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HEAT-TRANSFER TEST ON THE NASA/ROCKWELL INTERNATIONAL SPACE SHUTTLE ORBITER AT MACH NUMBER 8.0 IN AEDC/VKF TUNNEL B

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ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
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Heat-transfer data were obtained on a 0.0175-scale and on a 0.04-scale model of the NASA/Rockwell International Space Shuttle Orbiter. The data were obtained at Mach 8 in the AEDC/VKF Tunnel B at angles of attack from 25 to 42.5 deg and at several free-stream Reynolds numbers from 0.5×10^6 to 3.7×10^6 per ft.

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NOMENCLATURE

b, SKIN THICKNESS	Model skin thickness, in. or ft as noted
C	Local wing chord (see Fig. 3 and Table 4), in.
c_p, CP	Model skin material specific heat, Btu/lbm-°R
dT_w/dt, DTW/DT	Wall temperature change with time, °R/sec
GROUP	Data identification number
h_{FR}, HFR	Reference heat-transfer coefficient based on Fay-Riddell theory for a scaled 1-ft-diam sphere, R_n = 0.04-ft (83-ϕ) or 0.0175 (60-ϕ), Btu/ft²-sec-°R

$$HFR = \frac{0.005156}{\sqrt{R_n}} \left(2.27 \frac{(T_o)^{1.125}}{(198.6 + T_o)}\right)^{0.4} \left(p_\infty\right)^{0.5} \left(\frac{6M_\infty^2}{5}\right)^{0.875}$$

$$\left(\frac{6}{7M_\infty^2 - 1}\right)^{0.625} \left[\left(\frac{6M_\infty^2}{5}\right)^{3.5} \cdot \left(\frac{6}{7M_\infty^2 - 1}\right)^{2.5} - 1\right]^{0.25}$$

$$\left[0.2235 + 1.35 \times 10^{-5} (T_o + 560)\right]$$

h_o, H(TO)	Heat-transfer coefficient (see Eq. (1)), Btu/ft²-sec-°R
$h(0.9T_o)$, H(0.9TO)	Heat-transfer coefficient (see Eq. (4)), Btu/ft²-sec-°R
$h(T_{aw})$, H(TAW)	Heat-transfer coefficient (see Eq. (5)), Btu/ft²-sec-°R
L	Reference length, in. (see Figs. 2 and 3)
L/LN	Location coordinates for thermocouples in thrusters (see Fig. 2b)
M_∞, MACH NO.	Free-stream Mach number
MU-INF	Free-stream viscosity, lbf-sec/ft²
PHI, ϕ	Radial angle of thermocouple in model coordinates, deg (see Fig. 1)
P_o, PO	Tunnel stilling chamber pressure, psia

p_∞, P-INF	Free-stream static pressure, psia
QDOT	Heat-transfer rate, H(TO)/(TO-TW), Btu/ft^2-sec
q_∞, Q-INF	Free-stream dynamic pressure, psia
RE/FT	Free-stream unit Reynolds number, ft^{-1}
Re_L	Free-stream Reynolds number based on L
ROLL	Tunnel sector roll position, deg (180 denotes model inverted)
St_{FR}, STFR	Stanton number based on HFR, $HFR/\rho_\infty \cdot V_\infty \left[0.2235 + 1.35 \times 10^{-5} \quad (T_o + 560)\right]$
t	Time from model lift off, sec
T_{aw}, TAW	Computed adiabatic wall temperature (see Eq. (6)), °R
TC NO	Thermocouple number
T_∞, T-INF	Free-stream temperature, °R
T_o, TO	Tunnel stilling chamber temperature, °R
T_w, TW	Model wall temperature at midpoint of data interval, °R
V_∞, V-INF	Free-stream velocity, ft/sec
w	Model skin material density, lbm/ft^3
X	Axial distance from model nose or wing leading edge, in.
X_o	Axial distance from point 235 in. ahead of orbiter nose, in. (see Fig. 1)
X/L	Thermocouple axial distance values supplied by RI for plots. For TC No. > 68, L equals local wing chord (see Table 4)
Y/S	Thermocouple lateral distance from model C_L referenced to wing semi-span
α, ALPHA-M	Model angle of attack, deg

α_i, ALPHA-I	Indicated pitch mechanism angle of attack, deg
α_p, ALPHA-P	Sting prebend angle at zero sector pitch, deg
ρ_∞, RHO-INF	Free-stream density, lbm/ft^3
ε	Local model surface deflection angle (see Eq. 6), deg
θ	Orientation angle of thermocouple position with respect to thruster, deg (see Fig. 2b)

Subscript

i	Initial conditions

1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC) at the request of the National Aeronautics and Space Administration (NASA), Johnson Space Center (JSC), Houston, Texas, for Rockwell International (RI), Space Division, Downey, California, under Program Element 921E01. The NASA-JSC project monitor was Dorothy B. Lee (ES3) and the RI project monitors were Paul Lemoine (AD38) for the first test phase (A) and Jim Cummings (AD38) for the second test phase (B). The tests were conducted by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee, in the von Kármán Gas Dynamics Facility (VKF) Hypersonic Wind Tunnel (B) on February 20, and April 27, 1978, for Phases A and B, respectively, under ARO Project Number V41B-V2. Final data from these tests were mailed to both NASA-JSC and RI on March 21, and May 26, 1978, for Phases A and B, respectively.

For the Phase A test, the 0.04-scale model (83-ϕ) was used and the test conditions were Mach number 8 at free-stream unit Reynolds numbers of 0.5×10^6, 0.875×10^6, and 1.6×10^6 per ft. The model was tested at angles of attack from 25 to 42.5 deg. For Phase B, the 0.0175 model (60-ϕ) were used and the test conditions were free-stream unit Reynolds numbers 0.5×10^6, 1.5×10^6, 2.5×10^6, and 3.7×10^6 per ft, also at Mach number 8, with the model at angles of attack of 30, 35, and 40 deg.

The objectives in test Phase A were to obtain heat-transfer data on the 83-ϕ model after a leak at a lap joint in the model was detected and repaired to assess its effect on earlier data. Also an additional cross-sectional row of thermocouples were added to assess the peak heating at the chine. The objective in test Phase B was to measure the heat flux on the windward wing surface of the orbiter with a turbulent boundary layer. Wing leading edge and fuselage nose trips were used to produce the turbulent boundary layer.

Inquiries to obtain copies of the test data should be directed to Dorothy B. Lee, ES3, NASA-JSC, Houston, Texas, 77058. A microfilm record has been retained in the VKF at AEDC.

2.0 APPARATUS

2.1 WIND TUNNEL

Tunnel B is a closed circuit hypersonic wind tunnel with a 50-in.-diam test section. Two axisymmetric contoured nozzles are available to provide Mach numbers of 6 and 8 and the tunnel may be operated continuously over a range of pressure levels from 20 to 300 psia at $M_\infty = 6$, and 50 to 900 psia at $M_\infty = 8$, with air supplied by the VKF main compressor plant. Stagnation temperatures sufficient to avoid air liquefaction in the test section (up to 1350°R) are obtained through the use of a natural gas fired combustion heater. The entire tunnel (throat, nozzle, test section, and diffuser) is cooled by integral, external water jackets. The tunnel is equipped with a model injection system, which allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel may be found in the Test Facilities Handbook*.

Sketches of the tunnel are presented in Fig. 1, Appendix I.

2.2 MODELS

The test article for Test Phase A, designated the 83-ϕ model, is a 0.04-scale thin-skin thermocouple model of the forward 50 percent of the Rockwell International Space Shuttle Orbiter (Rockwell lines VL70-000140C), and the test article for test Phase B, designated the 60-ϕ model, is a 0.0175-scale thin-skin thermocouple model of the same orbiter configuration. Both models were constructed of 17-4PH stainless steel with a nominal 0.030-in. skin thickness at the instrumented areas. Sketches showing overall length and coordinate definitions are presented in Figs. 2 and 3; installation drawings are shown in Figs. 4 and 5; and photographs of each model injected in the Tunnel B test section are presented in Figs. 6 and 7 for the 83-ϕ (Phase A) and the 60-ϕ (Phase B) models, respectively. Rockwell International model dimensional data specifications for each model are presented in Table 1 (83-ϕ) and Table 2 (60-ϕ), Appendix II.

2.3 INSTRUMENTATION AND ACCURACY

Tunnel B stilling chamber pressure is measured with a 100- or 1000-psid transducer referenced to a near vacuum. Based on periodic comparisons with secondary standards, the accuracy (a bandwidth which includes 95-percent of residuals) of the transducers is estimated to be within ±0.1 percent of reading or ±0.06 psi, whichever is greater for the 100-psid range and ±0.1 percent or ±0.5 psi, whichever is greater for the 1000-psid range. Stilling chamber temperature measurements are made with Chromel®-Alumel® thermocouples which have an uncertainty of ±(1.5°F + 0.375 percent of reading) based on repeat calibrations.

The 83-ϕ model instrumentation consisted of 482 Chromel-constantan thermocouples (TC), of these 255 thermocouples were recorded for the subject tests. The 60-ϕ model instrumentation consisted of 548 iron-constantan thermocouples (TC), of these 69 thermocouples were monitored for the subject tests. The TC wire for both models was #30 AWG (0.010-in.) with Kapton® insulation. At the measurement point, the TC wires were spot welded to the inner surface of the model skin with approximately 0.02 in. between the two wires. The estimated temperature measurement accuracy is ±0.5 percent of the reading.

TC instrumentation locations for each model are illustrated in Figs. 8 and 9; their dimensional locations and skin thicknesses are tabulated in Tables 3 and 4.

The thermocouple output was digitized via a Beckman 210 converter system. The Beckman system was set up to sample 98 TC's every 0.067 sec;

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*Test Facilities Handbook (Tenth Edition). "von Kármán Gas Dynamics Facility, Vol. 4," Arnold Engineering Development Center, May 1974.

the analog-to-digital conversion introduced approximately ±0.5 deg uncertainty into the TC measurements.

3.0 PROCEDURE

3.1 TEST CONDITIONS

The test was conducted at approximately Mach number 8.0. The test Reynolds number, based on model length, was from 0.9 x 10^6 to 7.05 x 10^6. A summary of the test conditions at each Reynolds number for each model is given below.

					83-ϕ Model	60-ϕ Model
M_∞	P_o, psia	T_o, °R	q_∞, psia	p_∞, psia	$Re_L \times 10^{-6}$	$Re_L \times 10^{-6}$
7.88	85.0	1180.0	0.422	0.0097	1.08	0.90
7.93	165.0	1227.0	0.790	0.018	1.83	----
7.96	300.0	1267.0	1.412	0.032	----	2.73
7.97	338.0	1278.0	1.580	0.036	3.46	----
7.98	547.0	1310.0	2.539	0.057	----	4.72
8.00	853.0	1339.0	3.913	0.087	----	7.05

Test summaries, run logs, and photographic logs, showing all configurations tested and the variables for each are presented in Tables 5 and 6 for both test phases.

3.2 TEST PROCEDURE

Prior to each test run, the output of the thermocouples to be recorded were monitored to ascertain that all the model temperatures were approximately 80°F within ±5°F. The model was then injected at the desired test attitude, taking about 2 sec to reach the tunnel centerline. The model remained at this position for about 3 sec and was then retracted, after which it was cooled and prepared for a subsequent injection.

To insure a turbulent boundary-layer on the 60-ϕ model, spherical balls of various sizes were spotwelded to thin metal strips which were attached to the model surface (see Fig. 9 for locations and Table 6 for sizes).

3.3 DATA UNCERTAINTY

An evaluation of the influence of random measurement errors is presented in this section to provide a partial measure of the uncertainty of the final test results presented in this report. Although evaluation of the systematic measurement error (bias) is not included, it should be noted that the instrumentation accuracy values (given in Section 2.3) used in this evaluation represent a total uncertainty combination of both systematic and two-sigma random error contributions.

3.3.1 Test Conditions

Accuracy of the basic tunnel parameters P_o and T_o (see Section 2.3) and the two-sigma deviation in Mach number determined from test section flow calibrations were used to estimate uncertainties in the other free-stream properties, using the Taylor series method of error propagation; i.e.,

$$(\Delta F)^2 = \left(\frac{\partial F}{\partial X_1}\Delta X_1\right)^2 + \left(\frac{\partial F}{\partial X_2}\Delta X_2\right)^2 + \left(\frac{\partial F}{\partial X_3}\Delta X_3\right)^2 \ldots + \left(\frac{\partial F}{\partial X_n}\Delta X_n\right)^2$$

where ΔF is the absolute uncertainty in the dependent parameter $F = f(X_1, X_2, X_3 \ldots X_n)$; $X_1, X_2, X_3 \ldots X_n$ are the independent measurements; and $\Delta X_1, \Delta X_2, \Delta X_3 \ldots \Delta X_n$ are the errors in the independent measurements.

	Uncertainty (±), percent					
M_∞	M_∞	p_o	T_o	p_∞	q_∞	Re_L
7.88	0.5	0.1	0.4	3.3	2.3	1.5
7.93-7.96	0.4	↓	↓	2.5	1.7	1.2
7.97-8.00	0.3	↓	↓	1.6	1.1	0.9

3.3.2 Reduced Data

Estimated uncertainties for the individual terms in Eq. (2) were used in the Taylor series method of error propagation to obtain uncertainty values of heat-transfer coefficient as represented typically by the ranges listed below:

h_o	Uncertainty (±), percent
10^{-4}	10
10^{-3}	7
10^{-2}	5

3.4 DATA REDUCTION

The reduction of thin-skin thermocouple data normally involves only the calorimetric heat balance, which, in coefficient form is

$$h_o = wbc_p \frac{dT_w/dt}{T_o - T_w} \tag{1}$$

Radiation and conduction losses are neglected in this heat balance, and data reduction simply requires evaluation of dT_w/dt from the temperature-time data and determination of model material properties. For the present tests, radiation effects were negligible; however, conduction effects were potentially significant in several regions of the model. To permit identification of these regions and improve evaluation of the data, the following procedure was used.

Separation of variables and integration of Eq. (1), assuming constant w, b, c_p, and T_o yields

$$\frac{h_o}{wbc_p}(t - t_i) = \ln\frac{T_o - T_{w_i}}{T_o - T_w} \tag{2}$$

Since h_o/wbc_p is a constant, plotting $\ln[(T_o - T_{w_i})/(T_o - T_w)]$ versus time will give a straight line if conduction is negligible. Thus, deviations from a straight line can be interpreted as conduction effects.

The data were evaluated in this manner, and generally, a reasonably linear portion of the curve could be found for all thermocouples. A linear least-squares curve fit of $\ln[T_o - T_{w_i})/(T_o - T_w)]$ versus time was applied to the data beginning at the time when the model reached tunnel centerline and extending for a time span which was a function of the heating rate, as shown below:

Range	Number of Points
$dT_w/dt > 32$	5
$16 < dT_w/dt \leq 32$	7
$8 < dT_w/dt \leq 16$	9
$4 < dT_w/dt \leq 8$	13
$2 < dT_w/dt \leq 4$	17
$1 < dT_w/dt \leq 2$	25
$dT_w/dt \leq 1$	41

In general, the time spans given above were adequate to keep the evaluation of the right-hand side of Eq. (2) within the linear region. Strictly speaking, the value of c_p is not constant, as assumed, and the following relation

$$c_p = 0.0797 + (5.556 \times 10^{-5})\ T_w,\ \text{(17-4 PH stainless steel)} \tag{3}$$

was used with the computed value of T_w at the midpoint of the curve fit. The maximum variation of c_p over any curve fit was less than 1.5 percent. Thus, the assumption of constant c_p was reasonable. The value of density used for the 17-4 PH stainless steel skin was w = 490.0 lbm/ft^3 and the skin thickness (b) for each thermocouple is listed in either Table 3 or 4.

In addition to computing heat-transfer coefficients using T_o as the reference temperature, coefficients were computed using 0.9 T_o and a T_{aw} as the reference temperature, viz,

$$h(0.9\ T_o) = h_o \frac{(T_o - T_w)}{(0.9\ T_o - T_w)} \tag{4}$$

and

$$h(T_{aw}) = h_o \frac{(T_o - T_w)}{(T_{aw} - T_w)} \tag{5}$$

where T_{aw} is computed by the equation (supplied by RI)

$$T_{aw} = T_o \left[0.867 + 0.133 \left(\sin (\alpha + \varepsilon)\right)^{1.55}\right] \quad (6)$$

where

$$\alpha = \alpha_p - \alpha_i \quad (7)$$

is the model angle of attack and ε is the local model surface deflection angle at the thermocouple. The $h(T_{aw})$ calculation was done only with TC's 273 thru 295 for test Phase A and the ε values for these TC's are presented in the following table.

TC	ε, deg	TC	ε, deg
273	75.0	284	20.0
274	68.5	285	18.5
275	54.5	286	16.5
276	42.0	287	14.5
277	38.5	288	7.0
278	34.5	289	4.0
279	30.0	290	2.5
280	28.0	291	1.0
281	26.0	292	↓
282	24.5	293	↓
283	22.0	294	↓
		295	↓

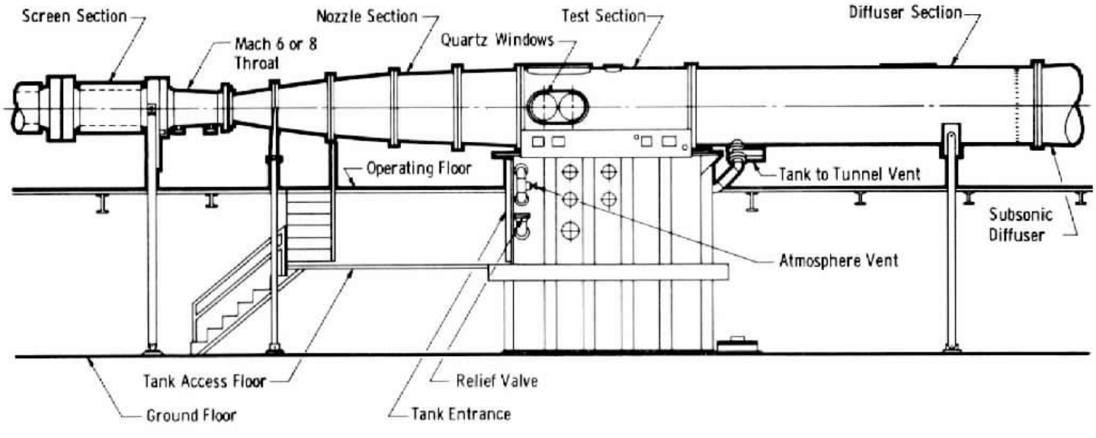
The same calculation was done with all TC's for the second test phase and the ε values are presented in Table 7.

