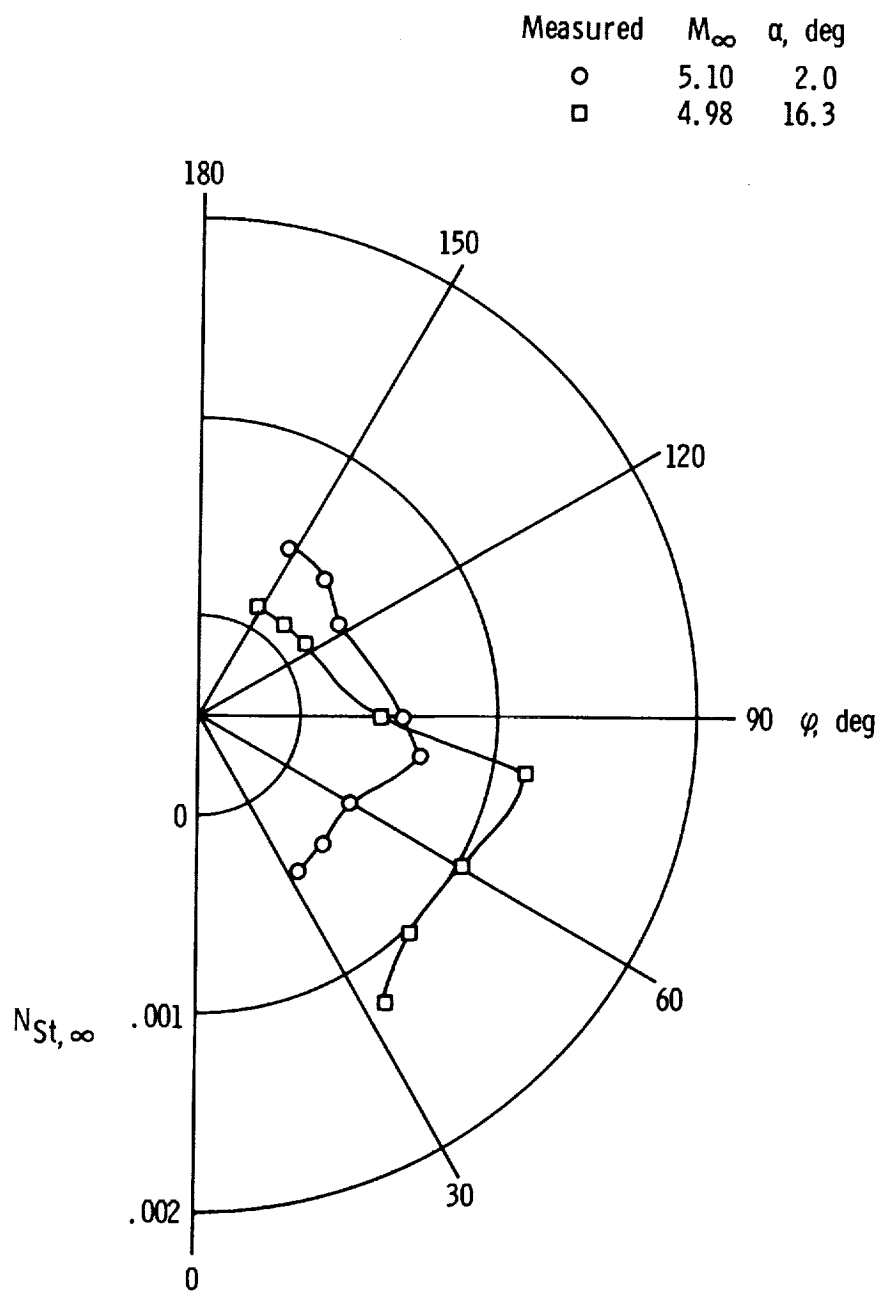
| Measured | Calculated (ref. 18) | $M_\infty$ | $\alpha$ , deg |
|----------|----------------------|------------|----------------|
| ○        | △                    | 5.10       | 2.0            |
| □        | ◇                    | 4.98       | 16.3           |



$$(e) \frac{x_f}{l} = 0.309.$$

Figure 7. - Continued.

[REDACTED]

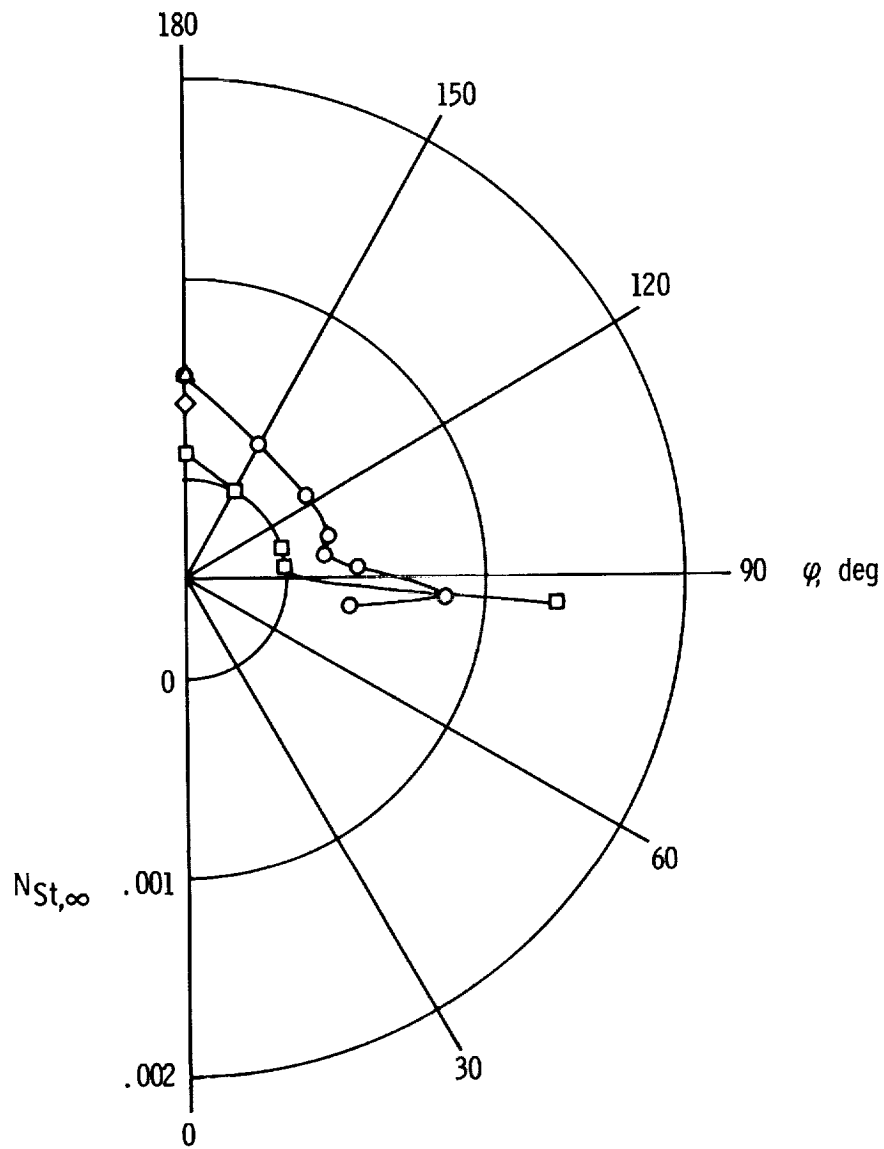


$$(f) \frac{x_f}{l} = 0.343.$$

Figure 7. - Continued.

CONFIDENTIAL

| Measured | Calculated (ref. 18) | $M_\infty$ | $\alpha$ , deg |
|----------|----------------------|------------|----------------|
| ○        | △                    | 5.10       | 2.0            |
| □        | ◇                    | 4.98       | 16.3           |



$$(g) \frac{x_f}{l} = 0.567.$$

Figure 7. - Concluded.