4.0 DATA PACKAGE PRESENTATION

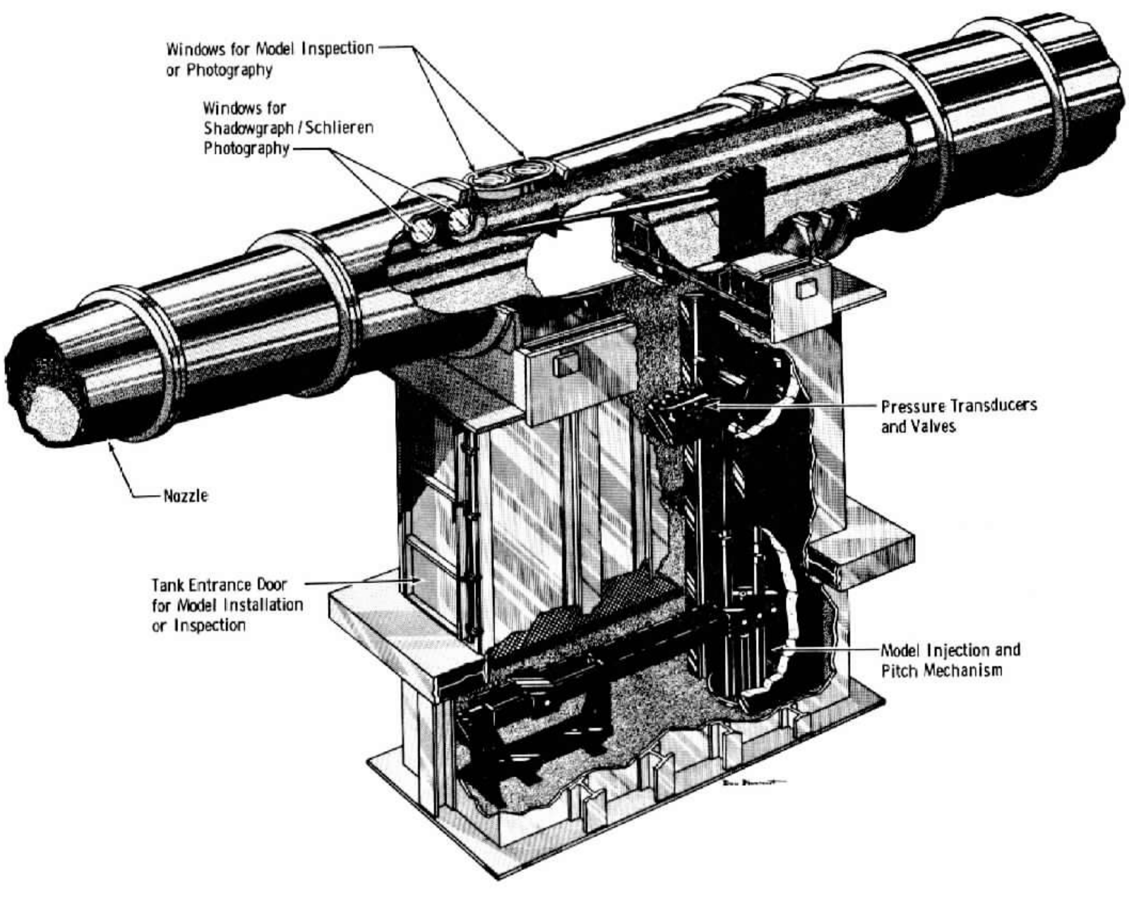
Sample data tabulations from both test phases are presented in Table 8; the parameters listed are identified in the Nomenclature. Representative plotted data are presented in Figs. 10 and 11 for the (A) and (B) test phases, respectively. Also shown are data obtained from previous tests using these same models. As can be seen, the agreement is excellent in both cases and is considered a validation of the current test results. Moreover, sealing the lap joint at the 83-ϕ model nose eliminated the rise in heating at $x/L \approx 0.02$ observed in the previous results shown in Fig. 10.

APPENDIX I

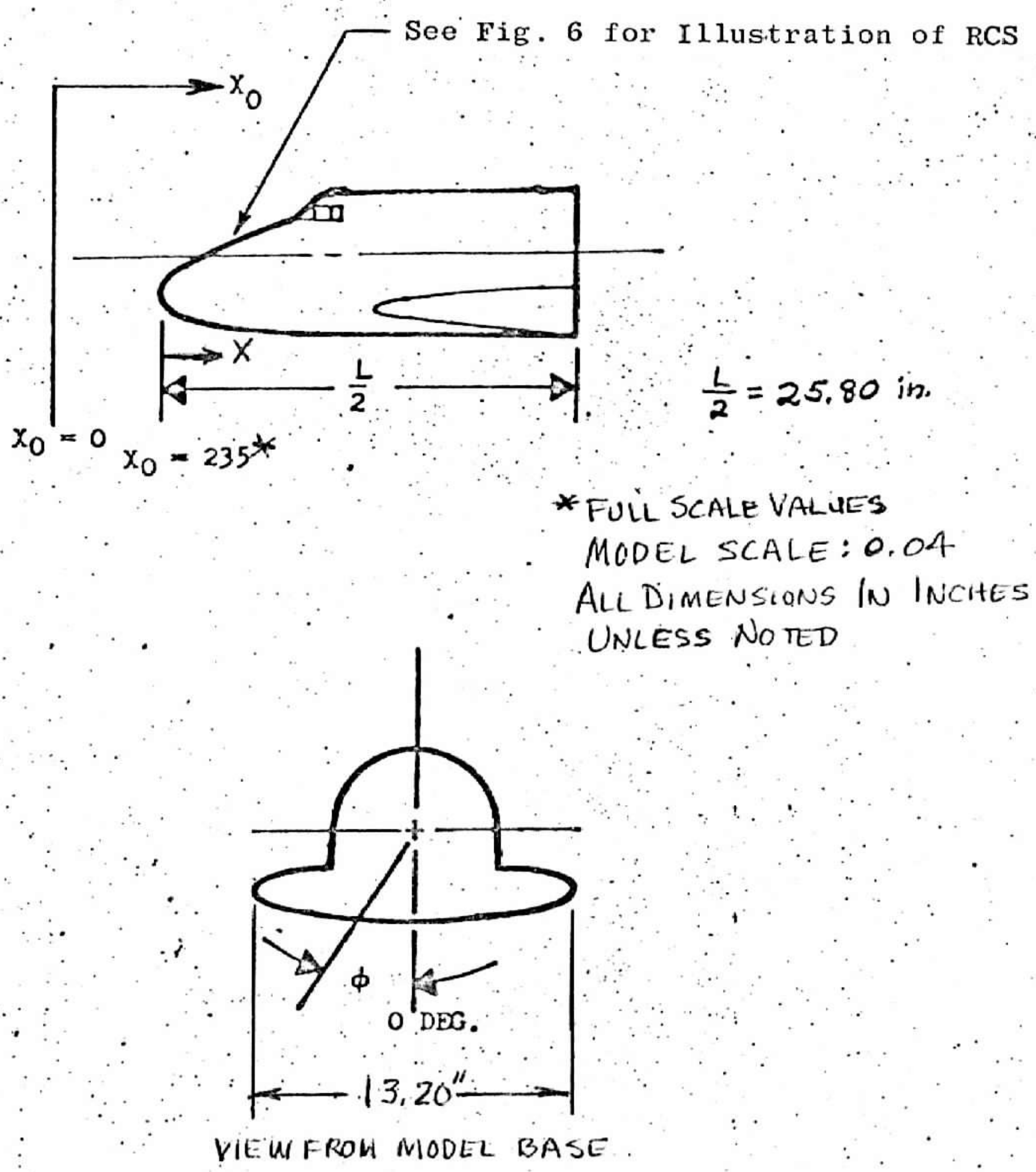
ILLUSTRATIONS



a. Tunnel assembly

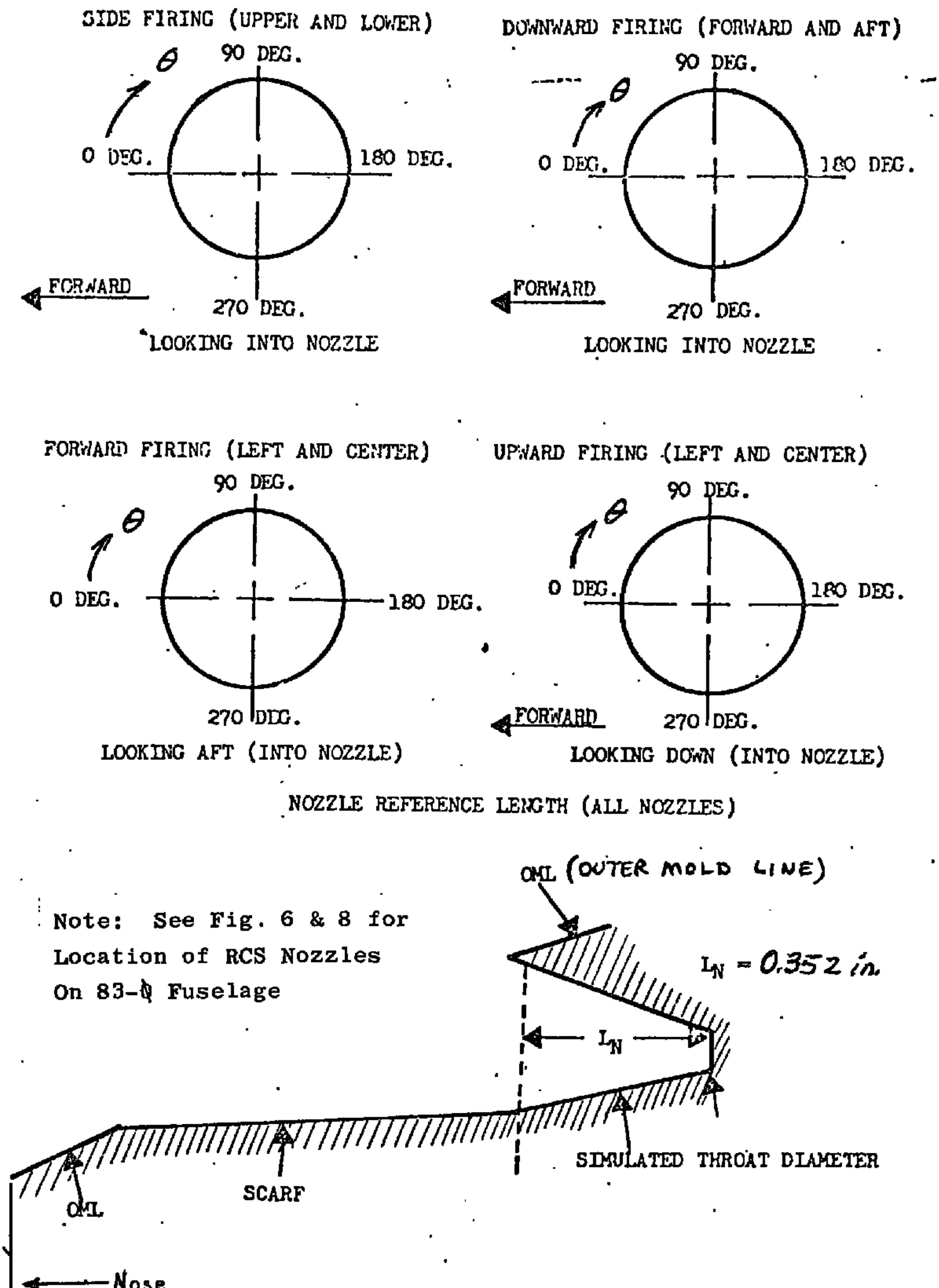


b. Tunnel test section
Fig. 1. Tunnel B



a. 83-Φ Model Coordinates and Dimensions

Figure 2. 83-Φ Model Coordinate Systems and Dimensions Defined



b. RCS Nozzle Reference System

Figure 2. Concluded

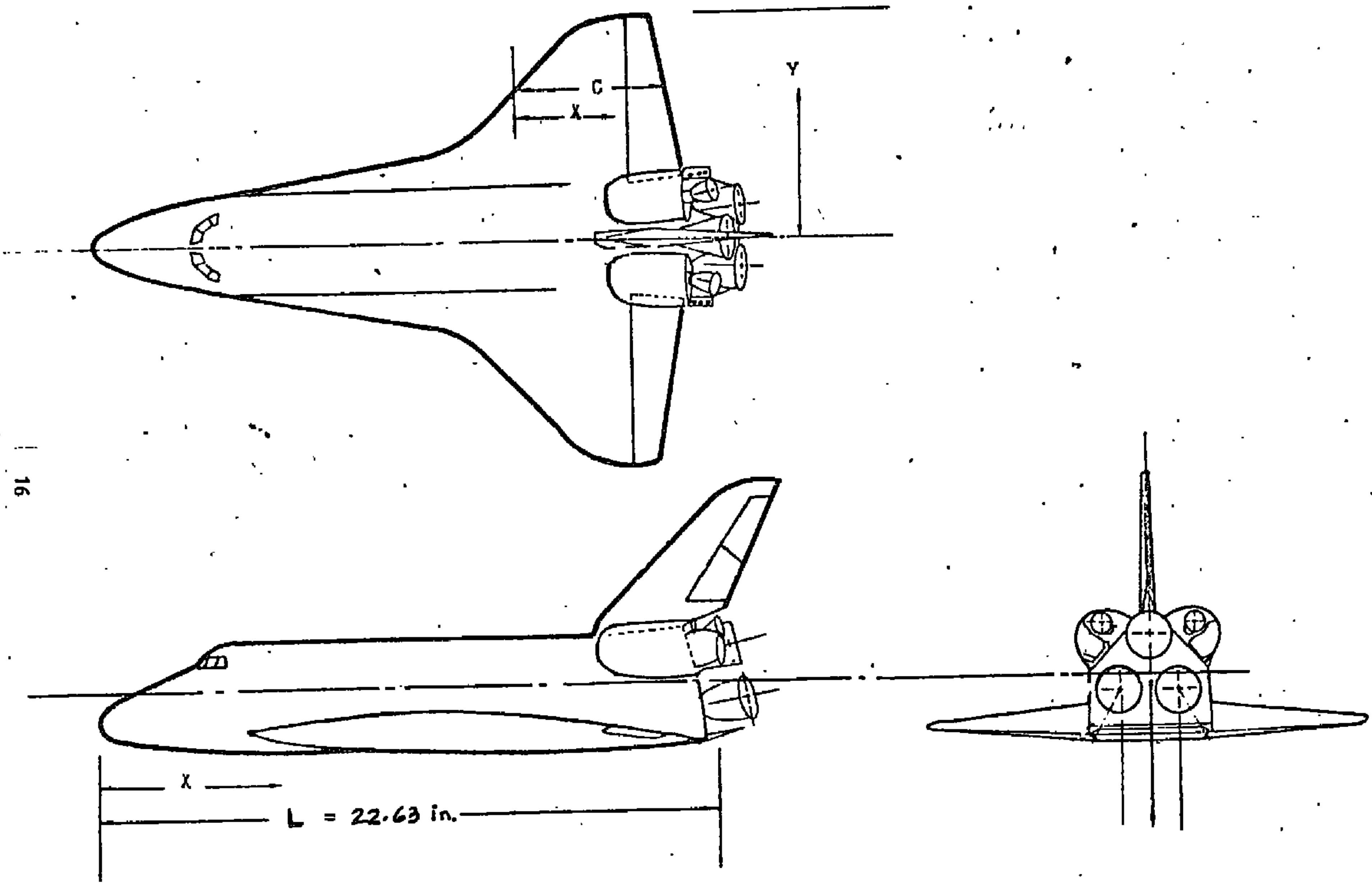


Figure 3. 60-ϕ Model Dimensions

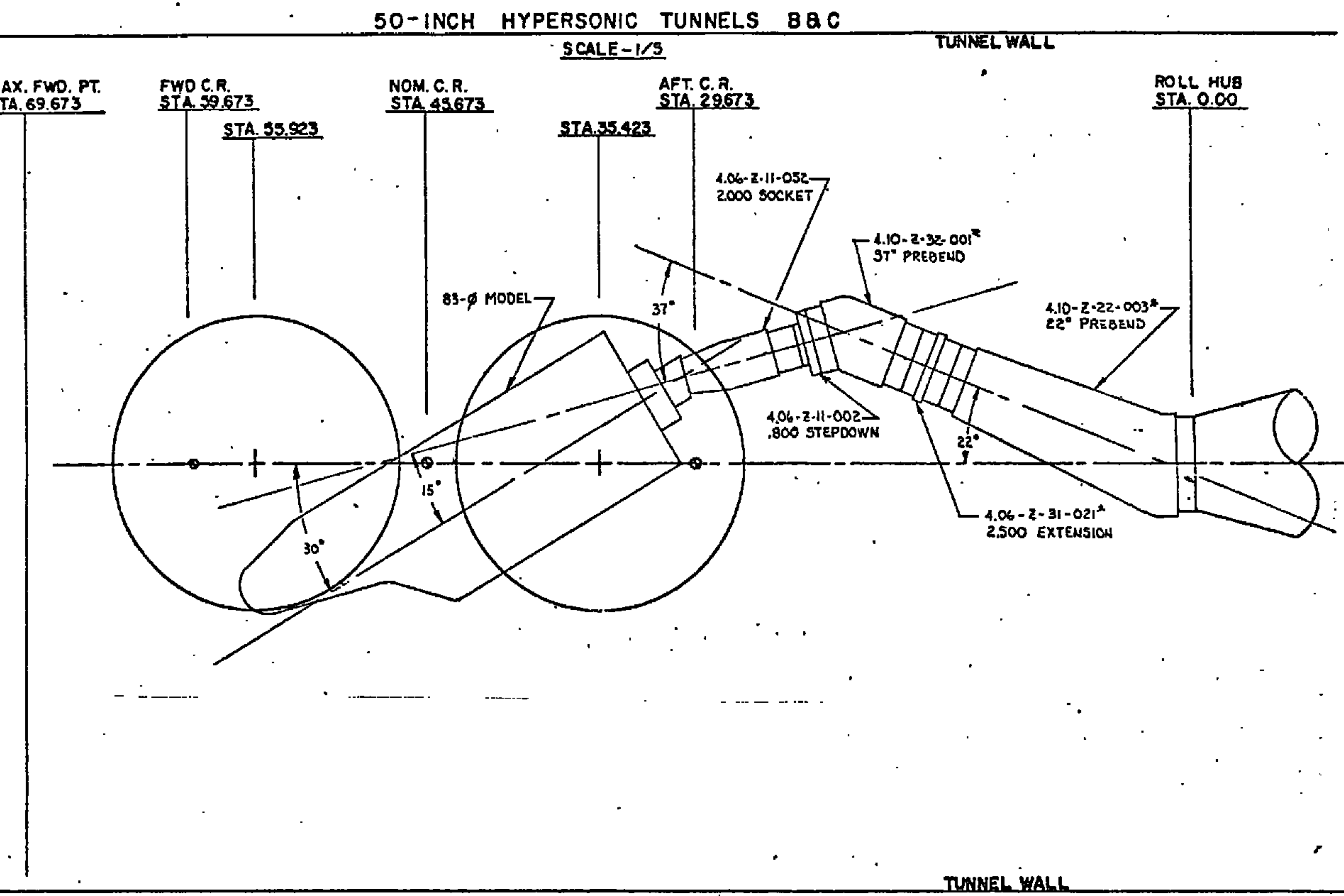


Figure 4. 83-ϕ Model Installation Sketch

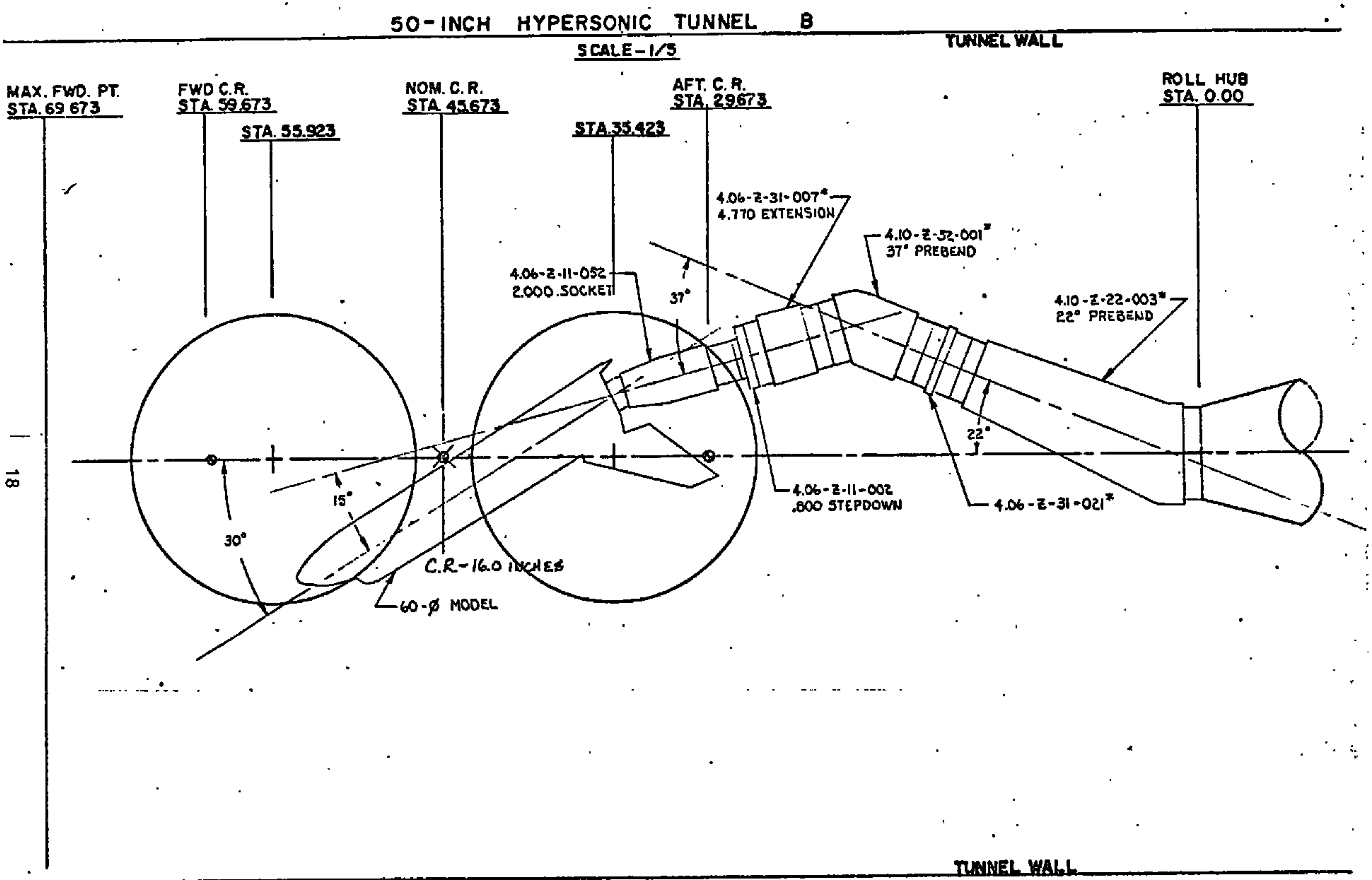


Figure 5. 60-ϕ Model Installation Sketch

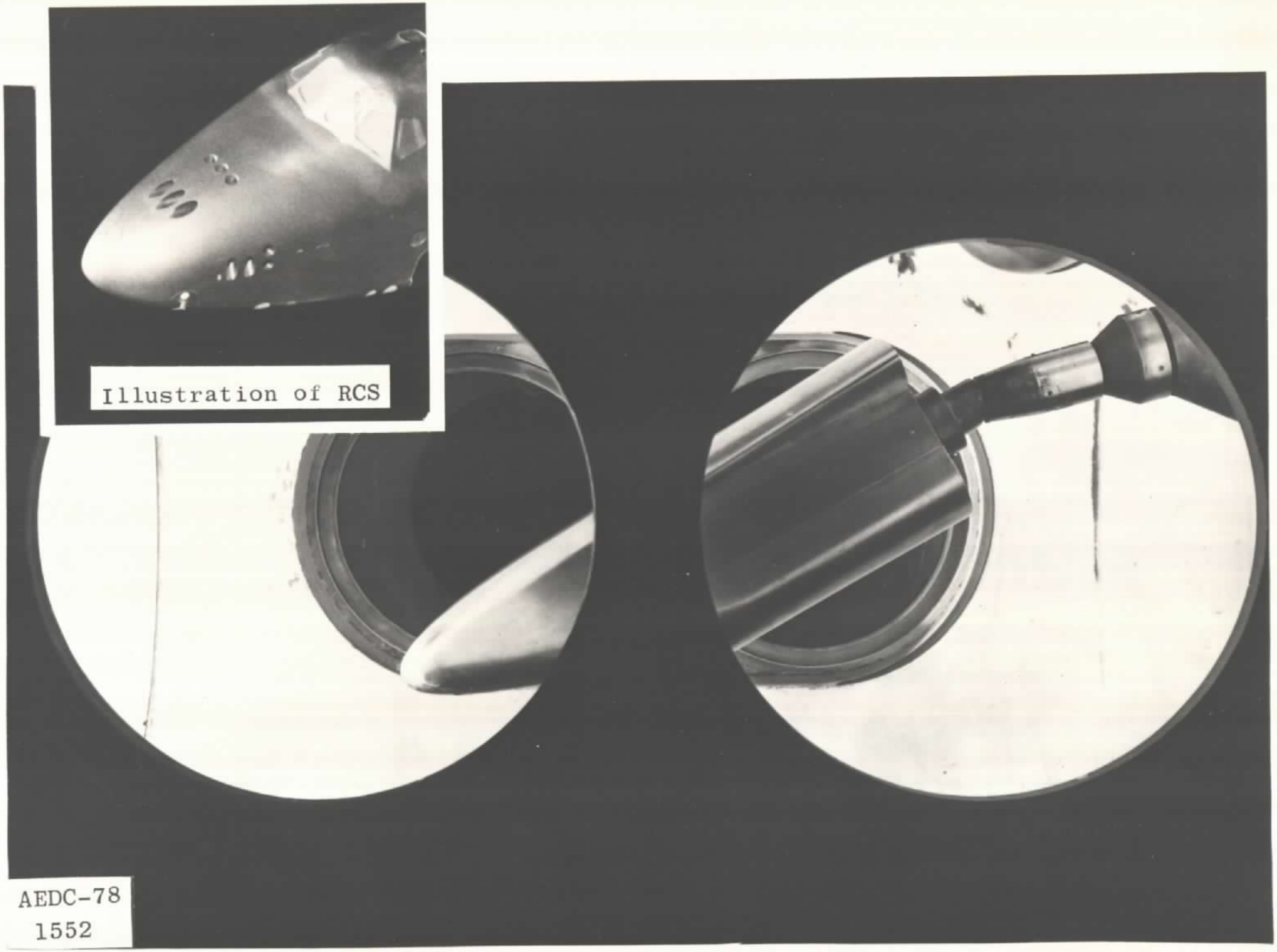


Figure 6. 83-ϕ Model Shown in Tunnel B at 30-Deg Angle-of-Attack

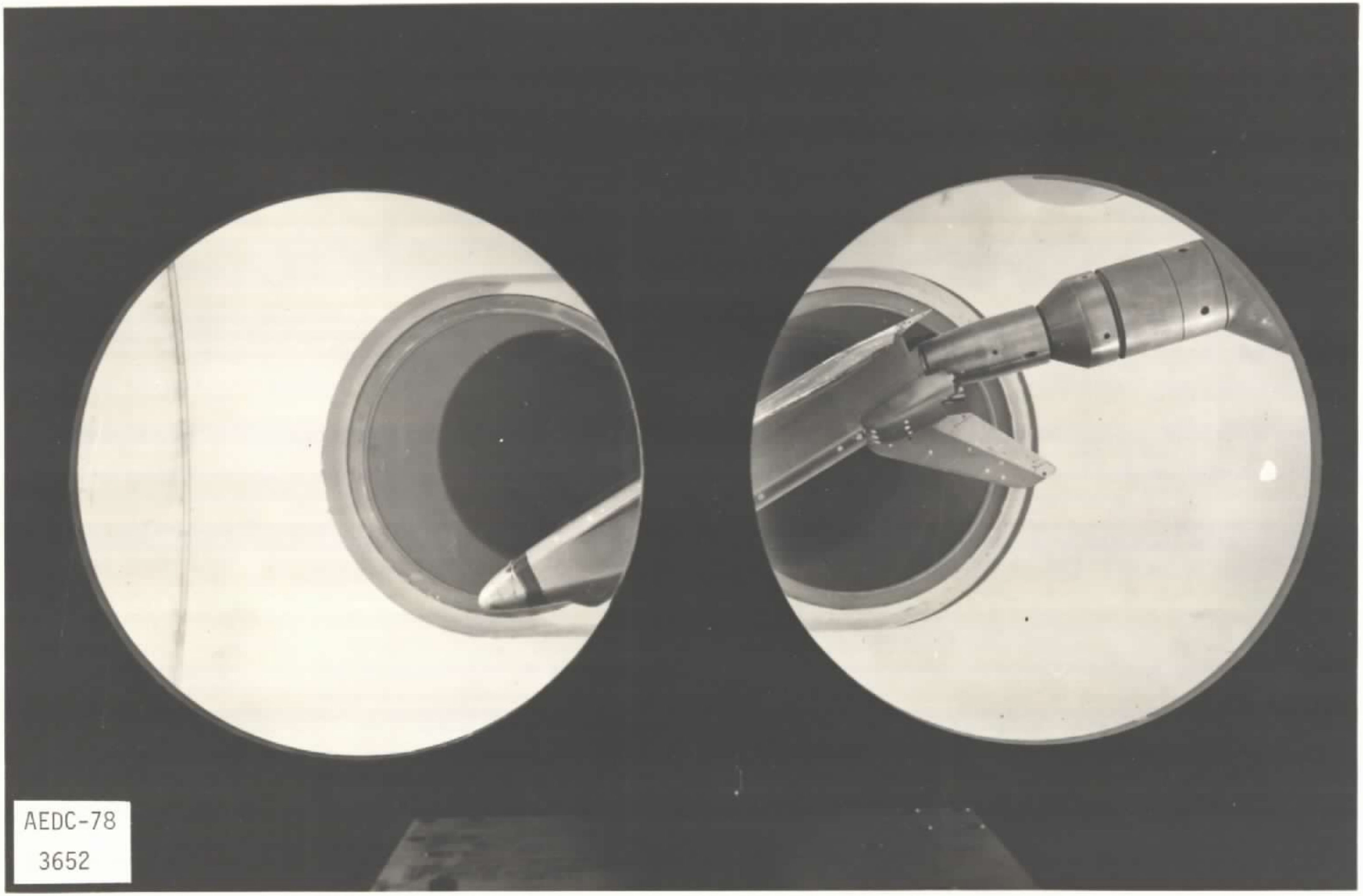
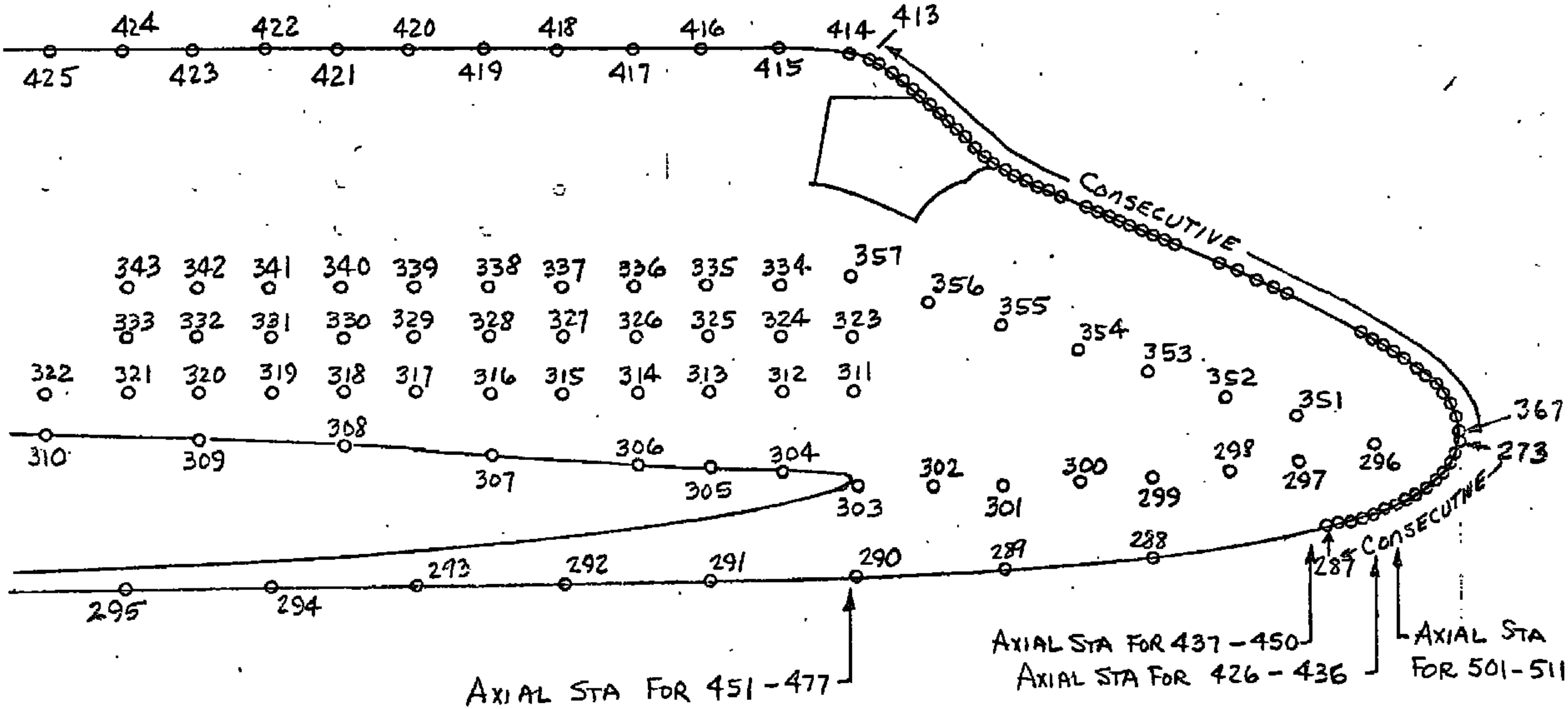
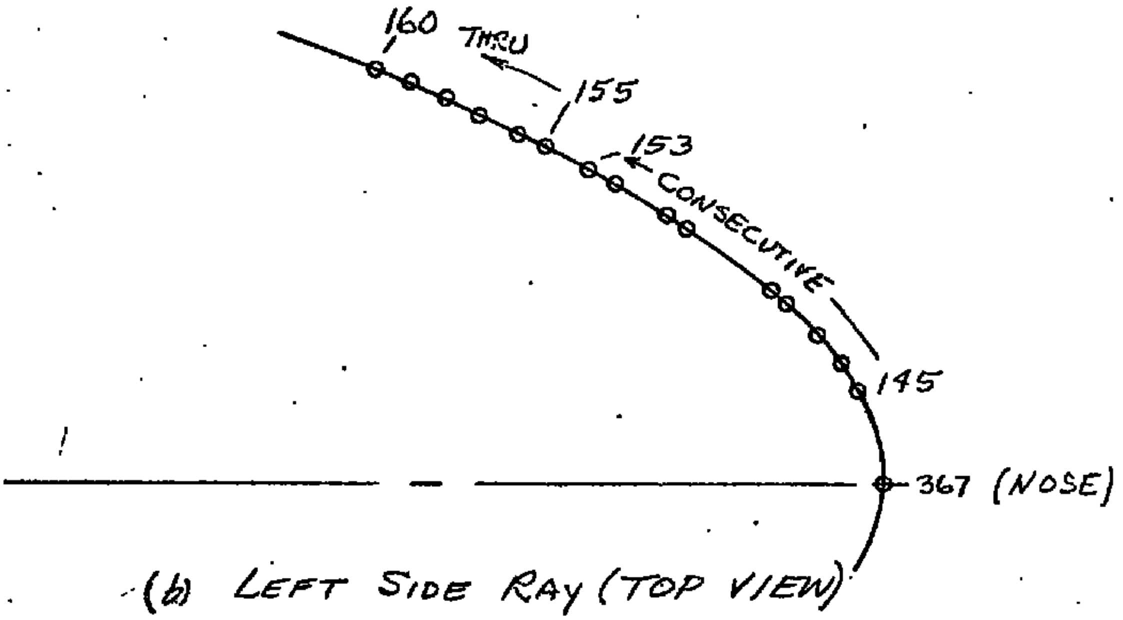