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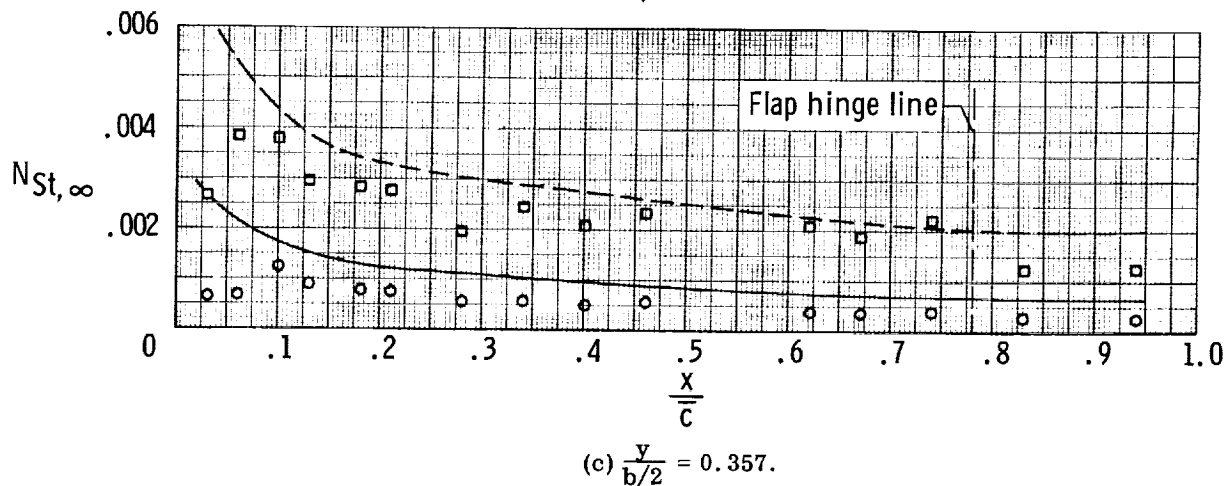
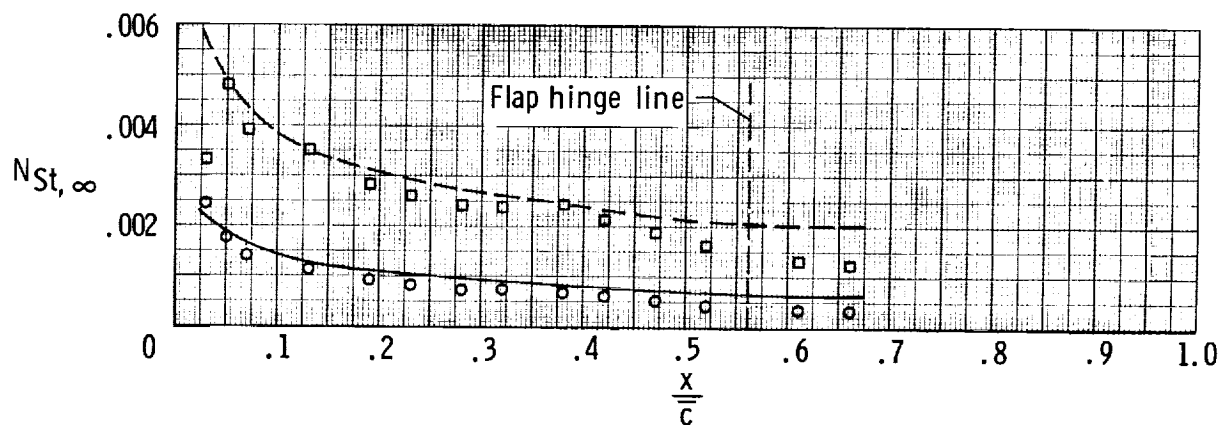
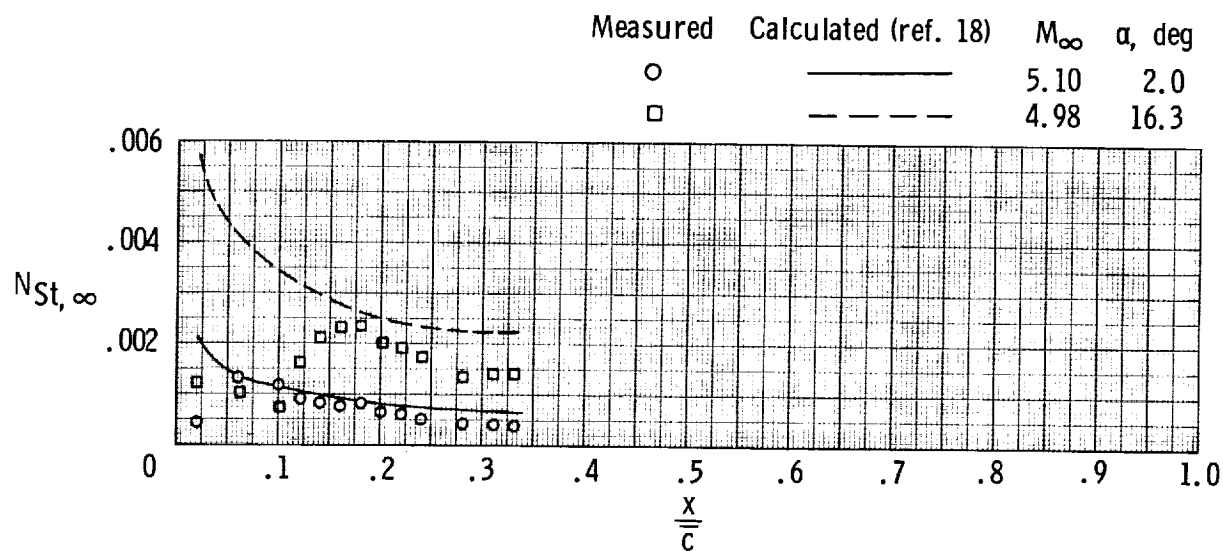
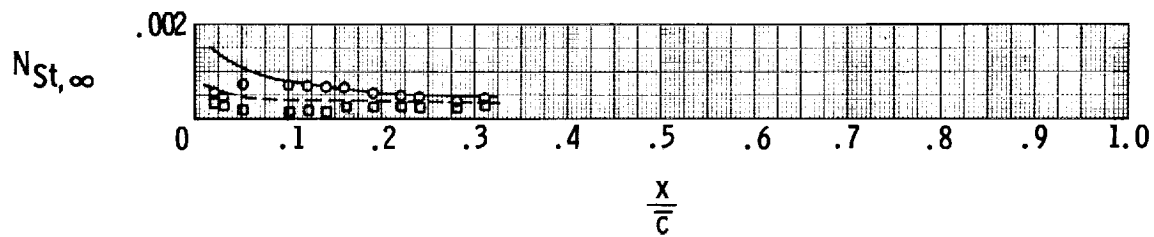
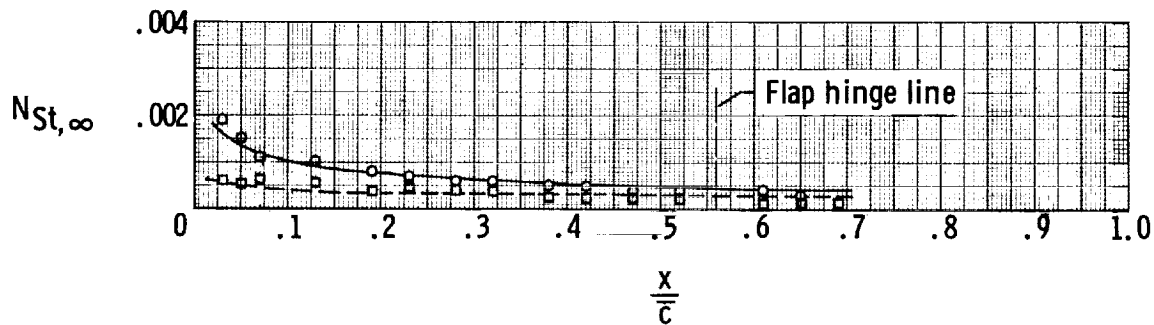


Figure 8. — Effect of angle of attack on distribution of Stanton numbers on lower surface of wing.