Figure 7. 60-ϕ Model Shown in Tunnel B at 30-Deg Angle-of-Attack

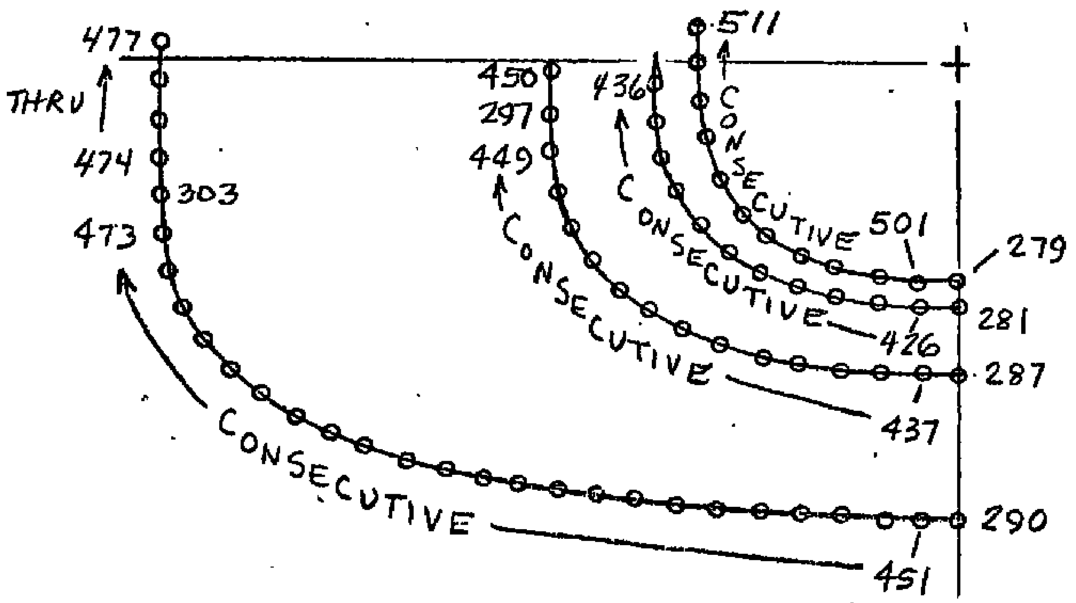


(a) TC LOCATIONS ON FUSELAGE RIGHT SIDE

FIG 8 - THERMOCOUPLE LOCATIONS ON 83-Ø MODEL



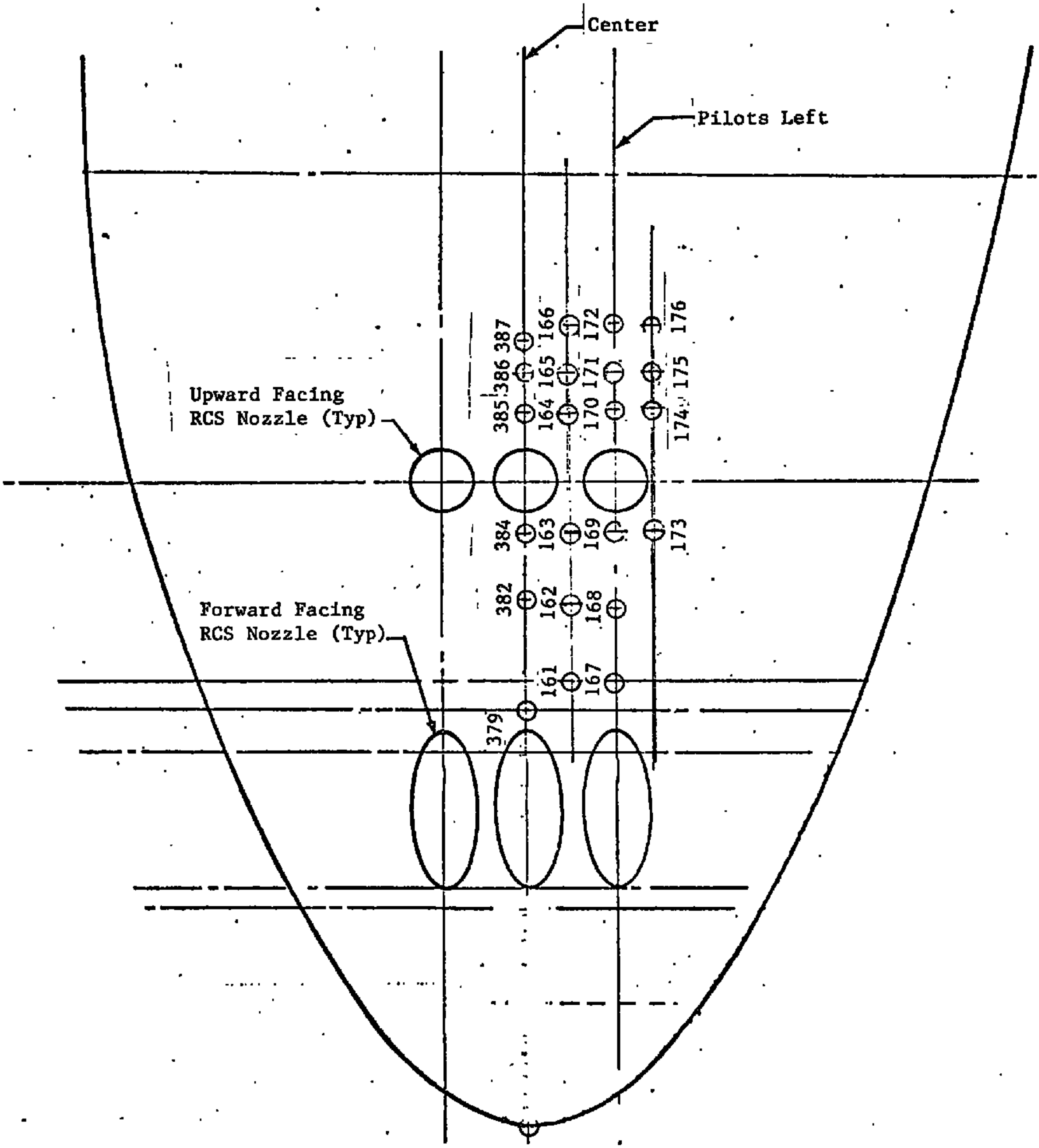
(b) LEFT SIDE RAY (TOP VIEW)



(c) RADIAL LOCATIONS

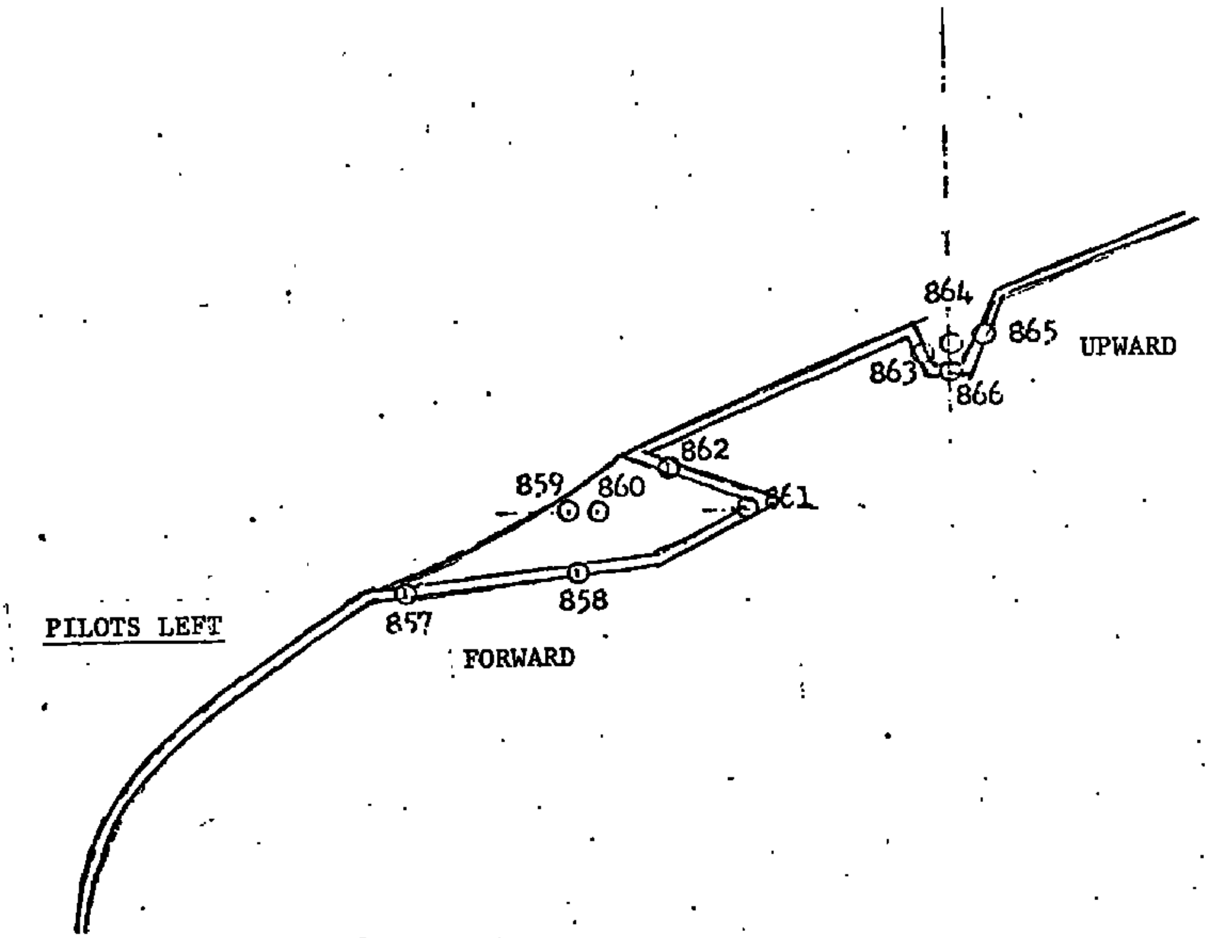
WINDWARD ℄
LOOKING DOWNSTREAM

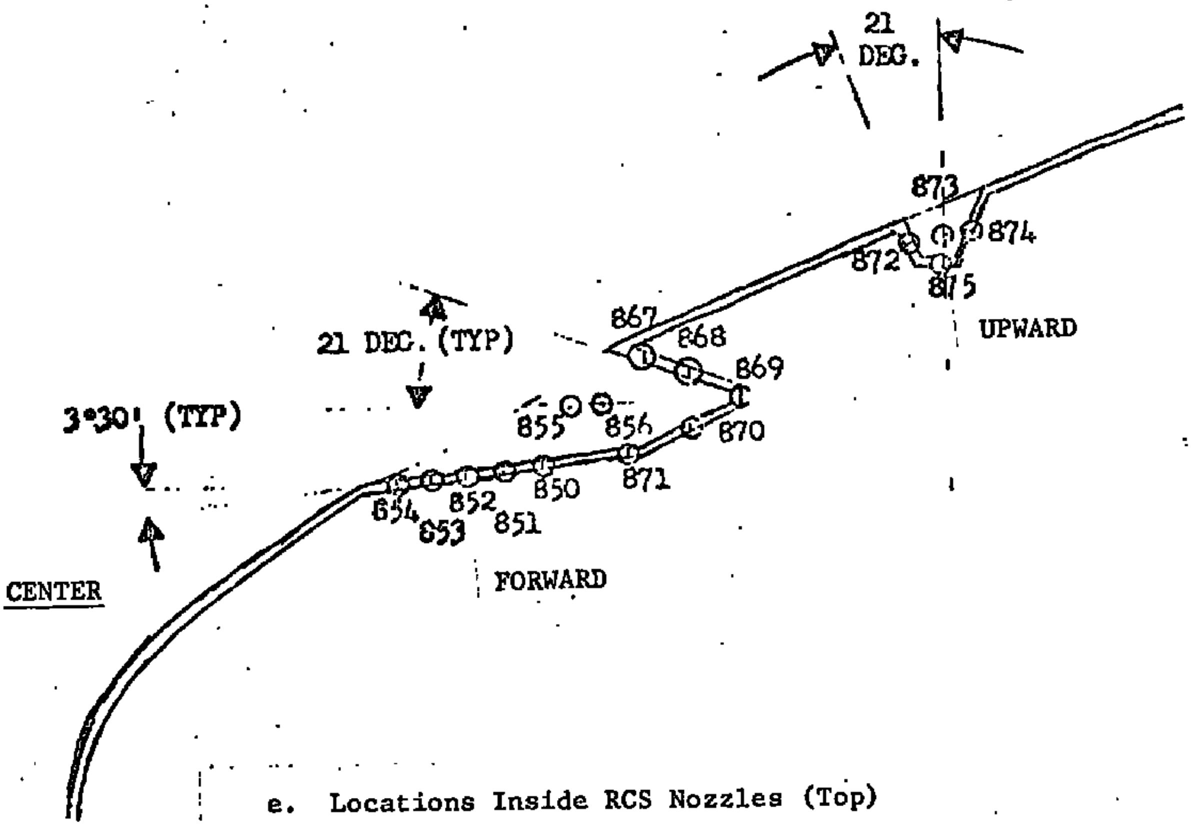
FIG 8 - CONTINUED



d. Locations Around RCS Nozzles (Top)