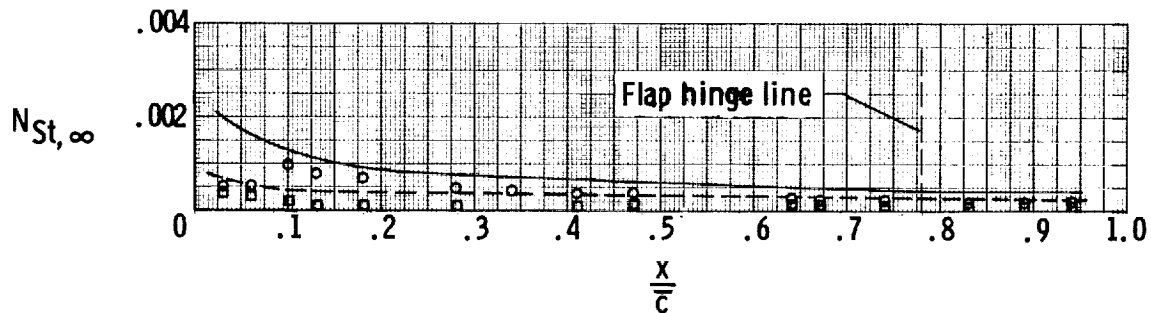
| Measured | Calculated (ref. 18) | $M_\infty$ | $\alpha$ , deg |
|----------|----------------------|------------|----------------|
| ○        | ————                 | 5.10       | 2.0            |
| □        | ----                 | 4.98       | 16.3           |



(a)  $\frac{y}{b/2} = 0.953$ .



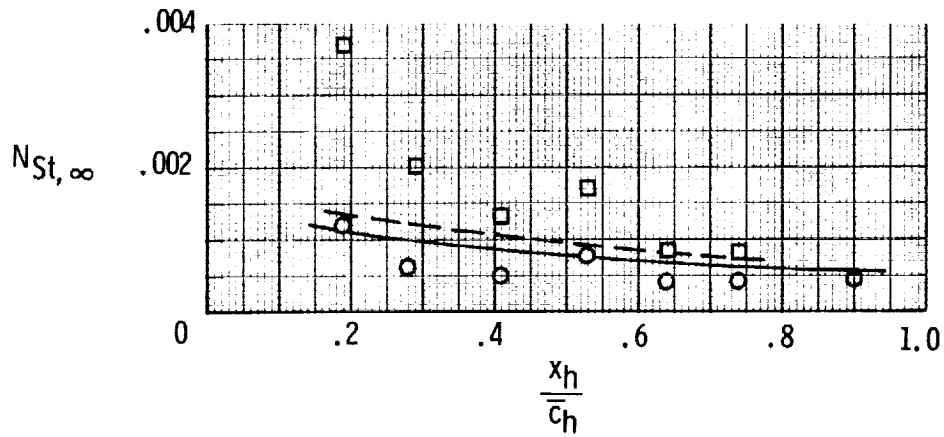
(b)  $\frac{y}{b/2} = 0.629$ .



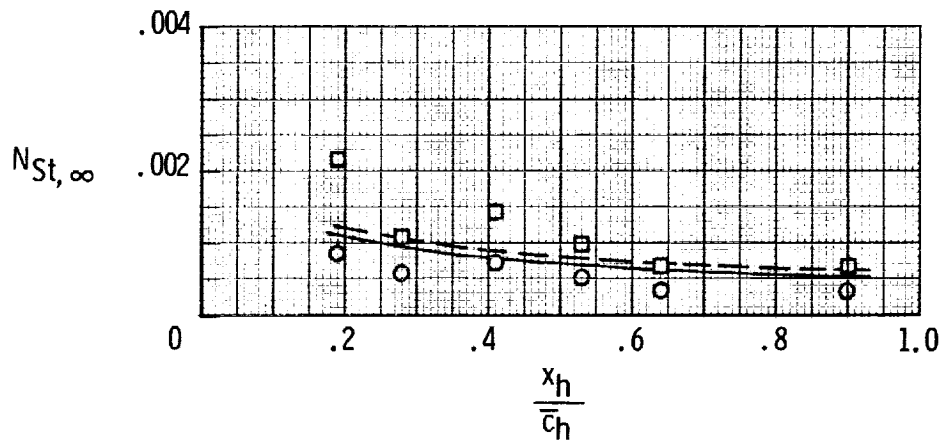
(c)  $\frac{y}{b/2} = 0.357$ .

Figure 9. — Effect of angle of attack on distribution of Stanton numbers on upper surface of wing.

| Measured | Calculated (ref. 18) | $M_\infty$ | $\alpha$ , deg |
|----------|----------------------|------------|----------------|
| ○        | ————                 | 5.10       | 2.0            |
| □        | -----                | 4.98       | 16.3           |



(a) Upper surface.

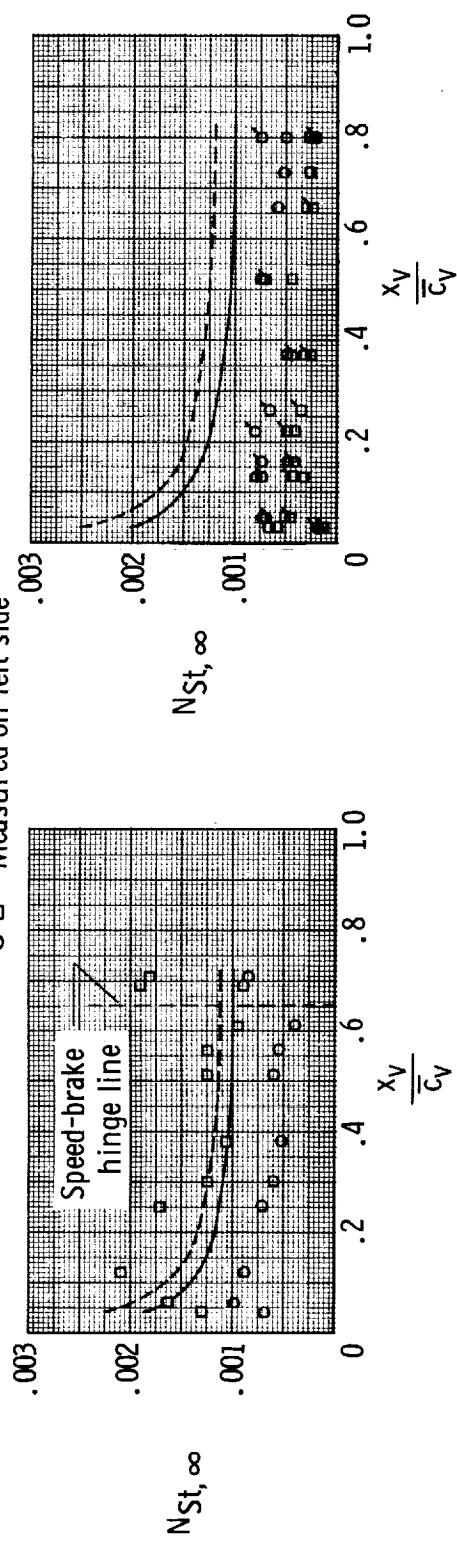


(b) Lower surface.

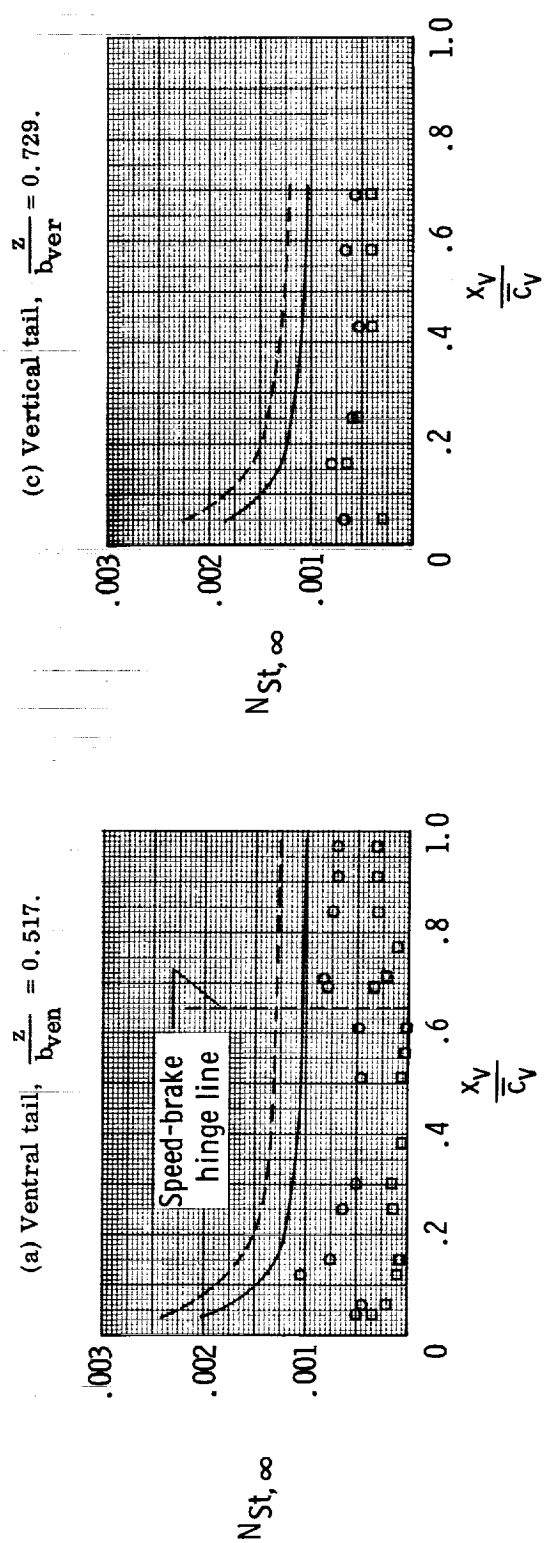
Figure 10.— Effect of angle of attack on distribution of Stanton numbers on horizontal tail.

|          |                      |            |                |
|----------|----------------------|------------|----------------|
| Measured | Calculated (ref. 18) | $M_\infty$ | $\alpha$ , deg |
| ○        | —                    | 5.10       | 2.0            |
| □        | - - - -              | 4.98       | 16.3           |

○ □ Measured on left side

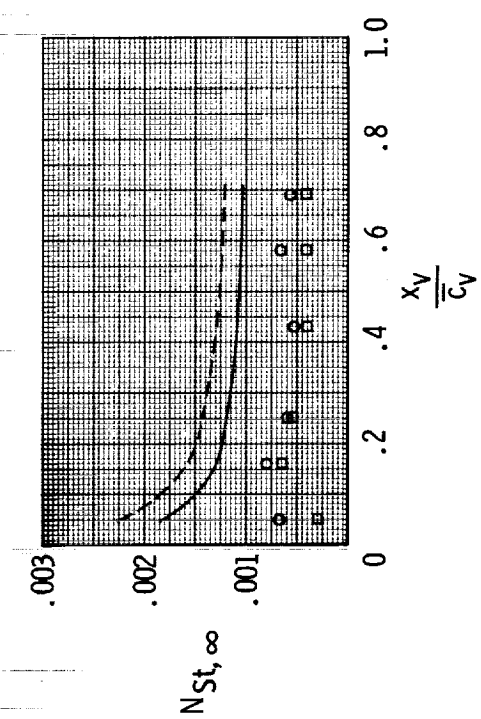


(a) Ventral tail,  $\frac{z}{b_{ver}} = 0.517$ .



(b) Vertical tail,  $\frac{z}{b_{ver}} = 0.455$ .

(c) Vertical tail,  $\frac{z}{b_{ver}} = 0.729$ .



(d) Vertical tail,  $\frac{z}{b_{ver}} = 0.963$ .

Figure 11. - Effect of angle of attack on distribution of Stanton numbers on ventral and vertical tails.