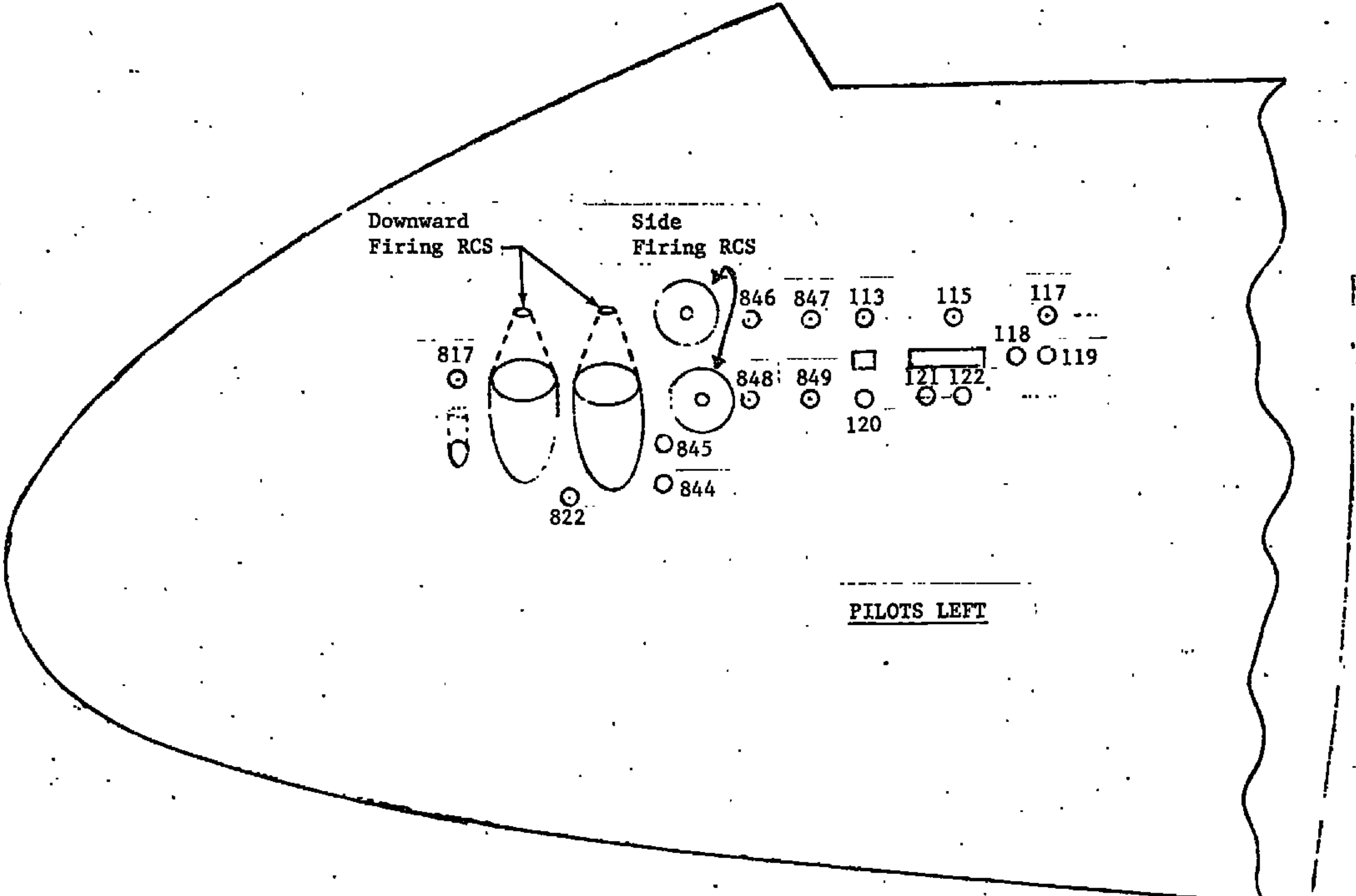
Figure 8. Continued





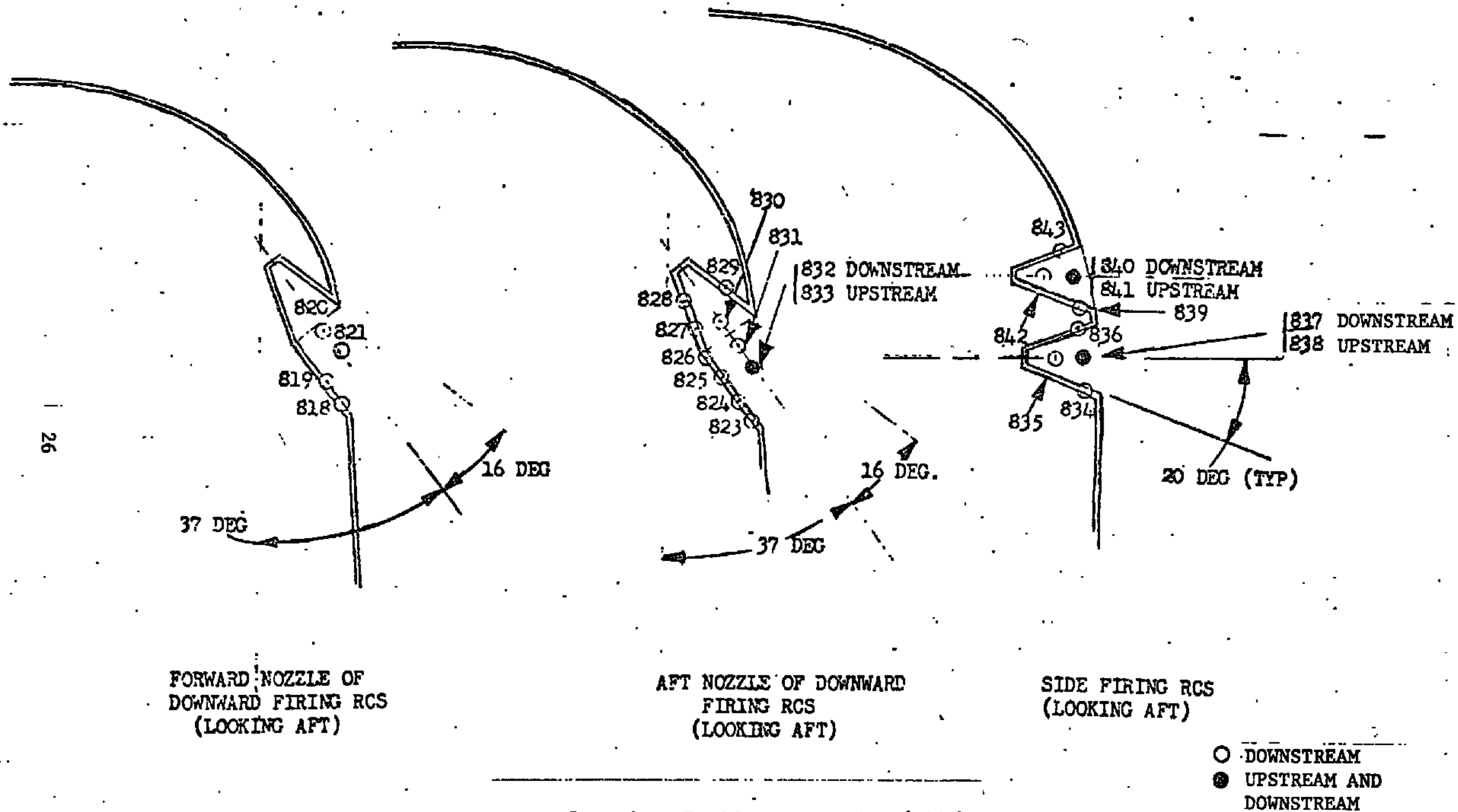
e. Locations Inside RCS Nozzles (Top)

Figure 8. Continued



f. Locations Around Side RCS Nozzles (Side)

Figure 8. Continued



g. Locations Inside RCS Nozzles (Side)

Figure 8. Concluded

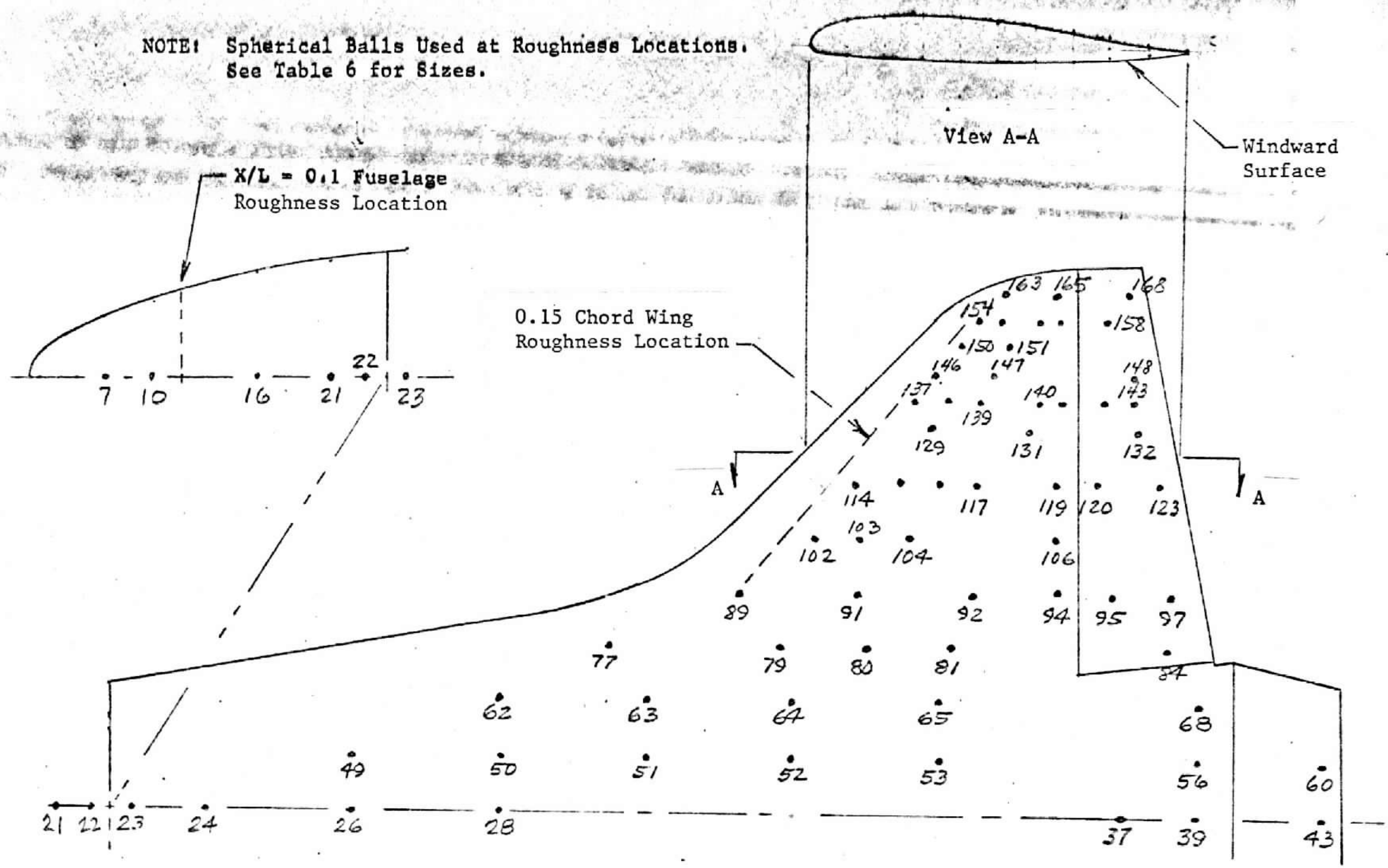


Figure 9. Thermocouple Locations on 60-ϕ Model

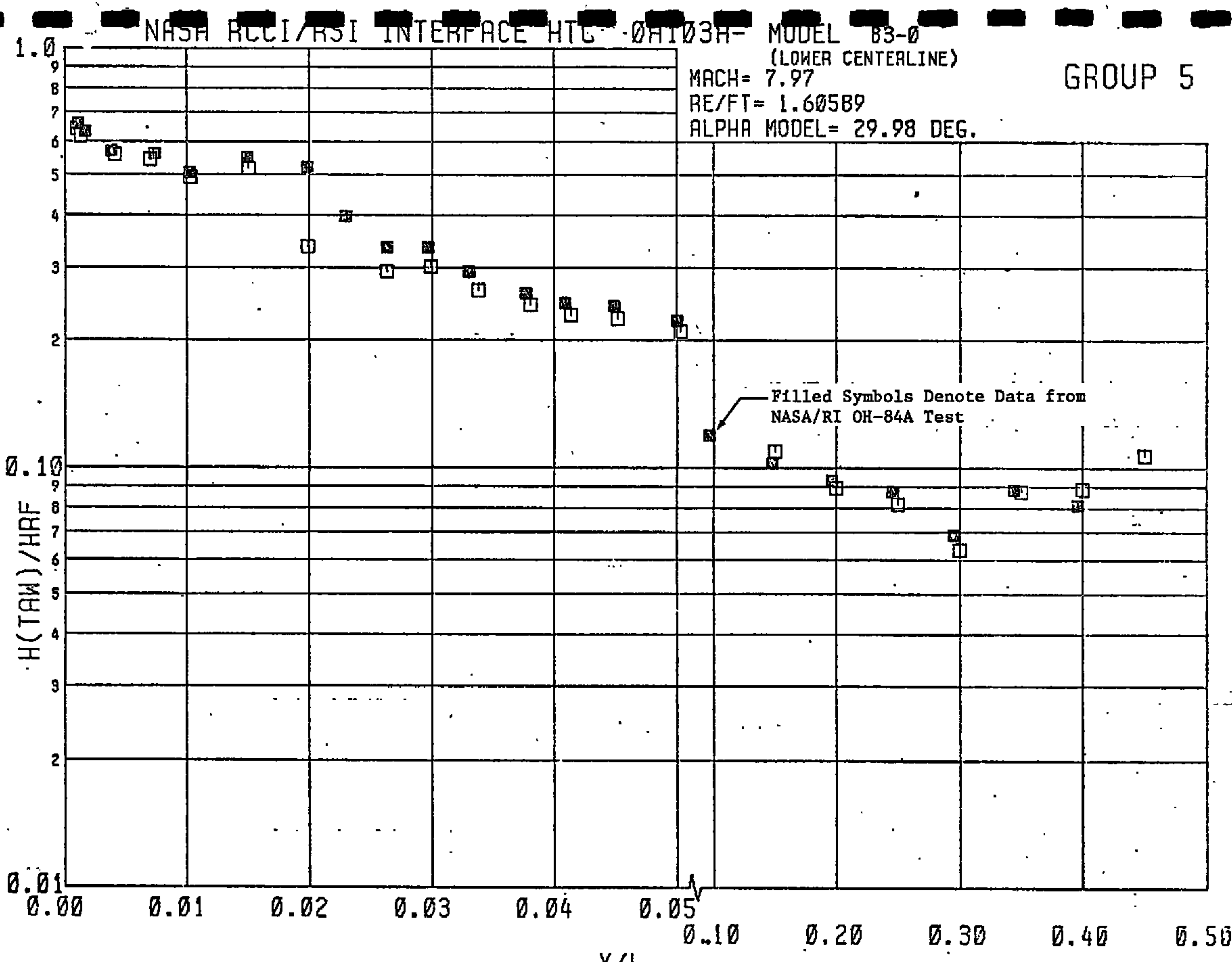


Figure 10. Comparisons of Current and Previous Data Results on the 83-ϕ Model

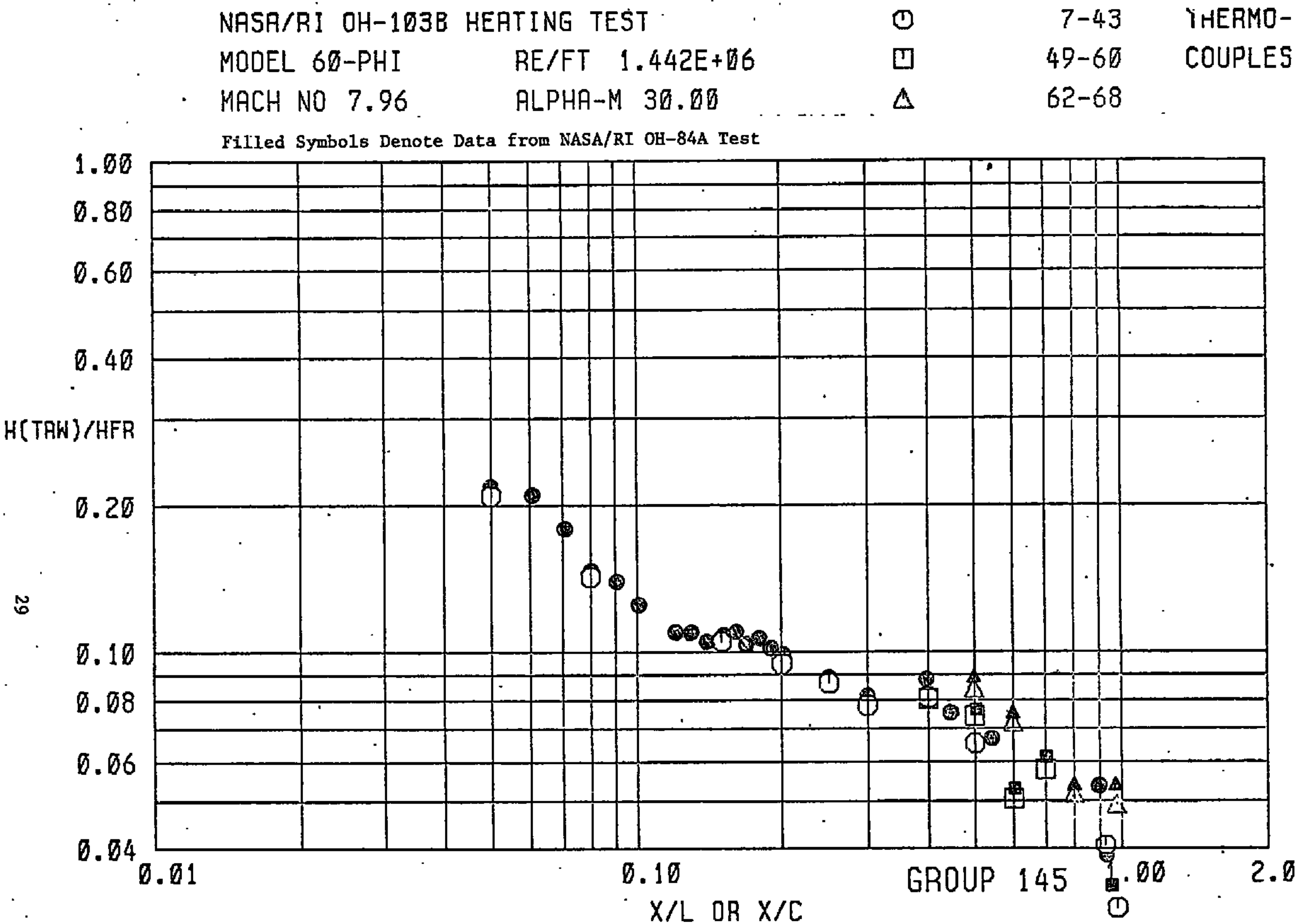


Figure 11. Comparisons of Current and Previous Data Results on the 60-Φ Model

APPENDIX II

TABLES

1. Model Dimensional Data - 83-ϕ Model
2. Model Dimensional Data - 60-ϕ Model
3. 83-ϕ Model Thermocouple Locations and Skin Thickness
4. 60-ϕ Model Thermocouple Locations and Skin Thickness
5. Test Summary and Test Logs: 83-ϕ Model
6. Test Summary and Test Logs: 60-ϕ Model
7. 60-ϕ Model Deflection Angles at Thermocouple Locations
8. Sample Tabulated Data

TABLE I

MODEL DIMENSIONAL DATA – 83-ϕ MODEL

MODEL COMPONENT : BODY - B_{60}

GENERAL DESCRIPTION : 50% orbiter forebody, vehicle 140C.