Detail A

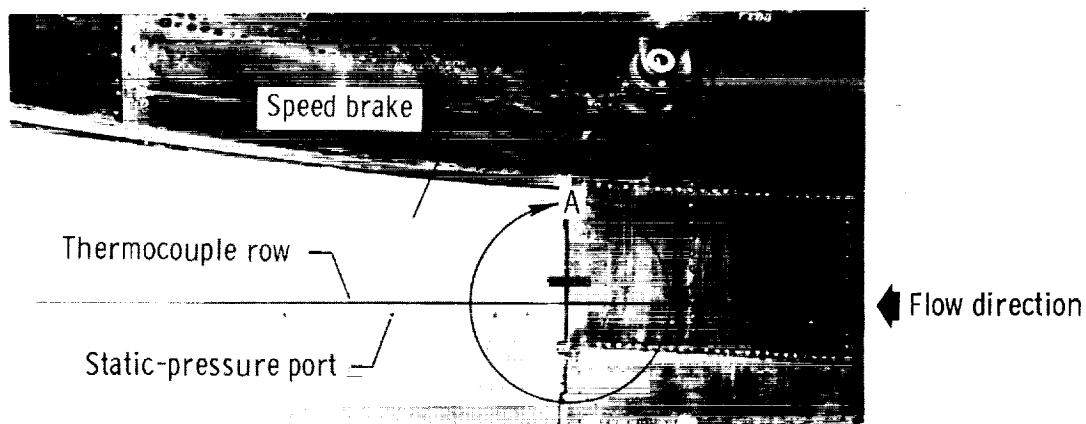
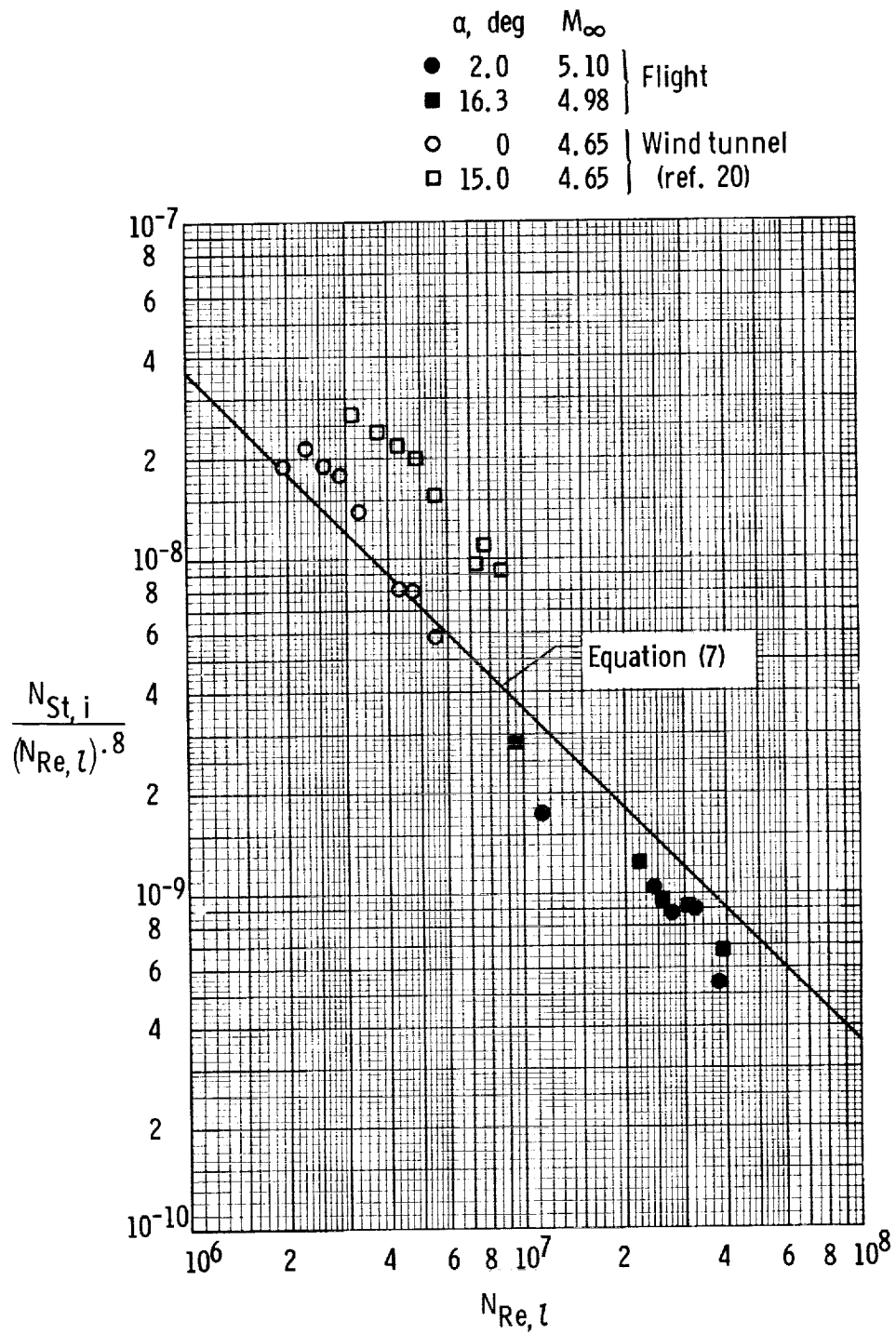
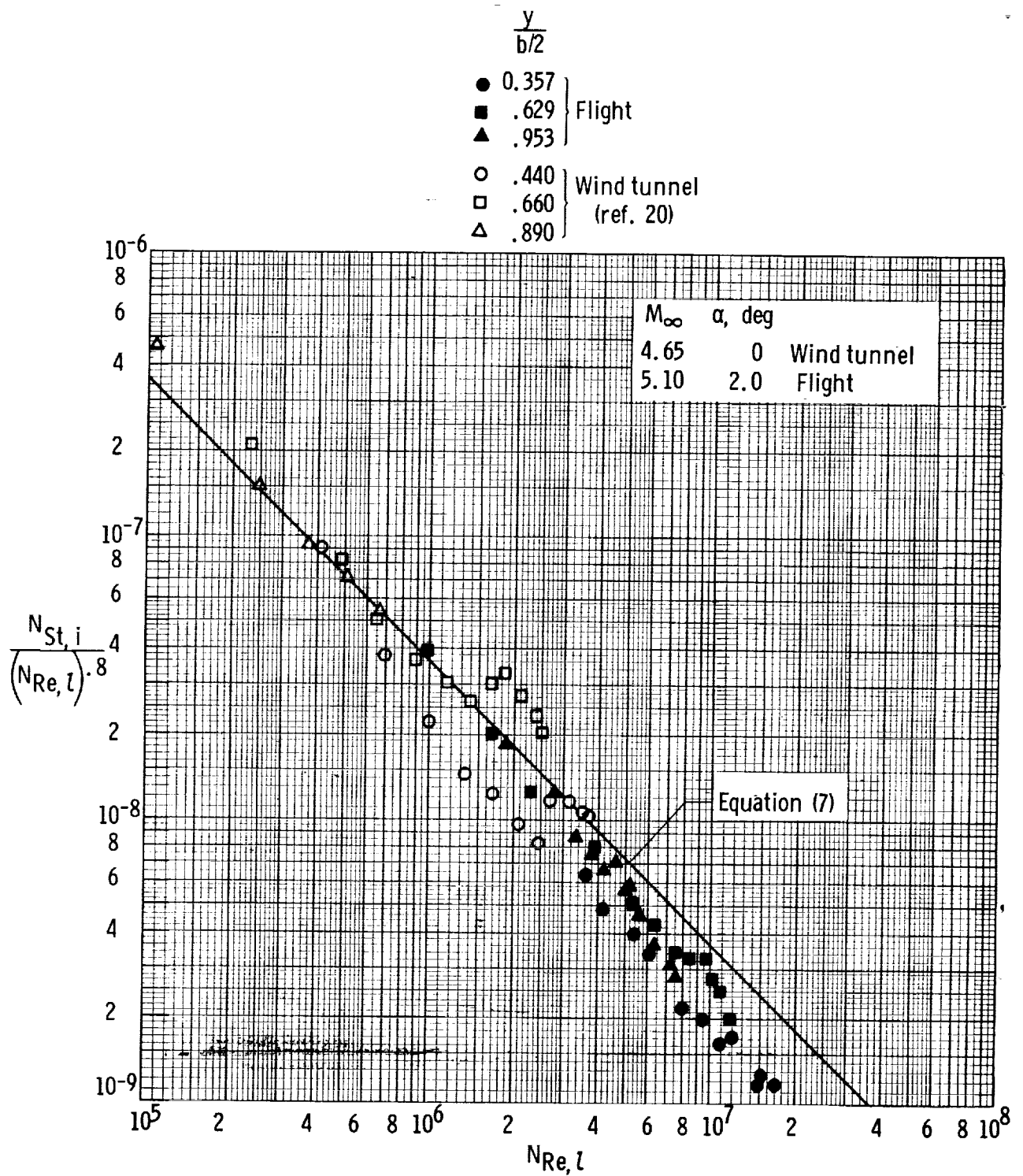


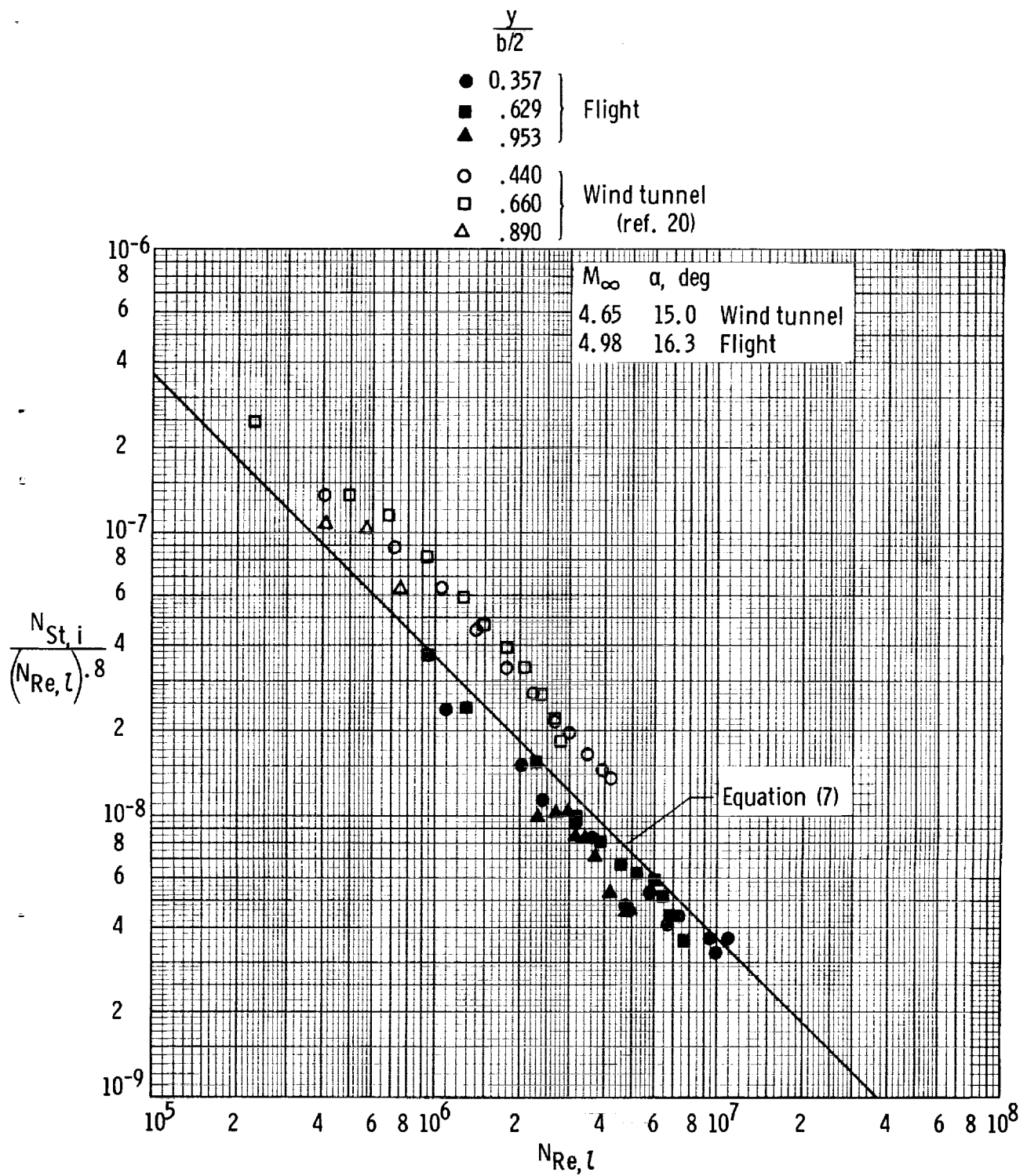
Figure 12. - Photograph of ventral tail showing discontinuity at speed-brake hinge area.