NOTE: This body includes a small portion of the wing glove.

MODEL SCALE: 0.040

DRAWING NUMBER : VL70-000140C

DIMENSIONS :

	FULL SCALE	MODEL SCALE
Length	645.15	25.80
Max Width	330.00	13.20
Max Depth		
Fineness Ratio		
Area		
Max. Cross-Sectional		
Planform		
Wetted		
Base		

TABLE I (Continued)

MODEL DIMENSIONAL DATA - 83-ϕ MODEL

MODEL COMPONENT : CANOPY - C_{10}

GENERAL DESCRIPTION : Configuration 4 canopy and windshield as used with B_{25}, six glass panes in windshield.

MODEL SCALE: 0.040

DRAWING NUMBER : VL70-000140B, 140C, 202B

DIMENSIONS :	FULL SCALE	MODEL SCALE
Length (X_o =434.643 to 670), In.	235.357	9.414
Max Width		
Max Depth (Glass, In.	28.00	1.12
Fineness Ratio		
Area		
Max. Cross-Sectional		
Planform		
Wetted		
Base		
Nose/windshield intersection, X_o =	434.643	17.386

TABLE 2

MODEL DIMENSIONAL DATA - 60-ϕ MODEL

MODEL COMPONENT : BODY - B_{62}

GENERAL DESCRIPTION : Configuration 140C orbiter fuselage. MCR 200-R4 Similar to 140A/B fuselage except aft body revised and improved midbody-wing-boot fairing, X_o = 940 to X_o = 1040

MODEL SCALE: 0.0175

DRAWING NUMBER : VL70-000140C, -000202C, -000205A
VL70-000200B, -000203

DIMENSIONS :	FULL SCALE	MODEL SCALE
Length (IML: FWD Sta X_o=238), In.	1290.3	22.58
Length (OML: Fwd Sta X_o=235), In.	1293.3	22.63
Max Width (At X_o = 1528.3), In.	264.0	4.62
Max Depth (At X_o = 1464), In.	250.0	4.38
Fineness Ratio	4.899	4.899
Area - Ft^2		
Max. Cross-Sectional	340.885	0.104
Planform		
Wetted		
Base		

TABLE 2 (Continued)

MODEL DIMENSIONAL DATA - 60-φ MODEL

MODEL COMPONENT : BODY FLAP - F_{10}

GENERAL DESCRIPTION : Configuration 140C body flap. Hingeline located at X_o = 1532, Z_o = 287.

MODEL SCALE: 0.0175

DRAWING NUMBER : VL70-000140C, -355114

DIMENSIONS :	FULL SCALE	MODEL SCALE
Length (X_o = 1525.5 to X_o = 1613), In.	87.50	1.531
Max Width (At L. E., X_o = 1525.5), In.	256.00	4.480
Max Depth (X_o = 1532), In.	19.798	0.346
Fineness Ratio		
Area - Ft^2		
Max. Cross-Sectional (At H. L.)	35.196	0.011
Planform	135.00	0.041
Wetted		
Base (X_o = 1613)	4.89	0.0015

TABLE 2 (Continued)

MODEL DIMENSIONAL DATA - 60-ϕ MODEL

MODEL COMPONENT : CANOPY - C_{12}

GENERAL DESCRIPTION : Configuration 140C orbiter canopy.
Vehicle cabin No. 31 updated to MCR 200-B4. Used with
fuselage B_{62}.

MODEL SCALE: 0.0175

DRAWING NUMBER : VL70-000140C, -000202B, -000204

DIMENSIONS :

	FULL SCALE	MODEL SCALE
Length (X_o = 434.643 to 578), In.	143.357	2.508
Max Width (At X_o = 513.127), In.	152.412	2.667
Max Depth (Z_o = 501 to 449.39), In.	51.61	0.903
Fineness Ratio		
Area		
Max. Cross-Sectional		
Planform		
Wetted		
Base		

TABLE 2 (Continued)

MODEL DIMENSIONAL DATA – 60-ϕ MODEL

MODEL COMPONENT: ELEVON E_{52}

GENERAL DESCRIPTION: Elevon for configuration 140C. Hingeline at X_o = 1387, elevon split line X_W = 312.5, 6.0", beveled edges, and centerbodies.

MODEL SCALE: 0.0175

DRAWING NUMBER: VL70-000140C, -006089, -006092

DIMENSIONS:	FULL-SCALE	MODEL SCALE
Area - Ft^2	210.0	0.064
Span (equivalent) - In.	349.2	6.111
Inb'd equivalent crord- In.	118.0	2.065
Outb'd equivalent chord	55.19	0.966
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord	0.2096	0.2096
At Outb'd equiv. chord	0.4004	0.4004
Sweep Back Angles, degrees		
Leading Edge	0.0	0.0
Tailing Edge	-10.056	-10.056
Hingeline	0.0	0.0
Area Moment (Product of area & $\overline{c}$)	1587.25	0.008
Mean Aerodynamic Chord, In.	90.7	1.587
Hingeline dihedral (origin at Z_0 = 261.3509), deg.	5.229	5.229

TABLE 2 (Continued)

MODEL DIMENSIONAL DATA - 60-ϕ MODEL

MODEL COMPONENT: OMS POD - M_{16}

GENERAL DESCRIPTION: Configuration 140C orbiter

OMS Pod - short pod.

MODEL SCALE: 0.0175

DRAWING NUMBER: VL70-008401, -008410

DIMENSIONS:	FULL SCALE	MODEL SCALE
Length (OMS Fwd Sta X_o = 1310.5), In.	258.50	4.524
Max Width (At X_o = 1511), In.	136.8	2.394
Max Depth (At X_o = 1511), In.	74.70	1.307
Fineness Ratio	2.484	2.484
Area = Ft^2		
Max. Cross-Sectional	58.864	0.018
Planform		
Wetted		
Base		

TABLE 2 (Continued)

MODEL DIMENSIONAL DATA - 60-ϕ MODEL

MODEL COMPONENT: RUDDER - R_{18}

GENERAL DESCRIPTION: The rudder is a secondary movable airfoil at the trailing edge of the vertical fin that imparts yaw forces. This dimensional data was calculated from the OML master dimensions.

MODEL SCALE: 0.0175

DRAWING NUMBER: Vehicle 5 Configuration MCR 200, Rev. 7

DIMENSIONS:	FULL-SCALE	MODEL SCALE
Area - Ft^2	97.84	0.030
Span (equivalent) - In.	198.614	3.476
Inb'd equivalent chord - In.	91.07	1.594
Outb'd equivalent chord - In.	50.80	0.889
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord	0.400	0.400
At Outb'd equiv. chord	0.400	0.400
Sweep Back Angles, degrees		
Leading Edge	34.833	34.833
Tailing Edge	26.249	26.249
Hingeline	34.833	34.833
Area Moment (Product of Area & $\bar{c}$), Ft^3	593.889	.0032
Mean Aerodynamic Chord, In.	72.840	1.275

TABLE 2 (Continued)

MODEL DIMENSIONAL DATA- 60-φ MODEL

MODEL COMPONENT: VERTICAL - V_8

GENERAL DESCRIPTION: Configuration 140C orbiter vertical tail (identical to configuration 140A/B vertical tail).

MODEL SCALE: 0.0175

DRAWING NUMBER: VL70-000140C, -000146B

DIMENSIONS:	FULL SCALE	MODEL SCALE
TOTAL DATA		
Area (Theo) - Ft^2		
Planform	413.253	0.127
Span (Theo) - In.	315.72	5.350
Aspect Ratio	1.675	1.675
Rate of Taper	0.507	0.507
Taper Ratio	0.404	0.404
Sweep-Back Angles, Degrees.		
Leading Edge	45.000	45.000
Trailing Edge	26.25	26.25
0.25 Element Line	41.13	41.13
Chords:		
Root (Theo) WP	268.50	4.699
Tip (Theo) WP	108.47	1.898
MAC	199.81	3.497
Fus. Sta. of .24 MAC	1463.35	25.609
W.P. of .25 MAC	635.52	11.122
B.L. of .25 MAC	0.0	0.0
Airfoil Section		
Leading Wedge Angle - Deg.	10.00	10.00
Trailing Wedge Angle - Deg.	14.92	14.92
Leading Edge Radius	2.00	2.00
Void Area	13.17	0.0040
Blanketed Area	0.0	0.0

TABLE 2 (Continued)

MODEL DIMENSIONAL DATA - 60-ϕ MODEL

MODEL COMPONENT: WING-W_{116}

GENERAL DESCRIPTION: Configuration 5

NOTE: Identical to W_{114} except airfoil thickness. Dihedral angle is along trailing edge of wing. Geometric twist = 0.

MODEL SCALE: 0.0175

TEST NO. - DRAWING NO.: VL70-000140A, -000200

DIMENSIONS:

	FULL-SCALE	MODEL SCALE
TOTAL DATA		
Area (Theo.) Ft^2		
Planform	2690.0	0.824
Span (Theo In.	936.68	16.392
Aspect Ratio	2.265	2.265
Rate of Taper	1.177	1.177
Taper Ratio	0.200	0.200
Dihedral Angle, degrees	3.500	3.500
Incidence Angle, degrees	0.500	0.500
Aerodynamic Twist, degrees		
Sweep Back Angles, degrees		
Leading Edge	45.000	45.000
Trailing Edge	-10.056	-10.056
0.25 Element Line	35.209	35.209
Chords:		
Root (Theo) B.P.0.0.	689.24	12.062
Tip, (Theo) B.P.	137.85	2.412
MAC	474.81	8.309
Fus. Sta. of .25 MAC	1136.83	19.895
W.P. of .25 MAC	290.58	5.085
B.L. of .25 MAC	182.13	3.187
EXPOSED DATA		
Area (Theo) Ft^2	1751.50	0.536
Span, (Theo) In. BP108	720.68	12.612
Aspect Ratio	2.059	2.059
Taper Ratio	0.245	0.245
Chords		
Root BP108	562.09	9.837
Tip 1.00 $\frac{b}{2}$	137.85	2.412
MAC	392.83	6.875
Fus. Sta. of .25 MAC	1185.98	20.755
W.P. of .25 MAC	294.30	5.150
B.L. of .25 MAC	251.77	4.406
Airfoil Section (Rockwell Mod NASA) XXXX-64		
Root $\frac{b}{2}$ =	0.113	0.113
Tip $\frac{b}{2}$ =	0.120	0.120
Data for (1) of (2) Sides		
Leading Edge Cuff		
Planform Area, Ft^2	113.18	0.035
Leading Edge Intersects Fus M.L. @ Sta	500.00	8.750
Leading Edge Intersects Wing @ Sta	1024.00	17.920

TABLE 3. 83-φ MODEL THERMOCOUPLE LOCATIONS AND SKIN THICKNESS

T/C NO.	LOCATION		X_o (INCHES)	X/L		φ, (DEGREES)	SKIN THICKNESS (INCHES)	
273	BOTTOM CENTERLINE		236.25	0.0010			0.0269	
274			237.37	0.0018			0.0272	
275			240.25	0.0041			0.0277	
276			244.00	0.0070			0.0280	
277			248.28	0.0103			0.0279	
278			254.48	0.0151			0.0283	
279			260.75	0.0199			0.0232	
280			265.00	0.0232			0.0210	
281			269.00	0.0263			0.0190	
282			273.63	0.0299			0.0230	
283			278.75	0.0338			0.0231	
284			284.25	0.0381			0.0230	
285			288.50	0.0414			0.0230	
286			293.5	0.0452			0.0240	
287			300.00	0.0503			0.0230	
288			364.330	0.100			0.0280	
289			428.995	0.150			0.0300	
290			493.660	0.200			0.0260	
291			558.325	0.250			0.0273	
292			622.990	0.300			0.0275	
293			687.655	0.350			0.0261	
294			752.320	0.400			0.0276	
295			816.985	0.450			0.0292	

Model Mat'l: 17-4

TABLE 3: Continued

T/C NO.	LOCATION	NOT USED	X_o (INCHES)	X/L		φ, (DEGREES)	SKIN THICKNESS (INCHES)	
	LOWER RCS NOZZLES							
131	↓	390.0	345.8	0.0857			0.0331	↓
132		390.0	359.5	0.0963			0.0261	
133		383.8	345.8	0.0857			0.0272	
134		377.3	347.8	0.0872			0.0300	
135		374.55	351.8	0.0903			0.0269	NOT USED
136		374.55	359.2	0.0960			0.0249	
137		370.55	347.8	0.0872			0.0293	
138		370.55	355.1	0.0928			0.0258	
139		366.05	340.5	0.0816			0.0286	
140		362.4	355.1	0.0934			0.0285	
141		362.4	360.8	0.0973			0.0296	
142		355.2	342.8	0.0833			0.0244	
143		355.2	353.8	0.0919			0.0225	
144	↓	349.0	357.7	0.0949			0.0295	↓
	PILOT LEFT NOSE T/C's							
145	(EVERY 0.2")	338.0	236.0	0.0008			0.0300	
146	↓	↓	238.0	0.0023			0.0306	
147			240.5	0.0043			0.0300	
148			243.75	0.0068			0.0310	
149			247.25	0.0095			0.0322	
150			250.75	0.0122			0.0319	
151			263.25	0.0218			0.0313	
152			267.5	0.0251			0.0302	
153			272.0	0.0286			0.0272	
154			276.25	0.0319			0.0277	
155			280.75	0.0354			0.0280	
156	↓	↓	285.0	0.0387			0.0277	

TABLE 3: Continued

T/C NO.	LOCATION	NOT USED	X_o (INCHES)	X/L		ϕ, (DEGREES)	SKIN THICKNESS (INCHES)	
	NOSE T/C'S							
160	(EVERY 0.2")	---	300.23	0.0506			0.0235	
157	↓	338.0	289.25	0.0420			0.0274	
158		338.0	294.75	0.0462			0.0274	
159		338.0	300.0	0.0503			0.0250	
	UPPER RCS NOZZLES							
161	↓	-7.5	315.0	0.0619			0.0265	
162		-7.5	326.7	0.0709			0.0212	
163		-7.5	339.3	0.0807			0.0275	
164		-7.5	357.0	0.0943			0.0292	
165		-7.5	361.5	0.0978			0.0282	
166		-7.5	366.0	0.1013			0.0287	
167		-15.0	315.0	0.0619			0.0303	
168		-15.0	326.7	0.0709			0.0235	
169		-15.0	339.3	0.0807			0.0272	
170		-15.0	357.0	0.0943			0.0280	
171		-15.0	361.5	0.0978			0.0270	
172		-15.0	366.0	0.1013			0.0292	
173		-22.5	339.3	0.0807			0.0299	
174		-22.5	357.0	0.0943			0.0255	
175		-22.5	361.5	0.0978			0.0321	
176		-22.5	366.0	0.1013			0.0305	

TABLE 3: Continued

T/C NO.	LOCATION		X_o (INCHES)	X/L		ϕ (DEGREES)	SKIN THICKNESS (INCHES)	
296	MHB LINE		267.333	0.025			0.0292	
297			299.665	0.050			0.0268	
298			331.998	0.075			0.0270	
299			364.330	0.100			0.0278	
300			396.663	0.125			0.0252	
301			428.995	0.150			0.0280	
302			461.327	0.175			0.0306	
303			493.660	0.200			0.0280	
304			525.993	0.225			0.0205	
305			558.325	0.250			0.0283	
306			590.658	0.275			0.0340	
307			655.323	0.325			0.0245	
308			719.988	0.375			0.0290	
309			784.318	0.425			0.0298	
311			493.66	0.200			0.0230	
312			525.993	0.225			0.0250	
313			558.325	0.250			0.0296	
314			590.658	0.275			0.0279	
315			622.990	0.300			0.0308	
316			655.323	0.325			0.0279	
317			687.655	0.350			0.0311	
318			719.988	0.375			0.0302	
319			752.320	0.400			0.0278	
321			816.985	0.450			0.0276	

TABLE 3: Continued

T/C NO.	LOCATION		X_o (INCHES)	X/L		φ (DEGREES)	SKIN THICKNESS (INCHES)	
322	MHB LINE		849.318	0.475			0.0260	
323			493.660	0.200			0.0259	
324			525.993	0.225			0.0268	
325			558.325	0.250			0.0279	
326			590.658	0.275			0.0261	
327			622.990	0.300			0.0286	
328			655.323	0.325			0.0249	
329			687.655	0.350			0.0306	
330			719.988	0.375			0.0282	
331			752.320	0.400			0.0269	
332			784.653	0.425			0.0276	
333			816.985	0.450			0.0273	
334			525.993	0.225			0.0255	
335			558.325	0.250			0.0289	
336			590.658	0.275			0.0262	
337			622.990	0.300			0.0308	
338			655.323	0.325			0.0269	
339			687.655	0.350			0.0302	
341			752.320	0.400			0.0279	
342			784.653	0.425			0.0270	
343			816.985	0.450			0.0276	
344			655.335	0.325			0.031	
345			687.655	0.350			0.030	
346			719.988	0.375			0.030	
347			752.320	0.400			0.030	
348			784.653	0.425			0.032	
349			816.985	0.450			0.031	
350			850.600	0.476			0.033	