(a) Lower fuselage.

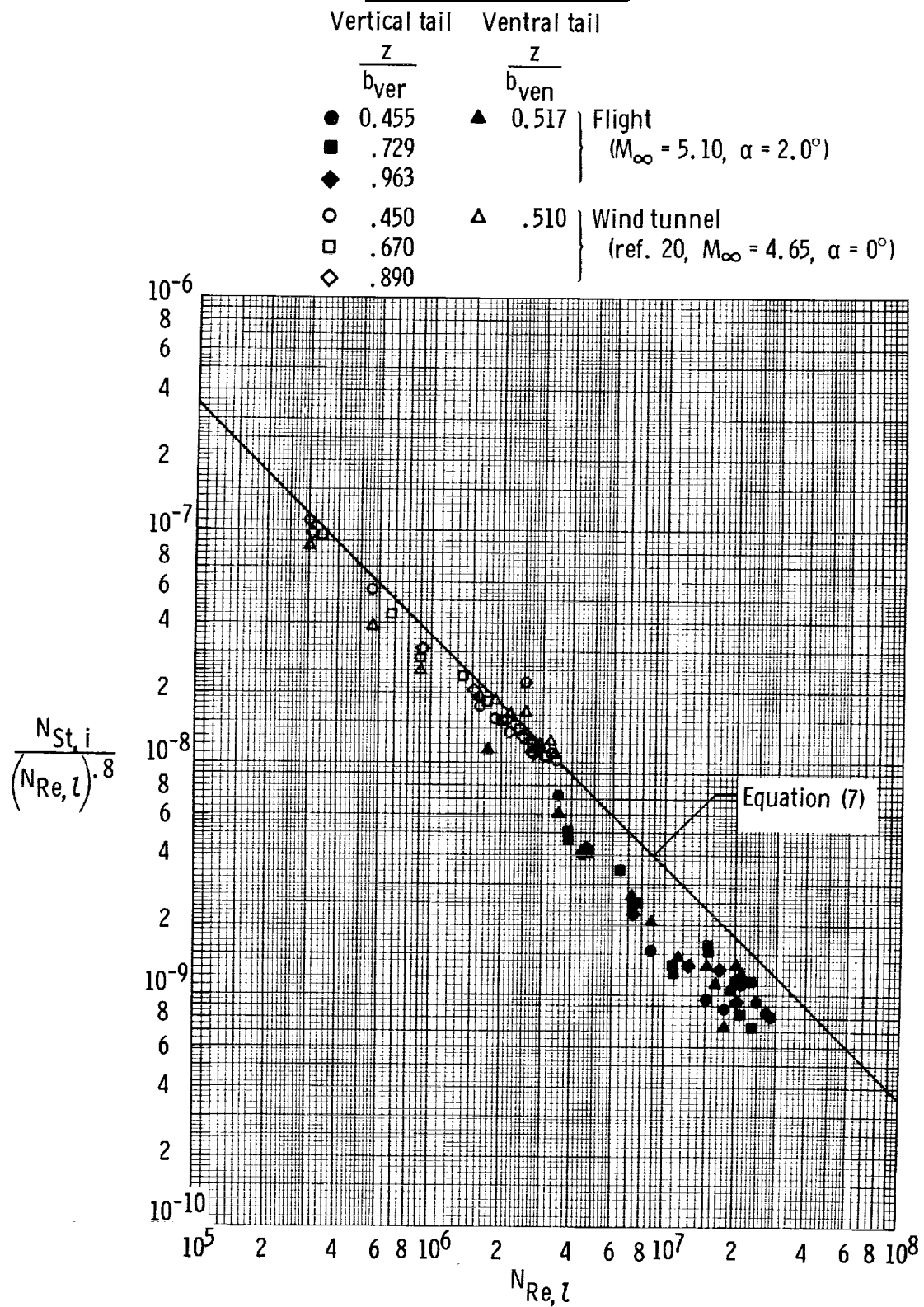
Figure 13. — Reynolds number correlation of wind-tunnel and flight data using Eckert's reference enthalpy method.





(c) Lower wing, high angle of attack.

Figure 13. - Continued.

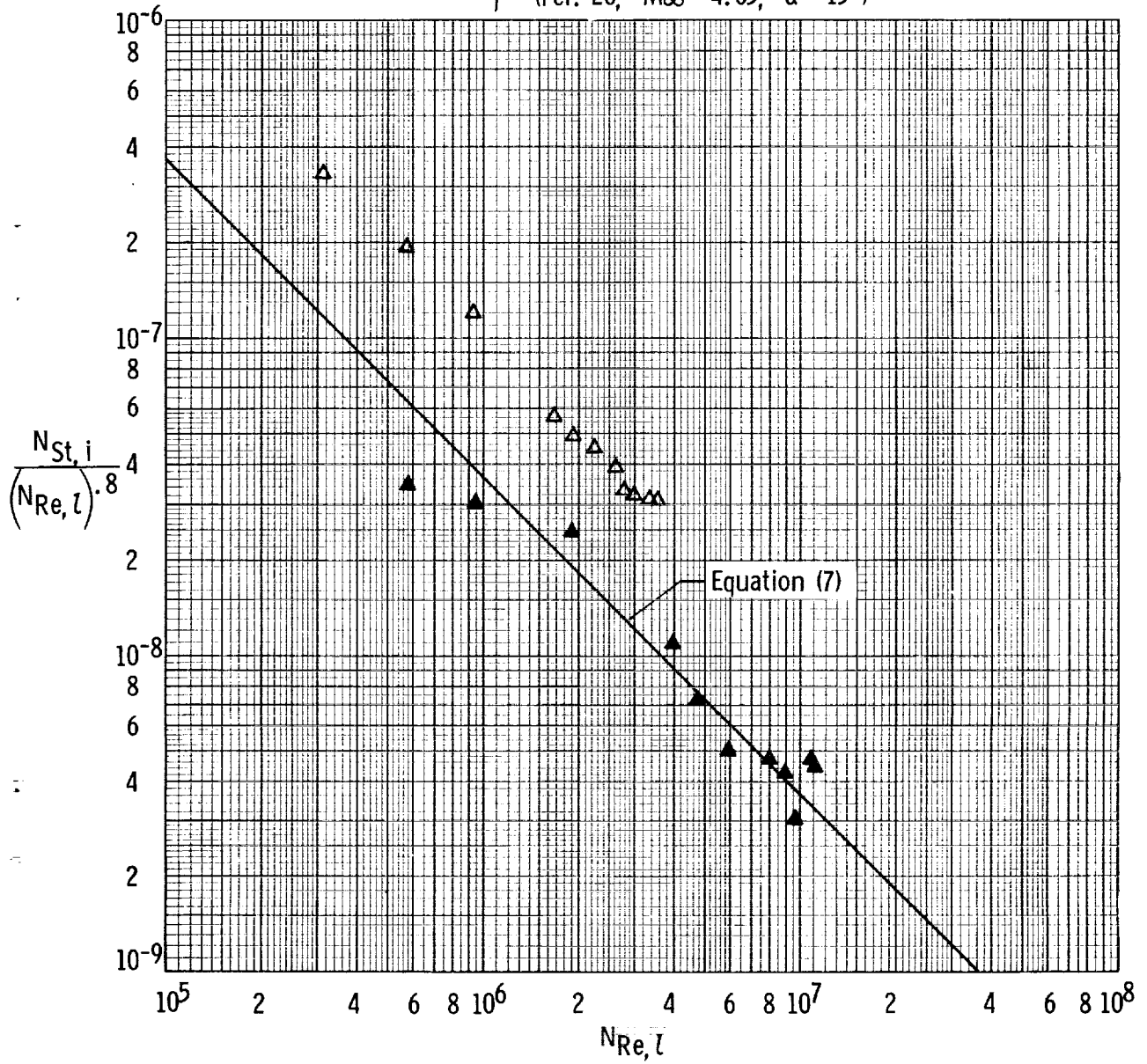


(d) Vertical and ventral tails, low angle of attack.