TABLE 3: Continued

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North American Rockwell

T/C NO.	LOCATION		X_o (INCHES)	X/L		ϕ (DEGREES)	SKIN THICKNESS (INCHES)	
351	CCL LINE		299.665	0.050			0.0271	
352			331.998	0.075			0.0269	
354			396.663	0.125			0.0268	
355			428.995	0.150			0.0273	
356			461.328	0.175			0.0311	
357			493.660	0.200			0.0262	
358			590.658	0.275			0.032	
359			622.990	0.300			0.0292	
360			655.323	0.325			0.030	
361			687.655	0.350			0.0305	
362			719.988	0.375			0.030	
363			752.320	0.400			0.032	
364			784.653	0.425			0.032	
365			816.985	0.450			0.032	
366			850.600	0.476			0.0315	

TABLE 3: Continued

T/C NO.	LOCATION		X_o (INCHES)	X/L		ϕ (DEGREES)	SKIN THICKNESS (INCHES)	
	CARGO BAY HINGES - HINGE NO. 2							
250	↓	664.8	405.0	0.3323			0.0281	NOT USED
251	↓	669.8	405.0	0.3362			0.0275	↓
	HINGE NO. 3							↓
252	↓	742.3	420.0	0.3923			0.0325	↓
253	↓	747.3	420.0	0.3961			0.0325	↓
254	↓	737.3	415.0	0.3884			0.034	↓
257	↓	732.3	405.0	0.3845			0.0302	↓
258	↓	737.3	405.0	0.3884			0.0305	↓
	TOP CENTERLINE							
357	↓		235.000	0.000			0.0263	
368	↓		236.000	0.0008			0.0284	
369	↓		237.500	0.0019			0.0262	
370	↓		239.750	0.0037			0.0273	
371	↓		242.500	0.0058			0.0219	
372	↓		246.250	0.0087			0.0268	
373	↓		250.250	0.0118			0.0293	
374	↓		254.50	0.0151			0.0293	
375	↓		258.50	0.0182			0.0306	
376	↓		262.75	0.0215			0.0215	
377	↓		266.75	0.0246			0.0261	
378	↓		271.00	0.0278			0.0261	
379	↓		313.75	0.0609			0.0275	
380	↓		318.50	0.0646			0.023	
381	↓		323.50	0.0684			0.029	
382	↓		328.25	0.0721			0.0293	
383	↓		333.25	0.0760			0.030	
384	↓		338.00	0.0796			0.0312	

T/C NO.	LOCATION		X_o (INCHES)	X/L		ϕ (DEGREES)	SKIN THICKNESS (INCHES)	
	TOP CENTERLINE							
385	↓		357.00	0.0789			0.0288	
386			357.00	0.0789			0.0265	
387			366.75	0.1019			0.0275	
388			385.00	0.1160			0.0213	
389			389.50	0.1195			0.0325	
390			394.25	0.1231			0.0353	
391			399.00	0.1268			0.0357	
392			403.75	0.1305			0.0384	
393			408.00	0.1338			0.0379	
394			413.00	0.1376			0.0376	
395			417.50	0.1411			0.0335	
396			422.25	0.1448			0.0332	
397			426.75	0.1483			0.0332	
398			431.50	0.1519			0.0315	
399			436.25	0.1556			0.0299	
400			439.63	0.1582			0.0302	
401			443.00	0.1608			0.0290	
402			446.50	0.1635			0.0279	
403			450.25	0.1664			0.0272	
404			453.75	0.1691			0.0271	NOT USED
405			457.50	0.1720			0.0271	↓
406			461.00	0.1748			0.0271	
407			463.75	0.1769			0.0289	
408			466.75	0.1800			0.0328	
409			471.75	0.1831			0.0322	
410			476.00	0.1863			0.0322	
411			480.00	0.1894			0.0336	
412	↓		474.75	0.1931			0.0304	↓

Space Division
North American Rockwell

TABLE 3: Continued

T/C NO.	LOCATION		X_o (INCHES)	X/L		φ, (DEGREES)	SKIN THICKNESS (INCHES)	
413	TOP CENTERLINE		490.00	0.1972			0.0300	
414			500.00	0.2049			0.0300	
415			525.993	0.2250			0.0221	
416			558.325	0.250			0.0262	NOT
417			590.658	.275			0.0330	USED
418			622.990	.300			0.0350	
419			655.323	.325			0.0330	
420			687.655	.350			0.0322	
421			719.988	.375			0.0329	
422			752.320	.400			0.0328	
423			784.652	.425			0.0316	
424			816.985	.450			0.0335	
425			849.318	.475			0.034	
426	PILOT RIGHT (Cross Section)		270	.027		350	0.0206	
427						343	0.0219	
428						335	0.0239	
429						324	0.0259	
430						320	0.0279	
431						310	0.0285	
432						303	0.0288	
433						295	0.0288	
434						287.5	0.0292	
435						280	0.0293	
436						273	0.0295	
437			300	.050		352.5	0.025	
438						347	0.0258	
439						339	0.0249	
440						334	0.024	

TABLE 3: Continued

T/C NO.	LOCATION		X_o (INCHES)	X/L		ϕ, (DEGREES)	SKIN THICKNESS (INCHES)	
441	PILOT RIGHT (Cross		300	.050		327.5	0.024	
442	Section)					321.5	0.028	
443						318	0.0283	
444						311	0.0270	
445						306	0.026	
446						300	0.0245	
447						295	0.0225	
448						289	0.0278	
449						284	0.0258	
450						274	0.0190	
451			500	.2049		355	0.025	
452						351	0.023	
453						346	0.023	
454						342	0.023	
455						338	0.023	
456						333	0.023	
457						330	0.023	
458						326	0.024	
459						322	0.026	
460						320	0.026	
461						317	0.027	
462						313.5	0.027	
463						310.5	0.026	
464						307	0.025	
465						305	0.0263	
466						303	0.027	
467						300.5	0.0265	
468						298	0.025	

TABLE 3: Continued

Space Division
North American Rockwell

T/C NO.	LOCATION		X_o (INCHES)	X/L		ϕ, (DEGREES)	SKIN THICKNESS (INCHES)	
469	PILOT RIGHT (Cross Section)		500	.2049		295	0.028	
470						292	0.023	
471						290	0.023	
472						287	0.021	
473						284	0.0275	
474						278	0.023	
475						275.5	0.023	
476						273	0.024	
477						270	0.0253	
501			260.75	.0200		348.5	0.022	
502						338.2	0.021	
503						328.7	0.025	
504						320.5	0.028	
505						312.3	0.027	
506						303.5	0.025	
507						296.5	0.021	
508						287	0.019	
509						278.6	0.023	
510						270.0	0.023	
511						262	0.026	

TABLE 3: Continued

RCS NOZZLES

(SIDE AND DOWNWARD FIRING - FIGURE 2(b))

T/C NO.	L/LN	θ, DEG	SKIN THICKNESS in.	REMARKS
DOWNWARD FIRING NOZZLES (FUSELAGE SIDE - FORWARD NOZZLE)				
817	--	--	0.0260	0.2 IN. FWD OF 0 DEG. REF ON NOZZLE
818	3.12	270	0.0300	
819	2.56	270	0.0360	
820	1.56	180	0.0300	
821	2.13	180	0.0300	
DOWNWARD FIRING NOZZLES (FUSELAGE SIDE - AFT NOZZLE)				
822	--	--	0.0270	BETWEEN DOWN FIRING NOZZLE
823	3.32	270	0.0400	
824	2.76	↑	0.0410	
825	2.19		0.0380	
826	1.62		0.0370	
827	1.05	↓	0.0240	
828	0.48	270	0.0230	
829	0.85	90	0.0230	
830	1.28	180	0.0230	
831	1.99	180	0.0300	
832	2.42	180	0.0300	
833	2.42	0	0.0310	
SIDE FIRING NOZZLES (FUSELAGE SIDE - LOWER NOZZLE)				
834	1.19	270	0.0280	
835	0.57	0	0.0280	
836	1.14	90	0.0285	
837	1.19	180	0.0280	
838	1.19	180	0.0280	
SIDE FIRING NOZZLES (FUSELAGE SIDE - UPPER NOZZLE)				
839	1.25	270	0.0295	
840	1.14	180	0.0300	
841	1.14	0	↑	
842	0.57	180		
843	0.94	90	↓	
844	--	--	0.0300	
845	--	--	0.0320	

L_N = LENGTH FROM NOZZLE THROAT

TABLE 3: Concluded

RCS NOZZLES

FORWARD AND UPWARD FIRING - FIGURE 2(b)

T/C NO.	$\frac{L}{LN}$	θ, DEG	SKIN THICKNESS, in.	REMARKS
CENTER FORWARD FIRING NOZZLE				
854	4.83	270	0.0310	
853	4.40	↕	0.0260	
852	4.00		0.0270	
851	3.55		0.0280	
850	3.13		0.0280	
871	1.99		0.0303	
870	0.48		0.0351	
869	0.00	270	0.0323	(CENTER)
868	0.51	90	0.0304	
867	1.14	90	0.0306	
855	2.13	0	0.0305	
856	1.70	0	0.0306	
LEFT FORWARD FIRING NOZZLE				
857	4.69	270	0.0305	
858	2.41	270	0.0331	
859	2.70	0	0.0295	
860	2.13	0	0.0291	
861	0.0	0	0.0343	(CENTER)
862	0.85	90	0.0125	
LEFT UPWARD FIRING NOZZLE				
863	0.20	0	0.0354	
864	0.26	90	0.0332	
865	0.48	180	0.0365	
866	0.00	0	0.0294	(CENTER)
CENTER UPWARD FIRING NOZZLE				
872	0.07	0	0.0384	
873	0.09	90	0.0403	
874	0.17	180	0.0532	
875	0.00	0	0.0305	(CENTER)

TABLE 4

60-ϕ MODEL THERMOCOUPLE LOCATIONS AND SKIN THICKNESS

T/C No.	X/L	Full Scale X_o	Full Scale Y	Full Scale Z_o*	Model Scale $X_{from\ nose}$	Model Scale Y	Model Scale $Z^*_{from\ FRP}$	ϕ_D	Skin Thickness, in.	Mat'l	Remarks
1	0	235.0	0	–	0	0	0	180	.040	17-4	Bottom C_L
2	.005	241.47			.113				.032		
3	.01	247.93			.226				.033		
4	.02	260.87			.453				.040		
5	.03	273.80			.679				.040		
6	.04	286.73			.905				.040		
7	.05	299.67			1.132				.033		
8	.06	312.60			1.358				.035		
9	.07	325.53			1.584				.032		
10	.08	338.46			1.811				.032		
11	.09	351.40			2.037				.035		
12	.10	364.33			2.263				.037		
13	.12	390.20			2.716				.040		
14	.13	403.13			2.942				.038		
15	.14	416.06			3.169				.035		
16	.15	429.00			3.395				.036		
17	.16	441.93			3.621				.036		
18	.17	454.86			3.848				.035		
19	.18	467.79			4.074				.035		
20	.19	480.73			4.300				.035		
21	.20	493.66			4.527				.035		
22	.225	525.99			5.092				.035		
23	.25	558.33			5.658				.035		
24	.30	622.99			6.790				.035		
25	.35	687.66			7.922				.035		
26	.40	752.32			9.053				.034		
27	.45	816.99			10.186				.033		
28	.50	881.65			11.316				.032		
29	.55	946.32			12.448				.030		
30	.60	1010.9			13.580				.030		
31	.65	1075.6			14.711				.030		
32	.70	1140.3			15.843				.029		
33	.75	1204.9			16.975				.030		
34	.80	1269.6			18.106				.030		

*Not Used

TABLE 4 Continued

T/C No.	X/L	Full Scale X_o	Full Scale Y	Full Scale Z_o*	Model Scale $X_{from\ nose}$	Model Scale Y	Model Scale $Z^*_{from\ FRP}$	ϕ_D	Skin Thickness, in.	Mat.1	Remarks
35	.85	1324.3	0	–	19.068	0	0	180	.029	17-4	Bottom ℄
36	.90	1398.9			20.369				.031		
37	.925	1431.3			20.935				.027		
38	.950	1463.6			21.501				.027		
39	.975	1493.9			22.067				.023		
40	1.015	1547.7			22.972				.030		
41	1.03	1567.1			23.312				.030		
42	1.045	1586.5			23.651				.028		
43	1.06	1605.0			23.977				.0265		
44	.05	299.67	25.0		1.132	.438		194	.032		Fuselage Bottom Surface
45	.10	364.33	20.0		2.263	.350		190	.036		
46	.15	429.0	24.0		3.395	.420		190	.035		
47	.20	493.66	25.0		4.527	.438		191.5	.034		
48	.20	493.66	50.0		4.527	.875		204	.025		
49	.40	752.32	46.8		9.053	.819		–	.028		
50	.50	881.65			11.316				.028		
51	.60	1010.9			13.580				.025		
52	.70	1140.3			15.843				.030		
53	.80	1269.6			18.106				.030		
54	.90	1398.6			20.369				.030		
55	.95	1463.6			21.501				.028		
56	.975	1495.9			22.067				.025		
57	1.015	1547.7			22.972				.028		
58	1.03	1567.1			23.312				.030		
59	1.045	1586.5			23.651				.030		
60	1.060	1605.0			23.977				.030		
61	.40	752.32	93.60		9.053	1.638			.031		
62	.50	881.63			11.316				.032		
63	.60	1010.0			13.580				.031		
64	.70	1140.3			15.848				.033		
65	.80	1269.6			19.106				.029		
66	.90	1308.6			20.369				.031		
67	.95	1463.6			11.501				.030		
68	.975	1495.9			12.067				.029		
									.028		

*Not Used

TABLE 4 Continued

T/C No.	Y/S	Full Scale X/C	Full Scale X_o	Full Scale Y	Model Scale X_{from} L.E.	Model Scale Y		Elevon T/C	Skin Thickness	Mat'l	Remarks
73	.30	0		140.5	0	2.459			.020	17-4	Wing Lower Sur.
74		.05			.670				.020		
75		.10			1.340				.026		
76		.20			2.680				.031		
77		.30			4.020				.030		C = 13.4 in.
78		.40			5.360				.031		
79		.50			6.700				.030		
80		.60			8.040				.030		
81		.70			9.380				.031		
82		.80			10.720				.030		
83		.90			12.060			X	.0305		
84		.95			12.730			X	.031		
85	.35	0		163.9	0	2.869			.026		
86	.40	0		187.3	0	3.287			.022		
87		.05			.438				.031		
~~88~~		.10			.876				.031		Open
89		.20			1.753				.030		C = 8.764 in.
90		.30			2.629				.031		
91		.40			3.506				.029		
92		.60			5.258				.033		
93		.70			6.135				.033		
94		.75			6.573				.030		
95		.85			7.449				.0295		
96		.90			7.888			X	.026		
97		.95			8.326			X	.0275		
~~98~~	.45	0		210.7	8.688			X	.030		Open
99	.50	0		234.1	0	4.098			.027		
100		.05			.364				.029		
101		.10			.727				.030		
102		.20			1.454				.031		C = 7.27 in.
103		.30			2.181				.031		
104		.40			2.908				.031		
105		.60			4.362				.032		
106		.70			5.089				.031		

TABLE 4 Continued

T/C No.	Y/S	Full Scale X/C	Full Scale X_o	Full Scale Y	Model Scale X_{from} L.E.	Model Scale Y		Elevon T/C	Skin Thickness	Mat'l	Remarks
107	.50	.90		234.1	6.543	4.098		X	.0285	17-4	Wing Lower Sur.
108	.55	0		257.6	0	4.508			.026		
109	.60	0		281.0	0	4.918			.024		
110		.025			.157				.029		
111		.05			.314				.028		
112		.075			.470				.030		
113		.10			.627				.031		
114		.20			1.254				.031		C = 6.27 in.
115		.30			1.882				.033		
116		.40			2.059				.032		
117		.50			3.136				.032		
118		.60			3.763				.032		
119		.70			4.390				.031		
120		.80			5.018			X	.030		
121		.85			5.331			X	.0305		
122		.90			5.695			X	.0295		
123		.95			5.958			X	.0295		
124	.65	0		309.4	0	5.327			.026		
125	.70	0		327.8	0	5.737			.017		
126		.025			.133				.024		
127		.10			.531				.032		
128		.20			1.061				.036		
129		.30			1.592				.036		C = 5.31 in.
130		.40			2.123				.035		
131		.60			3.84				.035		
132		.90			4.776			X	.031		
133	.75	0		352.8	0	6.174			.028		
134		.025			.121				.028		
135		.05			.241				.030		
136		.10			.483				.032		
137		.20			.965				.032		C = 4.825 in.
138		.30			1.448				.035		
139		.40			1.930				.034		
140		.60			2.895				.033		

TABLE 4 Concluded

T/C No.	Y/S	Full Scale X/C	X_o	Y	Model Scale X_{from} L.E.	Y		Elevon T/C	Skin Thickness	Mat'l	Remarks
141	.75	.70		352.8	3.378	6.174			.031	17-4	Wing Lower Surf.
142		.80			3.860			X	.027		C = 4.825 in.
143		.90			4.343			X	.0305		
144		.95			4.584			X	.0295		
145	.80	0		374.6	0	6.557			.024		
146		.20			.868				.032		C = 4.343 in.
147		.40			1.737				.031		
148		.90			3.908			X	.0305		
149	.85	0		398.1	0	6.967			.028		
150		.20			.772				.031		C = 3.860 in.
151		.40			1.544				.030		
152	.90	0		421.4	0	7.376			.028		
153		.10			.338				.030		
154		.20			.675				.031		C = 3.377 in.
155		.30			1.013				.031		
156		.50			1.689				.031		
157		.60			2.026				.032		
158		.80			2.702			X	.0285		
159		.90			3.039			X	.028		
160	.95	0		444.9	0	7.786			.030		
161		.05			.138				.031		
162		.10			.276				.030		
163		.20			.552				.032		C = 2.758 in.
164		.30			.827				.031		
165		.50			1.379				.030		
166		.70			1.931			X	.0295		
167		.80			2.206			X	.030		
168		.90			2.482			X	.0295		
243	.250	.085		117.0	1.357	2.049			.030		Wing Upper Surf.
244		.135			2.156				.050		
245		.225			3.593				.080		
246	.400	.05		187.3	.483	3.278			.024		
247		.20			1.753				.028		
248		.40			3.506				.024		

TABLE 5
TEST SUMMARY

Model Configuration: 83-ϕ

α, DEG	SWITCH POSITION	GROUP NUMBER		
		RE/FT = 0.5×10^6	RE/FT = 0.875×10^6	RE/FT = 1.6×10^6
25	1	20	46	1, 4
	2	21	47	2
	3	22, 45	48	3
30	1	23	49	5
	2	24	50	6
	3	25, 44	51	7
35	1	26, 38	52, 65	8
	2	27, 39	53	9
	3	28, 40	54	10
37.5	1	29, 41	56	11
	2	30, 42	57	12
	3	31, 43	58	13
40	1	32	59	14
	2	33	60	15
	3	34	61	16
42.5	1	68	66	17, 74
	2	69	–	18
	3	70	67	19

NOTES: Groups 35, 36, 37, 62, 63, and 64 omitted because of unsteady tunnel flow.
Group 55 omitted because of aborted lift-off sequence.
Three different hookups (switch positions) were required to sample all the 255 TC's.