Figure 13. - Continued.

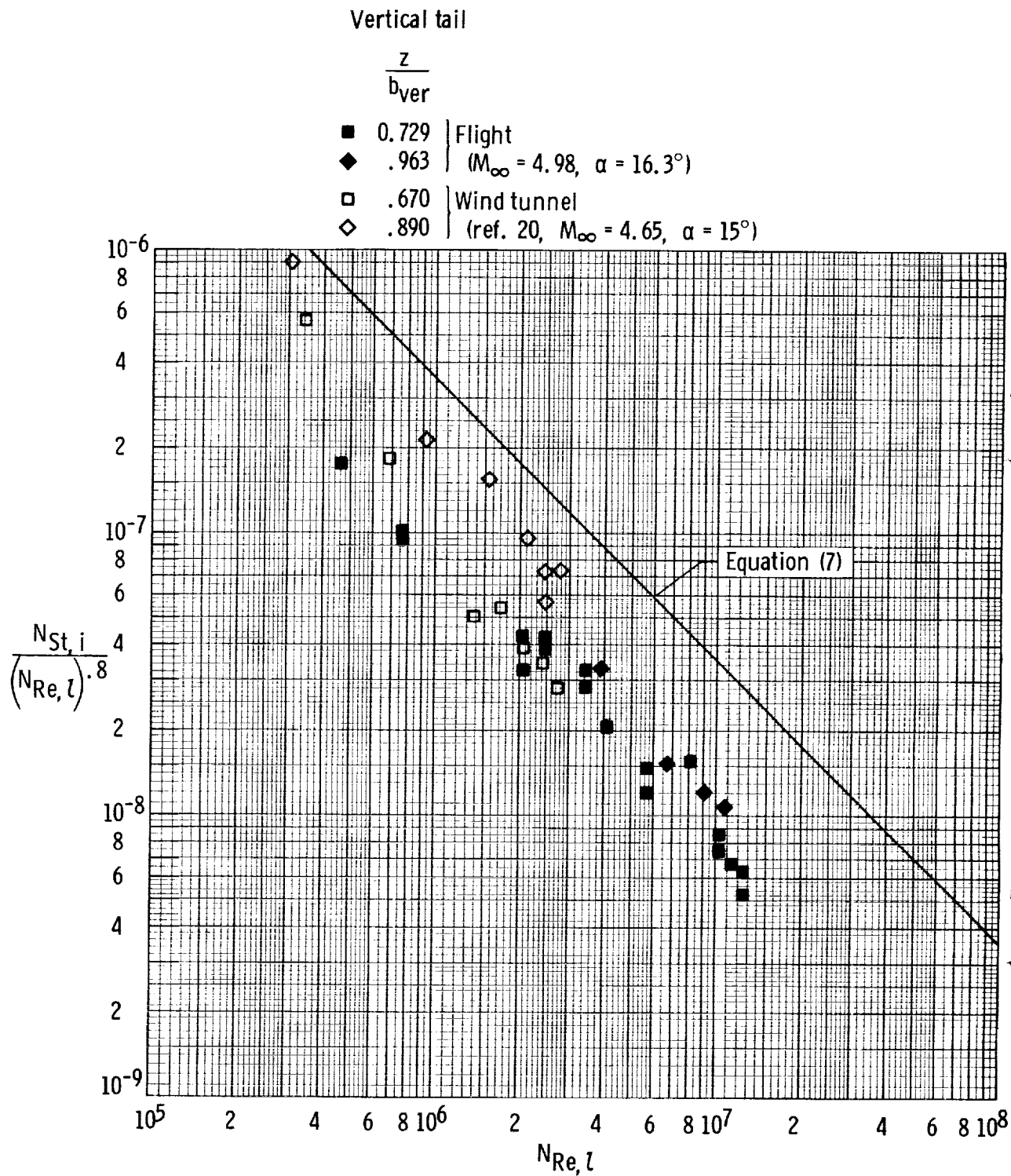
Ventral tail

$\frac{z}{b_{\text{ven}}}$   
 $\blacktriangle 0.517$  } Flight  
 $(M_\infty = 4.98, \alpha = 16.3^\circ)$   
 $\triangle .510$  } Wind tunnel  
 $(\text{ref. 20, } M_\infty = 4.65, \alpha = 15^\circ)$



(e) Ventral tail, high angle of attack.

Figure 13. - Continued.



(f) Vertical tail, high angle of attack.

Figure 13. - Concluded.

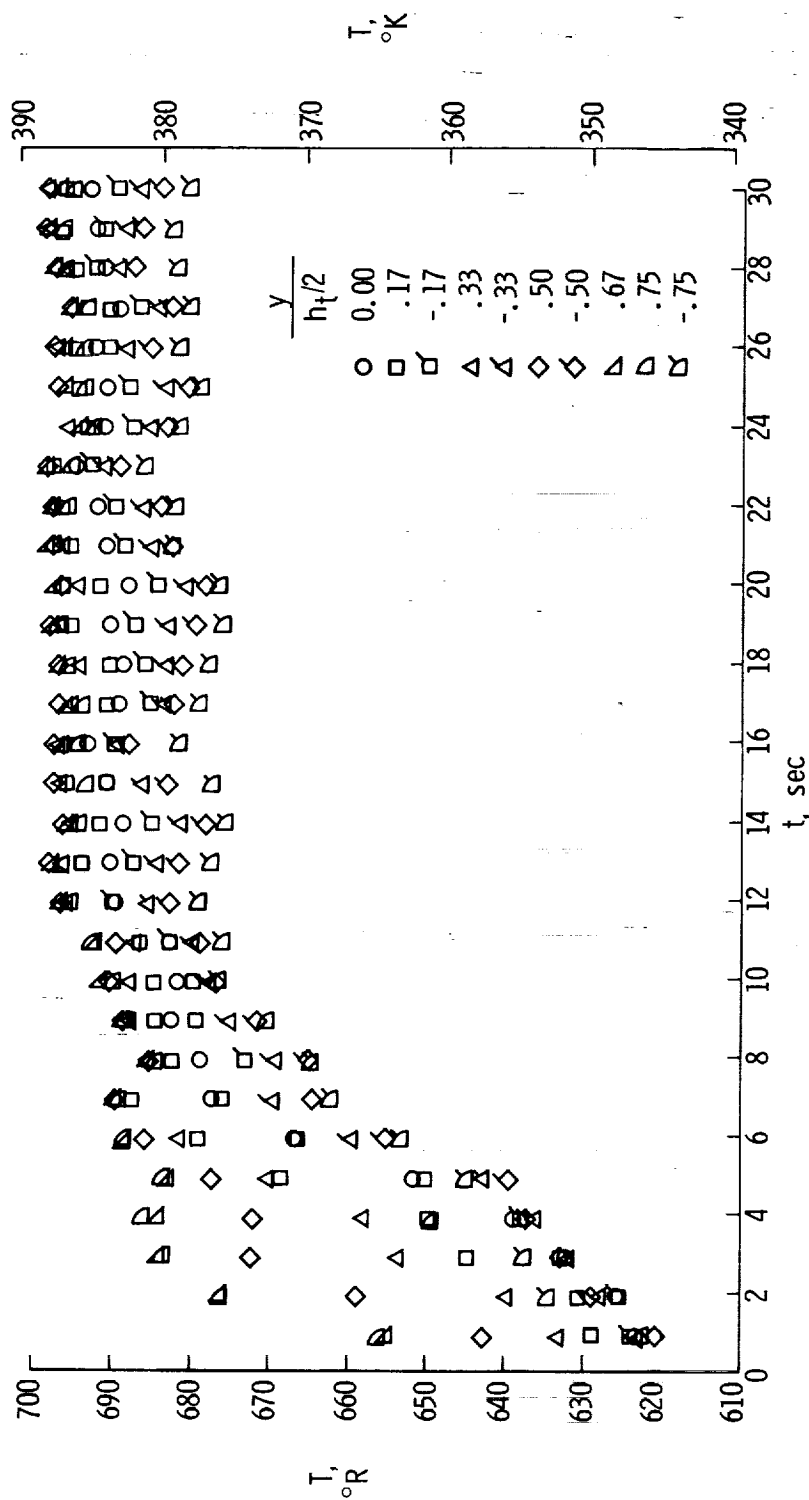


Figure 14. - Transient total-temperature distribution in the vertical plane of symmetry of the Langley Unitary Plan wind tunnel at  $M = 4.65$ ,  $\frac{h_t}{2} = 24$  in. (61 cm).

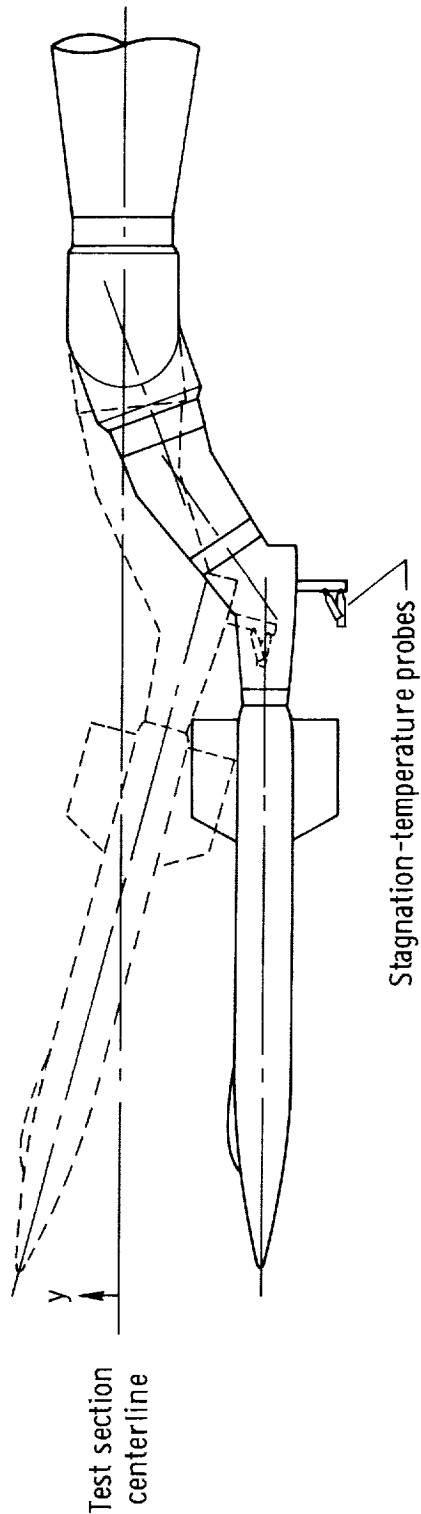
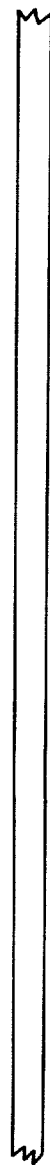
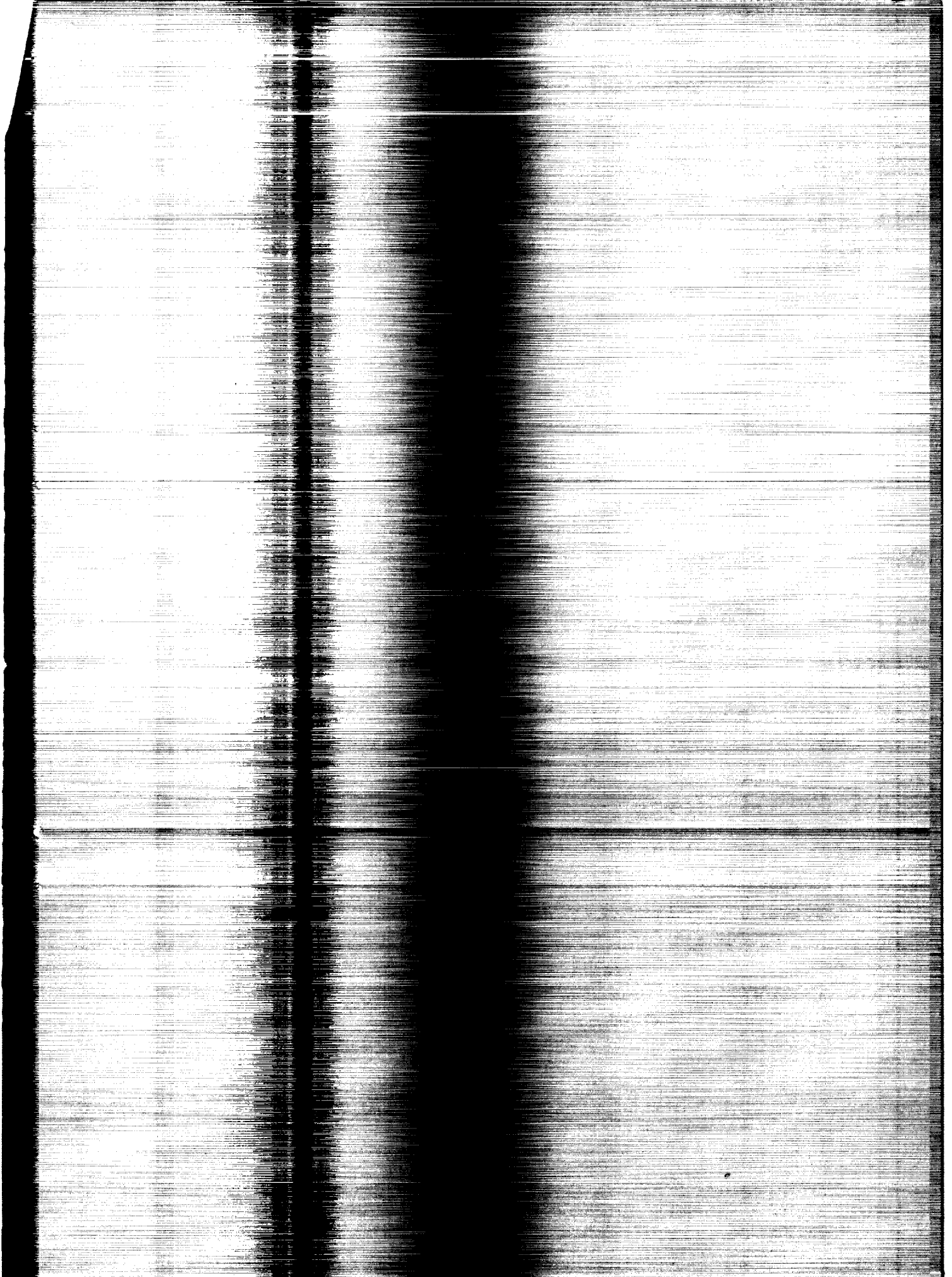


Figure 15. - Schematic side view of the 0.0667-scale model of the X-15 airplane in the Langley Unitary Plan wind tunnel.



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NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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