TABLE 6
TEST SUMMARY

Model Configuration: 60-ϕ

		Roughness Configuration						
RE/FT x 10^{-6}	α, deg	0000	0010	0015	2000	2015	3000	3015
0.5	30 35 40			113 114				118 119 120
1.5	30 35 40	145 146 147	143 144	108 109 110	140 141 142	124 125 126	149 150 151	121 122 123
2.5	30 35 40			105 106 107	137 138 139	128 129 130	152 153 154	115 116 117
3.7	30 35 40			101,104 102 103	134 135 136	131 132 133	155 156 157	

NOTES:

1. Groups 111, 112 omitted because of unsteady tunnel flow.
2. Groups 127, 148 are calibration data.
3. Roughness configuration code: XX YY

   XX denotes fuselage roughness size in thousandths of an inch located at X/L = 0.1

   YY denotes wing roughness size in thousandths of an inch located at X/C = 0.15

TABLE 7

60-ϕ MODEL DEFLECTION ANGLES AT THERMOCOUPLE LOCATIONS

T/C NO	ε°	T/C NO	ε°	T/C NO	ε°	T/C NO	ε°
1	90	21	2.0	41	-4.5	70	-4.5
2	50	22	1.4	42	-4.5	71	-4.5
3	35.5	23	1.0	43	-4.5	72	-4.5
4	23.0	24		49	1.0		
5	17.7	25		50		73	90.0
6	14.4	26		51		74	8.0
7	12.0	27		52		75	6.75
8	10.3	28		53		76	4.6
9	8.6	29		54		77	3.25
10	7.3	30		55		78	2.75
11	6.4	31				79	1.0
12	5.5	32		61	1.0	80	-1.1
13	4.3	33		62		81	0.75
14	3.9	34	1.0	63		82	-0.5
15	3.6	35	-1.5	64		83	-5.2
16	3.4	36	-2.0	65		84	-8.0
17	3.1	37	-2.6	66	-2.0		
18	2.8	38	-3.2	67	-3.2	85	90.0
19	2.6	39	-3.8	68	-3.8		
20	2.3	40	-4.5	69	-4.5		

TABLE 7 CONCLUDED

T/C No	ϵ°	T/C No	ϵ°	T/C No	ϵ°	T/C No	ϵ°
86	90.0	106	0.6	127	4.5	148	-7.25
87	12.5	108	90.0	128	2.25	149	90.0
88	6.9	109	90.0	129	1.2	150	2.5
89	2.5	110	16.75	130	1.2	151	2.0
90	1.1	111	10.5	131	1.0	152	90.0
91	1.0	112	6.25	132	-7.5	153	3.75
92	1.6	113	4.0	133	90.0	154	3.0
93	1.1	114	1.5	134	18.0	155	2.25
94	0.2	115	1.5	135	9.0	157	1.75
95	-3.5	116	1.75	136	4.5	158	-3.0
96	-7.5	117	1.1	137	2.1	159	-7.75
97	-9.25	118	1.0	138	1.6	160	90.0
98	90.0	119	-0.5	139	1.5	161	8.5
99	90.0	120	-3.5	141	1.0	162	5.0
100	11.2	121	-4.6	142	-3.4	163	2.5
101	5.0	122	-8.0	143	-7.4	164	2.0
102	2.0	123	-9.25	144	-8.9	165	1.5
103	1.5	124	90.0	145	90.0	166	-0.5
104	1.25	125	90.0	146	2.0	167	-4.5
105	1.0	126	17.5	147	1.75	168	-7.5

TABLE 8 SAMPLE TABULATED DATA

PAGE 1

SVERDRUP-ARO-INC
AEDC DIVISION
VON KARMAN GAS DYNAMICS FACILITY
50 HYPERSONIC TUNNEL B
ARNOLD AIR FORCE STATION, TN.
DATE 02/20/78 PROJECT NO. V41B-V2A

83-φ MODEL

PROJECT ENGRS E.C. KNOX / W.K. CRAIN

GROUP	MODEL	MACH NO.	PO,PSIA	TO,DEGR	ALPHA-M,DEG	ALPHA-I,DEG	ALPHA-P,DEG	ROLL,DEG	SWITCH POS
5	83-0	7.97	338.16	1277.67	29.98	0.02	30.00	180.00	1

T-INF (DEG R)	P-INF (PSIA)	Q-INF (PSIA)	V-INF (FT/S)	RHO-INF (LBM/FT3)	MU-INF (LBF-S/FT2)	RE/FT (FT-1)	HFR(R=0.04 FT) (BTU/FT2-S-DEGR)	STFR (R=0.04FT)
93.2	3.55E-02	1.578	3772.5	1.028E-03	7.502E-08	1.61E+06	2.035E-02	2.122E-02

TC NO	SKIN THICKNESS (IN)	CP (BTU/ LB-DEGR)	TW (DEGR)	DTW/DT (DEG/S)	Q-DOT (BTU/FT2-S)	HTO (BTU/FT2-S-DEGR)	HTO/ HFR	H(.9TO) (BTU/FT2-S-DEGR)	H(.9TO)/ HFR	H(TAW) (BTU/FT2-S-DEGR)	H(TAW) /HFR	LOCATION
												BOTTOM CL X/L
273	0.0269	0.1129	598.2	69.17	8.580	1.263E-02	0.621	1.555E-02	0.764	1.280E-02	0.629	0.0010
274	0.0272	0.1128	595.4	67.43	8.446	1.238E-02	0.608	1.523E-02	0.749	1.243E-02	0.611	0.0018
275	0.0277	0.1128	595.6	60.90	7.769	1.139E-02	0.560	1.402E-02	0.689	1.141E-02	0.561	0.0041
276	0.0280	0.1124	588.7	57.68	7.413	1.076E-02	0.529	1.321E-02	0.649	1.096E-02	0.539	0.0070
277	0.0279	0.1123	586.3	53.22	6.807	9.846E-03	0.484	1.208E-02	0.594	1.011E-02	0.497	0.0103
278	0.0283	0.1119	579.6	54.52	7.051	1.010E-02	0.496	1.236E-02	0.608	1.048E-02	0.515	0.0151
279	0.0232	0.1116	573.4	42.09	4.449	6.317E-03	0.310	7.717E-03	0.379	6.637E-03	0.326	0.0159
280	0.0210	0.1093	540.6	15.72	1.480	2.007E-03	0.099	2.428E-03	0.119	2.118E-03	0.104	0.0232
281	0.0190	0.1116	574.0	44.21	3.828	5.439E-03	0.267	6.646E-03	0.327	5.792E-03	0.285	0.0263
282	0.0230	0.1113	569.1	37.86	3.958	5.586E-03	0.275	6.815E-03	0.335	5.978E-03	0.294	0.0299
283	0.0231	0.1110	562.8	33.57	3.514	4.916E-03	0.242	5.986E-03	0.294	5.305E-03	0.261	0.0338
284	0.0230	0.1109	561.6	30.80	3.208	4.480E-03	0.220	5.453E-03	0.268	4.872E-03	0.239	0.0391
285	0.0230	0.1108	560.4	29.12	3.031	4.226E-03	0.208	5.142E-03	0.253	4.621E-03	0.227	0.0414
286	0.0240	0.1106	555.9	27.41	2.971	4.116E-03	0.202	5.001E-03	0.246	4.535E-03	0.223	0.0452
287	0.0230	0.1107	558.1	26.31	2.736	3.802E-03	0.187	4.623E-03	0.227	4.225E-03	0.206	0.0503
288	DELETE											
289	0.0300	0.1093	532.9	10.54	1.411	1.894E-03	0.093	2.287E-03	0.112	2.191E-03	0.108	0.1500
290	0.0260	0.1094	534.1	9.97	1.157	1.556E-03	0.076	1.879E-03	0.092	1.812E-03	0.089	0.2000
291	0.0273	0.1094	534.7	8.38	1.022	1.376E-03	0.068	1.662E-03	0.082	1.613E-03	0.079	0.2500
292	0.0275	0.1095	536.1	6.40	0.787	1.061E-03	0.052	1.282E-03	0.063	1.244E-03	0.061	0.3000
293	0.0261	0.1102	549.3	9.15	1.075	1.476E-03	0.073	1.790E-03	0.088	1.737E-03	0.085	0.3500
294	0.0276	0.1103	550.6	8.93	1.109	1.526E-03	0.075	1.851E-03	0.091	1.796E-03	0.088	0.4000
295	0.0292	0.1103	551.1	9.71	1.278	1.759E-03	0.086	2.134E-03	0.105	2.070E-03	0.102	0.4500
												STA 10.43 PHI, DEG
501	0.0220	0.1117	575.8	41.71	4.185	5.963E-03	0.293	7.290E-03	0.358			348.5000
502	0.0210	0.1114	571.2	42.51	4.062	5.750E-03	0.283	7.019E-03	0.345			338.2000
503	0.0250	0.1115	573.2	40.30	4.589	6.514E-03	0.320	7.957E-03	0.391			328.6000
504	0.0280	0.1110	563.2	39.77	5.047	7.064E-03	0.347	8.602E-03	0.423			320.5000
505	0.0270	0.1113	568.4	39.74	4.753	6.701E-03	0.329	8.174E-03	0.402			312.3000
506	0.0250	0.1111	564.6	39.51	4.479	6.282E-03	0.309	7.654E-03	0.376			305.5000
507	0.0210	0.1112	567.5	41.48	3.956	5.571E-03	0.274	6.793E-03	0.334			296.5000
508	0.0190	0.1110	562.9	36.85	3.172	4.438E-03	0.219	5.404E-03	0.266			287.0000
509	0.0230	0.1104	552.0	27.63	2.884	3.975E-03	0.195	4.824E-03	0.237			278.6000
510	0.0230	0.1102	548.5	23.47	2.428	3.330E-03	0.164	4.037E-03	0.198			270.0000
511	0.0260	0.1101	546.3	20.81	2.431	3.324E-03	0.163	4.028E-03	0.198			262.0000

NOTE: Only first page each group presented as typical all pages.

TABLE 8. CONCLUDED

60-Φ MODEL TRIP GEOM: 0.0 0 FUSELAGE / 0.0 0 WING

GROUP	MODEL	MACH NO.	PO,PSIA	TO,DEGR	ALPHA-M,DEG	ALPHA-I,DEG	ALPHA-P,DEG	ROLL,DEG	SWITCH POS
145	60-0	7.96	301.54	1274.67	30.00	-0.00	30.00	180.00	1

T-INF (DEG R)	P-INF (PSIA)	Q-INF (PSIA)	V-INF (FT/S)	RHO-INF (LBM/FT3)	MU-INF (LBF-S/FT2)	RE/FT (FT-1)	HFR(R=0.0175 FT) (BTU/FT2-S-DEGR)	STFR (R=0.0175FT)
93.2	3.19E-02	1.415	3767.8	9.237E-04	7.502E-08	1.44E+06	2.923E-02	3.383E-02

TC NO	SKIN THICKNESS (IN)	CP (BTU/ LB-DEGR)	TW (DEGR)	DTW/DT (DEG/S)	Q-DOT (BTU/FT2-S)	HTO (BTU/FT2-S-DEGR)	HTO/ HFR	H(.9TO) (BTU/FT2-S-DEGR)	H(.9TO)/ HFR	H(TAW) (BTU/FT2-S-DEGR)	H(TAW) /HFR	DIMENSION X/L	Y/S
7	0.0330	0.1104	551.9	26.40	3.926	5.432E-03	0.186	6.596E-03	0.226	6.095E-03	0.206	0.05	.000
10	0.0320	0.1100	546.0	18.43	2.650	3.636E-03	0.124	4.407E-03	0.151	4.159E-03	0.142	0.08	.000
16	0.0360	0.1099	543.6	11.91	1.924	2.632E-03	0.090	3.188E-03	0.109	3.061E-03	0.105	0.15	.000
21	0.0350	0.1099	543.0	11.00	1.727	2.360E-03	0.081	2.858E-03	0.098	2.761E-03	0.094	0.20	.000
22	OPEN												
23	0.0350	0.1098	541.0	10.06	1.578	2.150E-03	0.074	2.603E-03	0.089	2.525E-03	0.086	0.25	.000
24	0.0350	0.1097	540.6	9.09	1.426	1.942E-03	0.066	2.350E-03	0.080	2.280E-03	0.078	0.30	.000
26	0.0340	0.1100	545.0	9.59	1.464	2.006E-03	0.069	2.431E-03	0.083	2.358E-03	0.081	0.40	.000
28	0.0320	0.1101	546.3	8.25	1.187	1.629E-03	0.056	1.975E-03	0.068	1.916E-03	0.066	0.50	.000
37	0.0270	0.1102	548.7	5.93	0.721	9.924E-04	0.034	1.204E-03	0.041	1.186E-03	0.041	0.92	.000
39	0.0230	0.1102	549.4	5.17	0.535	7.373E-04	0.025	8.945E-04	0.031	8.861E-04	0.030	0.98	.000
43	0.0265	0.1098	541.9	2.21	0.262	3.581E-04	0.012	4.335E-04	0.015	4.308E-04	0.015	1.06	.000
49	0.0280	0.1100	546.2	11.55	1.453	1.995E-03	0.068	2.418E-03	0.083	2.346E-03	0.080	0.40	.100
50	0.0280	0.1102	549.5	10.61	1.337	1.844E-03	0.063	2.237E-03	0.077	2.170E-03	0.074	0.50	.100
51	0.0250	0.1103	550.6	8.08	0.909	1.256E-03	0.043	1.524E-03	0.052	1.478E-03	0.051	0.60	.100
52	0.0300	0.1104	553.2	7.66	1.036	1.436E-03	0.049	1.744E-03	0.060	1.691E-03	0.058	0.70	.100
53	OPEN												
56	0.0280	0.1100	546.0	2.76	0.347	4.762E-04	0.016	5.772E-04	0.020	5.599E-04	0.019	0.98	.100
60	0.0310	0.1098	541.5	2.55	0.354	4.832E-04	0.017	5.849E-04	0.020	5.676E-04	0.019	1.06	.000
62	0.0310	0.1102	548.4	10.91	1.521	2.095E-03	0.072	2.541E-03	0.087	2.464E-03	0.084	0.50	.200
63	0.0330	0.1103	551.2	8.77	1.303	1.801E-03	0.062	2.187E-03	0.075	2.121E-03	0.073	0.60	.200
64	OPEN												
65	0.0310	0.1104	552.8	6.63	0.927	1.284E-03	0.044	1.560E-03	0.053	1.513E-03	0.052	0.80	.200
68	0.0280	0.1102	549.7	6.88	0.867	1.196E-03	0.041	1.451E-03	0.050	1.438E-03	0.049	0.98	.200
77	0.0300	0.1105	553.5	13.20	1.785	2.476E-03	0.085	3.007E-03	0.103	2.887E-03	0.099	0.30	.300
79	0.0300	0.1103	550.4	5.85	0.791	1.092E-03	0.037	1.325E-03	0.045	1.285E-03	0.044	0.50	.300
80	0.0300	0.1103	551.6	4.98	0.674	9.317E-04	0.032	1.131E-03	0.039	1.096E-03	0.038	0.60	.300
81	0.0310	0.1103	551.2	4.61	0.643	8.893E-04	0.030	1.080E-03	0.037	1.048E-03	0.036	0.70	.300
84	0.0310	0.1096	539.0	1.60	0.222	3.013E-04	0.010	3.644E-04	0.012	3.431E-04	0.012	0.95	.300
89	0.0300	0.1105	554.9	15.25	2.065	2.869E-03	0.098	3.486E-03	0.119	3.358E-03	0.115	0.20	.401
91	0.0290	0.1105	553.7	9.98	1.305	1.810E-03	0.062	2.199E-03	0.075	2.132E-03	0.073	0.40	.401
92	0.0330	0.1105	553.9	8.89	1.324	1.837E-03	0.063	2.231E-03	0.076	2.158E-03	0.074	0.60	.401
94	0.0300	0.1104	552.0	9.03	1.221	1.689E-03	0.058	2.051E-03	0.070	1.996E-03	0.068	0.75	.401
95	0.0295	0.1101	548.0	8.31	1.103	1.518E-03	0.052	1.841E-03	0.063	1.821E-03	0.062	0.85	.401
97	0.0275	0.1099	544.0	5.50	0.679	9.292E-04	0.032	1.126E-03	0.039	1.141E-03	0.039	0.95	.401

NOTE: Only first page each group presented as typical all pages.